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Non-destructive testing — Ultrasonic testing — Through-transmission technique

Essais non destructifs — Contrôle par ultrasons — Technique par transmission

Reference number
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Contents

Page

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 16823:2012), which has been technically revised.

The main changes are as follows:

— normative references have been updated;

— figures have been improved;

— terminology has been aligned throughout the whole document.

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 documents 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 as a method for detection and sizing of discontinuities*

Non-destructive testing — Ultrasonic testing — Through-transmission technique

1 Scope

This document specifies the principles of ultrasonic through-transmission techniques.

Through-transmission techniques can be used for:

— detection of discontinuities;

— determination of sound attenuation.

The general principles required for the use of ultrasonic testing of industrial products are described in ISO 16810.

The through-transmission technique is used for the testing of flat products, e.g. plates and sheets.

Further, it can be used for tests, for example:

— where the shape, dimensions or orientation of possible discontinuities are unfavourable for direct reflection;

— of materials with high sound attenuation;

— on thin test objects.

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*[1)]

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

ISO 7963, *Non-destructive testing — Ultrasonic testing — Specification for calibration block No. 2*[1)]

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

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.

1) It is intended to replace the term “calibration block“ by "standard block“ during the next revision of the standard.

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 NDT personnel

For requirements concerning non-destructive testing (NDT) personnel, the requirements given in ISO 16810 shall apply.

5 Test equipment

5.1 Instrument

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

5.2 Probes

5.2.1 General

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

5.2.2 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 5.2.3 and 5.2.4 shall be considered in relation to the characteristics of the test object stated above.

5.2.3 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 for single-probe setups to detect planar discontinuities that are unfavourably orientated.

b) Apart from the above considerations, the selection of frequency shall take into account the influences of 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 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.

5.2.4 Dead zone

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

5.2.5 Damping

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

5.2.6 Focusing probes

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

5.3 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.

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

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

5.4 Standard blocks

The blocks which shall be used for setting the ultrasonic equipment are specified in ISO 2400 and ISO 7963.

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

5.5 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.

   A 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.

   For further details, see 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 and compared to the requirements for the accuracy of the test.

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

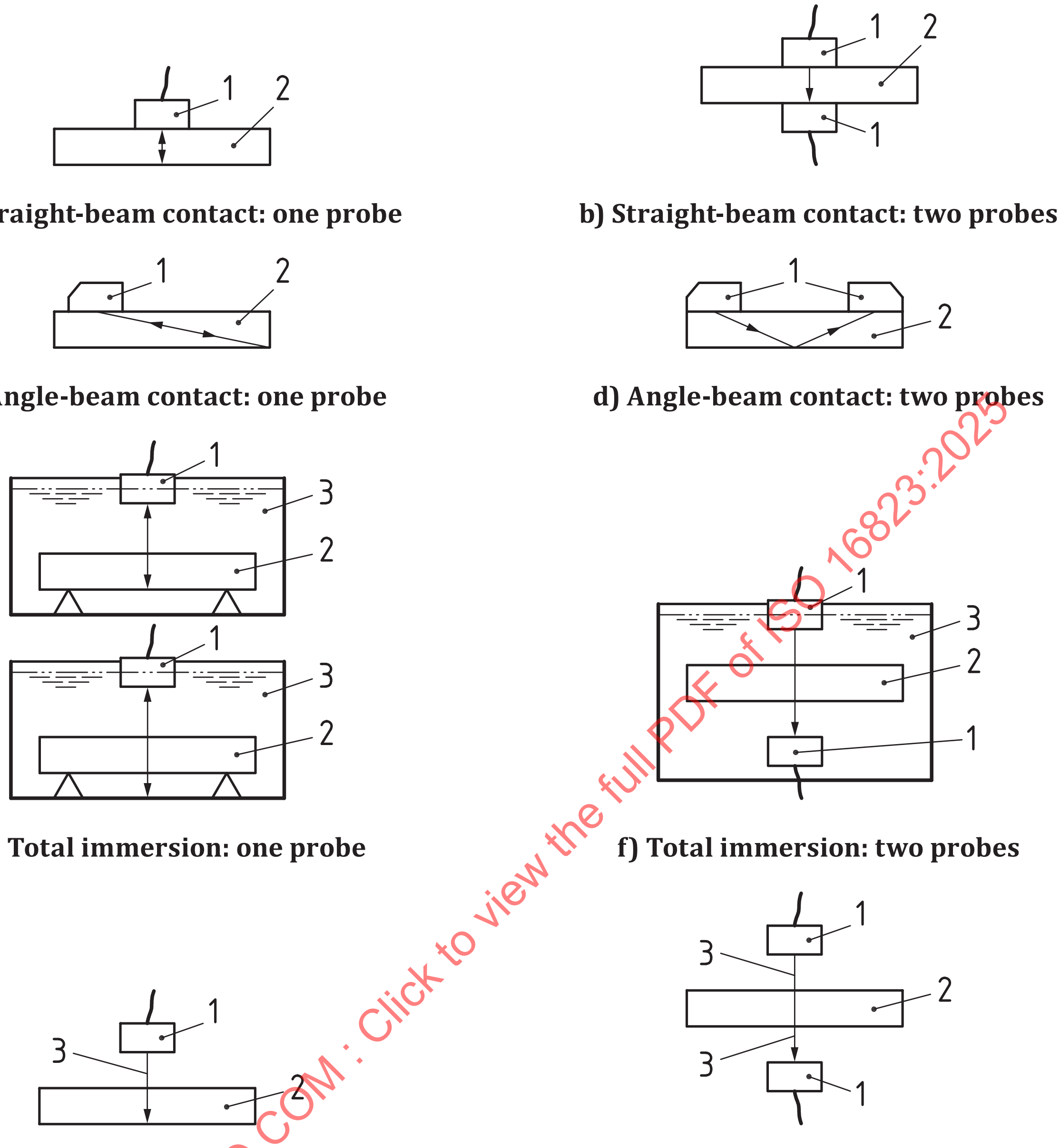
5.6 Specific test blocks

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.

6 Principles of testing

6.1 Basic techniques and setup

In its simplest application two probes, one emitting and the second receiving, are placed so that the receiving probe receives the sound transmitted through the test object. This can be achieved with straight-beam probes or angle-beam probes, see Figure 1, b), d), f), and h).



a) Straight-beam contact: one probe

b) Straight-beam contact: two probes

c) Angle-beam contact: one probe

d) Angle-beam contact: two probes

e) Total immersion: one probe

f) Total immersion: two probes

g) Local immersion (squirter): one probe

h) Local immersion (squirter): two probes

Key

1 probe

2 test object

3 water

Figure 1 — Possible configurations for the through-transmission technique

Alternatively, the testing can be carried out using a single probe where the sound is reflected on the opposite surface of the test object (back wall) or on a separate surface beyond the test object, see Figure 1, a), c), e), and g). See also Table 1.

Table 1 — Techniques and typical setups used in the through-transmission technique

	Continuous waves	Pulses
Wave mode	longitudinal or transverse	longitudinal or transverse
Number of probes	2	1 or 2
Angle of incidence	normal	normal or oblique
Evaluation of	amplitude of received signal	amplitude or time of flight of received signal

The decrease in amplitude of the received signal can be used to indicate the presence of a discontinuity located in the sound path, or to indicate material attenuation.

In addition, the position of the received signal along the time base of the instrument can be used to indicate material thickness.

Testing can be carried out with either continuous or pulsed ultrasonic waves, except when the technique is used for thickness determination where only ultrasonic pulses can be used.

Straight-beam or angle-beam probes can be used depending on the scope of the testing.

Ultrasound can be coupled to the test object by means of a couplant, by a squirter jet, by immersing the test object or by applying a wheel probe.

6.2 Capability of detection of discontinuities

When used for the detection of discontinuities, any discontinuity (or group of discontinuities) shall intercept a significant proportion (i.e. 25 % to 50 %) of the cross-sectional area of the ultrasonic beam before an unambiguous change in signal amplitude is observed.

This technique can only be used for detecting discontinuities or groups of discontinuities which are relatively large compared to the sound beam area, e.g. laminations in plate material.

Within the limitations mentioned above, this technique provides positive proof of the absence of a discontinuity at any position along the sound path. However, it does not indicate the position in depth of a detected discontinuity.

6.3 Requirements for geometry and access

The transmission technique requires that the geometry of the test object and access to its surfaces allow the transmitting and receiving probes to be so positioned that their beam axes are coincident, either with or without intermediate reflection from a surface of the test object.

6.4 Effects of variations in coupling, angulation and alignment of probes

The through-transmission technique is particularly sensitive to variations in probe coupling and misangulation due to surface irregularities, since these factors also cause a marked reduction in received signal amplitude.

To improve the uniformity of coupling immersion or squirter scanning is most frequently used.

Dressing of the surface to improve coupling uniformity can be necessary, especially for contact scanning.

When using separate transmitting and receiving probes and/or a reflecting object on the opposite side of the test object, their positions in relation to each other are also critical, and wherever possible they should be maintained in alignment.

7 Test technique

7.1 General

The technique described under this clause refers to the detection of discontinuities, and where applicable, their size determination, and to the determination of sound attenuation in the material.

7.2 Sensitivity setting

a) The test sensitivity shall be set on either a reference block of the same relevant dimensions, surface finish and similar ultrasonic properties as the test object or on an area of the latter known to be free from discontinuities and of known or previously determined attenuation in accordance with 7.5.

b) The probes shall be maintained in alignment and in ultrasonic contact with the reference block or the test object.

c) The gain shall be adjusted to set the received signal to a specified level.

d) For manual testing, a level of 80 % of full screen height is recommended.

7.3 Scanning

Scanning shall be carried out in accordance with the requirements of the applicable test procedure, at all times keeping the probes in correct alignment to each other and to the test object.

7.4 Evaluation of discontinuities

a) The evaluation of discontinuities shall be done in accordance with the relevant standard or specification.

b) For discontinuities where the received signal amplitude during scanning is reduced to below the evaluation level, the evaluation criteria and requirements can be summarized as follows:

   1) confirm that the reduction in signal amplitude is not due to loss of coupling or to a normal geometrical feature of the test object;

   2) determine the maximum reduction in received signal amplitude. When the zone causing the signal to fall below the evaluation level is smaller than the beam width, it is possible to relate the reduction in amplitude to the area of an discontinuity, perpendicular to the sound beam, placed at a given depth;

   3) determine as accurately as possible the area of the discontinuity through which the sound beam is being attenuated;

   4) determine if an discontinuity is continuous or intermittent;

   5) if either a complete or a partial loss of the received signal amplitude is observed, due to a single large discontinuity, the extent of the discontinuity may be plotted by noting those positions of the sound beam at which the received signal amplitude has fallen by a given value (most frequently 6 dB) below its value in a zone of the test object free of discontinuities.

7.5 Determination of the attenuation coefficient

7.5.1 General

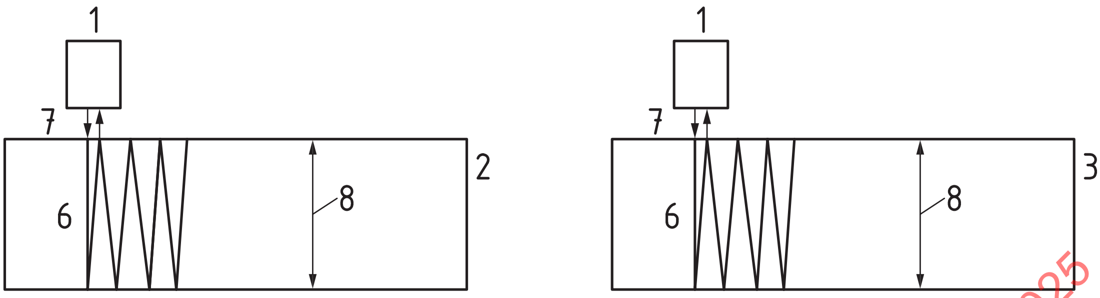
The energy loss, usually called attenuation, is normally expressed as an attenuation coefficient determined in dB per metre of sound path in the test object.

The value depends on the type of wave, i.e. longitudinal or transverse, on the ultrasonic frequency and on the structure of the tested material.

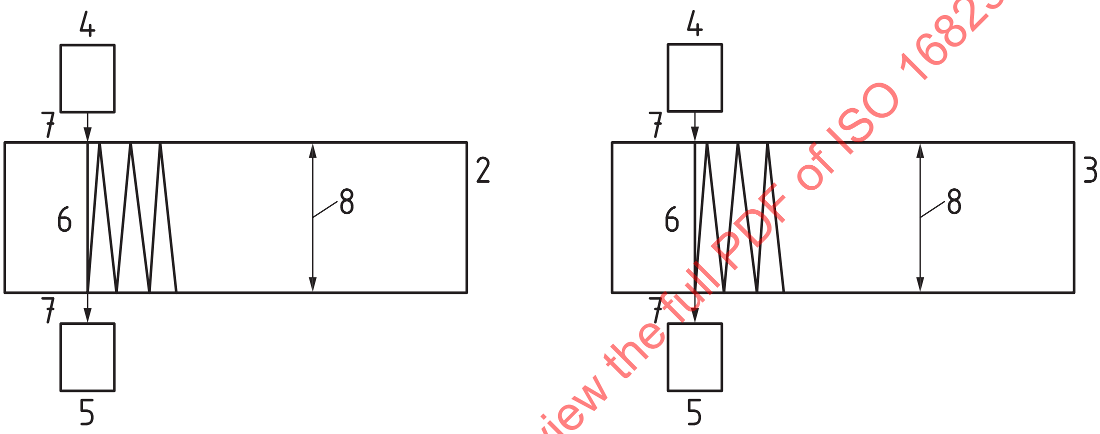
Two techniques for determining the attenuation coefficient are described in 7.5.2 and 7.5.3.

7.5.2 Comparative technique using a reference block

This technique is based on determining the difference in amplitude between 2 echoes. The technique can employ either one probe acting as both transmitter and receiver, or two separate probes, one transmitting and one receiving, positioned on opposite sides of the test object (see Figure 2).



a) Setup with one probe acting as transmitter and receiver



b) Setup with two probes, one acting as transmitter and one acting as receiver

Key

1 probe acting as transmitter and receiver
2 test object with unknown attenuation coefficient α1
3 reference block with known attenuation coefficient α2
4 probe acting as transmitter
5 probe acting as receiver
6 sound path in the material with multiple reflections
7 sound path in the couplant
8 thickness of the test object or the reference block

Figure 2 — Determination of attenuation coefficient by comparative technique

The first echo is that transmitted through a test object whose attenuation coefficient, α_1, is to be determined.

The second echo is that transmitted through a reference block attenuation coefficient, α_2, is known.

It is important to use the same determination conditions: ultrasonic probes, instrument, coupling medium and same settings for each amplitude determination, and the samples shall be of the same thickness and surface finish. If reflection is used, no couplant is allowed at the reflective surface to ensure total reflection unless the couplant is uniform and the same for both the test object and the reference block.

Either the first received echo, or any subsequent multiple echo may be used.

The attenuation coefficient (α_1 in dB/m) in the material to be tested for a fixed gain setting is given by Formula (1):

$$\alpha_1 = \alpha_2 - \frac{20\log_{10}\left(\frac{A_1}{A_2}\right)}{B} \tag{1}$$

or equivalent for amplitudes at the same screen height by Formula (2)

$$\alpha_1 = \alpha_2 + \left(\frac{V_1 - V_2}{B}\right) \tag{2}$$

where

α_1 is the attenuation coefficient of the test block;

α_2 is the known attenuation coefficient of the reference block;

B is the total sound path length in the test object (m);

A_1 is the amplitude of the signal through the test object;

A_2 is the amplitude of the signal through the reference sample with known attenuation coefficient;

V_1 is the gain in decibel for the signal through the test object;

V_2 is the gain in decibel for the signal through the reference block.

7.5.3 Technique using the test object only

This technique is based on comparing the amplitude of one echo (A_m) of a series of multiple echoes, from a sample of material to be tested, with the amplitude of a subsequent echo (A_n) within the same series (see Figure 3).

The technique can employ any of the probe configurations described in 7.5.2, but the following additional requirements apply:

a) the sound path of the echoes used for the determination shall be longer than three near field lengths. Formula (3) and Formula (4) apply for non-focusing probes;

b) allowance shall be made for the loss each time the pulse is reflected at a material/water interface.

The attenuation coefficient (α in dB/m) in the material to be tested for a fixed gain setting is given by Formula (3)

$$\alpha = \frac{20\log\left(\frac{A_m}{A_n}\right) + 20\log\left(\frac{B_m}{B_n}\right) + 40(n-m)\log(R)}{2(n-m)d} \tag{3}$$

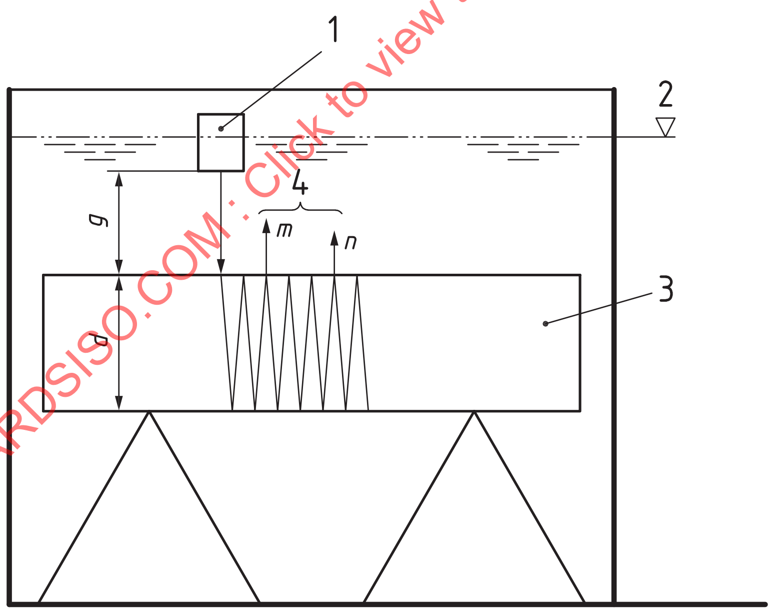
or equivalent for amplitudes at the same screen height by Formula (4)

$$\alpha = \frac{(V_n - V_m) + 20\log\left(\frac{B_m}{B_n}\right) + 40(n-m)\log(R)}{2(n-m)d} \tag{4}$$

where

α is the attenuation coefficient in the test object;

$B_m = 2[g + md(c_s / c_w)]$	is the equivalent water path of the m^{th} echo;
$B_n = 2[g + nd(c_s / c_w)]$	is the equivalent water path of the n^{th} echo;
c_s	is the longitudinal sound velocity in the test object (m/s);
c_w	is the sound velocity in water (1 480 m/s);
d	is the thickness of the test object (m);
g	is the water delay between probe and test object (m);
m, n	are the numbers of evaluated echoes ($n > m$);
A_m	is the amplitude of m^{th} echo;
A_n	is the amplitude of n^{th} echo;
$R = \left\lvert \frac{Z_s - Z_w}{Z_s + Z_w} \right\rvert$	is the modulus of reflection coefficient water/test object, resp. test object/water;
V_m	is the gain in decibel for the m^{th} echo (dB);
V_n	is the gain in decibel for the n^{th} echo (dB);
Z_s	is the acoustical impedance of the test object (Pa·s/m);
Z_w	is the acoustical impedance of water (1,480 × 10^6 Pa·s/m).



Key

1	probe	d	thickness of test object
2	water level	g	water delay path between probe and test object
3	test object	m, n	numbers of evaluated echoes
4	series of echoes		

NOTE Not to scale.

Figure 3 — Determination of the attenuation coefficient of the test object without a reference block