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Non-destructive testing — Ultrasonic testing — Testing for discontinuities perpendicular to the surface

Essais non destructifs — Contrôle par ultrasons — Contrôle des discontinuités perpendiculaires à la surface

Reference number
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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 16826:2012), which has been technically revised.

The main changes are as follows:

— revised figures and formulae;

— editorial revisions.

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 on ultrasonic testing 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 — Testing for discontinuities perpendicular to the surface

1 Scope

This document specifies principles for the tandem technique and the longitudinal-longitudinal-transverse wave (LLT) technique for detection of discontinuities perpendicular to the surface or almost perpendicular to the surface.

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

The tandem or LLT techniques can be used for the detection of embedded planar discontinuities.

This document gives guidelines for the testing of metallic materials with a thickness between 40 mm and 500 mm with parallel or concentric surfaces.

The procedures provided in this document can be used for testing of other materials or smaller thickness if special measures are taken according to a written testing procedure.

Phased array techniques can also be applied for the tandem technique and the LLT technique, but 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 5577, *Non-destructive testing — Ultrasonic testing — Vocabulary*

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

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 Test equipment and test personnel

The requirements of ISO 16810 on test equipment and test personnel shall be applied unless stated otherwise.

5 Tandem technique

5.1 General

a) The testing normally shall be carried out using two similar 45° angle-beam transverse wave probes, one probe operating as transmitter and the other probe as receiver.

b) For wall thicknesses larger than 160 mm, different transducer sizes for the transmitter probe and the receiver probe should be used to ensure approximately the same beam dimensions in the test zone.

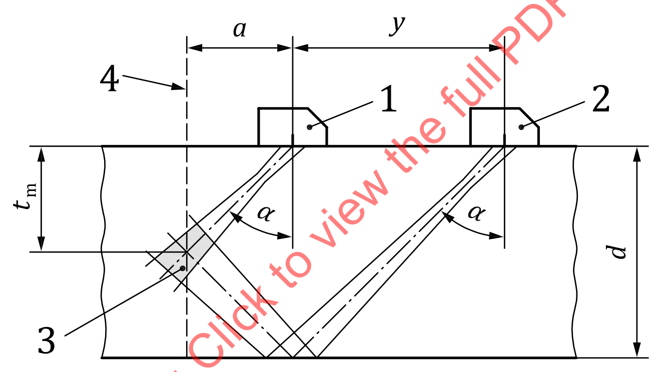
c) The use of beam angles other than 45° may be necessary to comply with particular geometrical conditions of the test object and/or the orientation of the expected discontinuity.

d) Beam angles that give rise to mode conversion shall be avoided.

NOTE For a test object with parallel surfaces, the use of transverse wave probes with a beam angle of 60° results in the beam impinging on the reference line at 30°, which can result in mode conversion on a discontinuity in steel test objects.

e) The probes shall be located in a line with their beam axes in the same direction.

The sound beam from the rear probe will, after reflection from the opposite surface, intersect the sound beam from the front probe, as shown in Figure 1. The area of intersection of the beams is the test zone. The intersection of the beam axes is the centre of the test zone, located at the reference line.



Key

1	front probe	d	material thickness
2	rear probe	t_m	depth of the intersection of the beam axes
3	test zone	y	probe distance
4	reference line	α	beam angle
a	projected distance		

Figure 1 — Basic principle of tandem technique

When testing objects with plane parallel surfaces, the distance between the probes can be determined using Formula (1):

$$y = 2(d - t_m)\tan\alpha \quad (1)$$

For 45° beam angles Formula (2) can be used:

$$y = 2(d - t_m) \quad (2)$$

where

- d is the material thickness;
- t_m is the depth of the intersection of the beam axes;
- α is the beam angle.

5.2 Probe movement

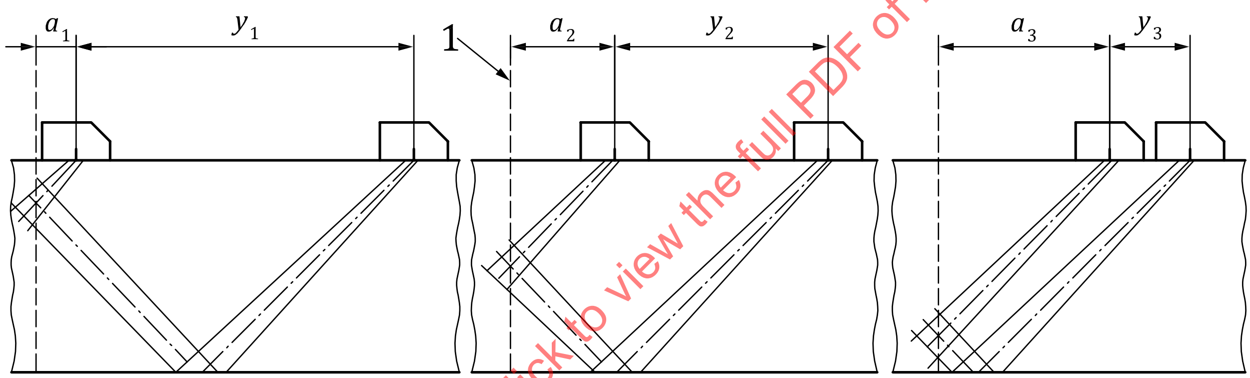
Probe movement (scanning) shall be performed in either of the following ways:

a) both probes shall be moved along the surface with a fixed probe distance (y).

In this way only one test zone is covered at a time, and the scanning shall be repeated with different probe distances until the complete test volume has been tested;

b) both probes shall be moved simultaneously but in opposite directions (forward and backward respectively), such that the sum of their distances from the reference line [a + (a + y)] remains constant, thereby scanning the full thickness of the test object in one continuous movement, as shown in Figure 2.

For example, the reference line can be the vertical weld axis.



Key

1	reference line
a_1, a_2, a_3	projected distance
y_1, y_2, y_3	probe distance

Figure 2 — Probes at different distances for test zones at different depths (schematic)

5.3 Time base setting

All relevant echoes will appear at the same sound path distance, which corresponds to the sound path for full skip for probes with the beams in opposite directions. Therefore, the setting of the time base is not critical. However, the echo of the signal along this path should be located at a specified position, e.g. at 80 % of full screen width, and indications in the vicinity of this specified position should be also displayed/recorded.

5.4 Sensitivity setting

The setting of sensitivity shall be performed using one of the following reflector types:

a) the opposite surface, where the back-wall echo is used;

b) disc-shaped reflectors perpendicular to the scanning surface (e.g. flat-bottomed holes), which shall be located at the intersection of the beam axes;

c) side-drilled holes located at the intersection of the beam axes and at the borders of the test zones.

5.5 Determination of test zones

Because of beam divergence, the shape of the test zone is not exactly a square or a rectangle and the dimensions of the test zone vary depending on the depth of the test zone.

a) To ensure that the sensitivity throughout the thickness does not fall below a certain level, a sufficient number of test zones shall be used to cover the thickness of the test object taking the beam divergence into account.

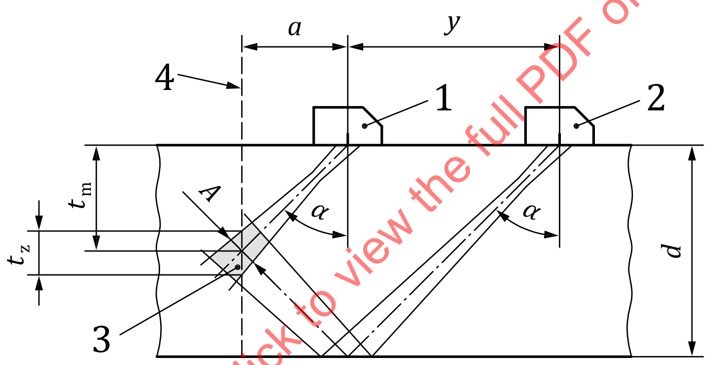
b) The probes shall be selected to ensure suitable beam characteristics, especially in the area near the test surface due to the near field length of the front probe.

The test zone near the opposite surface can require that the transducers for both beams are mounted in a single probe housing.

The test zones at the surfaces may be tested using a single probe with pulse-echo technique to detect corner reflections.

c) The height of the test zone (t_z) is defined as the height of the test zone at the reference line through the intersection point of the beam axes, see Figure 3.

d) The height of the test zones shall be selected so that the sensitivity at the edges of the test zones is not more than 6 dB below the sensitivity in the intersection point of the beam axes.



Key

1	front probe	t_m	depth of the intersection of the beam axes
2	rear probe	t_z	height of the test zone
3	test zone	α	beam angle
4	reference line	a	projected distance
A	beam dimension of the front probe	y	probe distance
d	material thickness		

Figure 3 — Height of test zone

e) The height of each test zone (t_z) shall be determined by using a reference block with reflectors at different depths or approximated using Formula (3), based on the dimension A of the direct beam in the test zone (6 dB drop), see Figure 3.

$$t_z = \frac{A}{\sin\alpha} \approx \frac{\lambda \cdot t_m}{D_{\text{eff}} \cdot \sin\alpha \cdot \cos\alpha} \quad (3)$$

For 45° beam angles Formula (4) can be used:

$$t_z \approx \frac{2 \cdot \lambda \cdot t_m}{D_{\text{eff}}} \quad (4)$$

where

A	is the beam dimension of the front probe;
t_m	is the depth of the intersection of the beam axes;
α	is the beam angle;
λ	is the wavelength;
D_{eff}	is the effective transducer size.

f) When equally sized test zones are preferred then the height of the smallest test zone shall be used for all test zones and the minimum number of test zones n_{tz} shall be calculated according to Formula (5):

$$n_{tz} = \frac{d}{t_{z,min}} \quad (5)$$

where

d	is the material thickness;
$t_{z,\min}$	is the height of the smallest test zone;
n_{tz}	is an upward rounded number (integer) 1, 2, 3, etc.

g) Alternatively, the height and number of the test zones shall be determined graphically using scale drawings of the calculated or measured 6 dB beam profiles of the individual beams (using the pulse–echo technique).

h) The probe distance, y (see Figure 1) shall be adjusted for each test zone to have the intersection of the beam axes in the centre of the selected test zone.

5.6 Depth-gain diagram for tandem technique

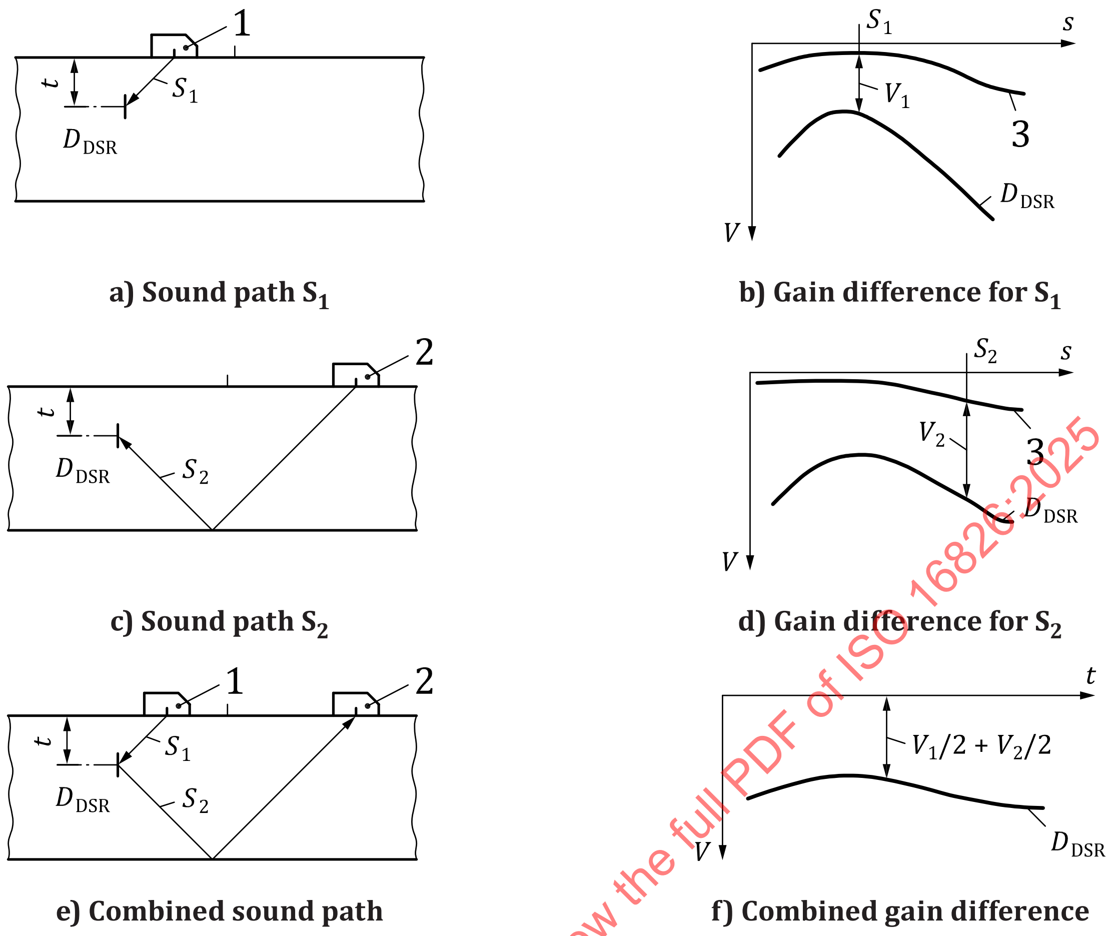
Depth-gain diagrams for tandem technique show the relationship between depth and gain for a given size of disc-shaped reflector. Because the depth of the intersection of the beam axes (t_m) depends on the spacing of the probes (y), this diagram is the result of multiple probe distances (y) and it gives no information on the height of each test zone (t_z).

Depth-gain diagrams for tandem technique may be derived from the general distance-gain-size diagram (DGS diagram) or based on probe specific diagrams.

The diagrams are prepared as shown in Figure 4.

For each depth, the gain differences V_1 and V_2 are derived from the specific diagrams for the probes or from the general DGS diagram.

The mean value of V_1 and V_2 is used to establish a depth-amplitude curve for the specific tandem technique, based on the specified disc-shaped reflector (DSR).



Key

1	front probe
2	rear probe
3	backwall echo curve
D_{DSR}	diameter of disc-shaped reflector
s	sound path
S_1, S_2	sound path distance
t	depth
V	gain
V_1, V_2	gain difference

Figure 4 — Preparation of depth-gain diagram for tandem technique

5.7 Corrections of sensitivity

a) Depending on the method used for sensitivity setting, corrections for transfer and attenuation losses may be applicable.

b) In addition to this, compensation shall be made for the reduction of sensitivity that will occur at the edges of the test zone.

Either 6 dB or the value measured on disc-shaped reflectors (flat-bottomed holes) at the border of the test zones shall be used.

5.8 Test objects with concentric surfaces

5.8.1 General

a) The use of 45° angle-beam probes is limited to $d/D \leq 0{,}04$ for convex scanning surfaces and $d/D \leq 0{,}05$ for concave scanning surfaces, where *d* is the material thickness and *D* is the external diameter of the test object.

b) Where applicable, the angles of incidence shall be changed to prevent mode conversions that can result in reduced sensitivity.

c) The probe spacing (y) for the testing on concentric surfaces may be calculated using the Formulae in 5.8.2 or 5.8.3.

d) Alternatively, the probe spacing can be determined graphically using scale drawings of the calculated or measured 6 dB beam profiles of the individual beams when using pulse–echo technique.

NOTE In Annex A, nomograms are given for determination of the distances for concave and convex scanning surfaces without calculation.

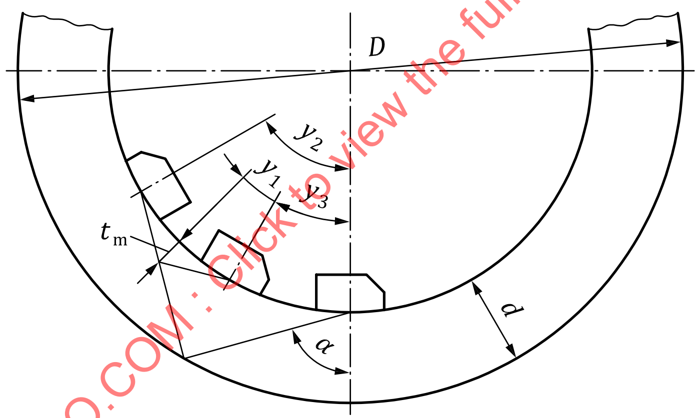
5.8.2 Scanning on a concave surface

For testing on concave surfaces, the probe spacing (y) may be calculated using Formulae (6), (7) and (8). For explanation of the symbols see Figure 5.

$$y_1 = \frac{\pi(D-2d)}{360°}\left\{\alpha - \arcsin\left(\frac{D-2d}{D-2d+2t_m}\sin\alpha\right)\right\} \tag{6}$$

$$y_2 = \frac{\pi(D-2d)}{180°}\left\{\alpha - \arcsin\left(\frac{D-2d}{D}\sin\alpha\right)\right\} \tag{7}$$

$$y_3 = \frac{\pi(D-2d)}{180°}\left\{\arcsin\left(\frac{D-2d}{D-2d+2t_m}\sin\alpha\right) - \arcsin\left(\frac{D-2d}{D}\sin\alpha\right)\right\} \tag{8}$$



Key

D	external diameter of concentric surface
d	material thickness
t_m	depth of the intersection of the beam axes
y_1, y_2, y_3	distances on the test surface (arc lengths)
α	beam angle

Figure 5 — Scanning on a concave surface

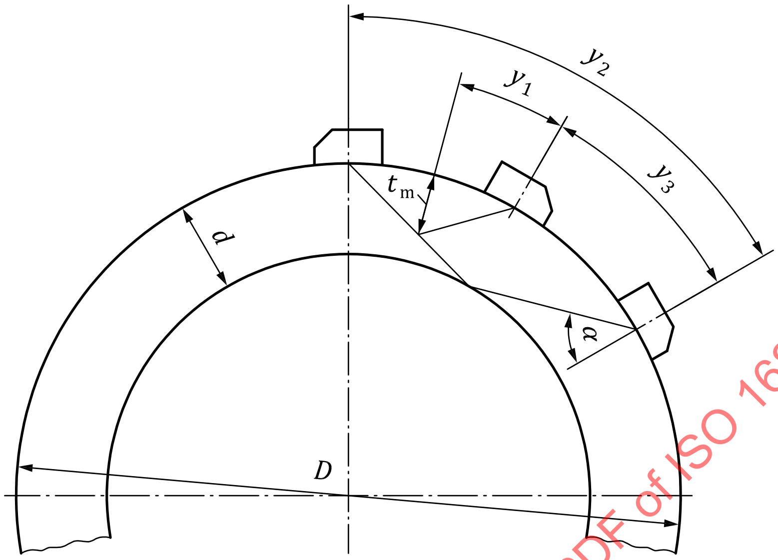
5.8.3 Scanning on a convex surface

For testing on convex surfaces, the probe spacing (y) may be calculated using Formulae (9), (10) and (11), for explanation of the symbols see Figure 6.

$$y_1 = \frac{\pi D}{360°}\left\{\arcsin\left(\frac{D\sin\alpha}{D-2t_m}\right) - \alpha\right\} \tag{9}$$

$$y_2 = \frac{\pi D}{180°}\left\{\arcsin\left(\frac{D\sin\alpha}{D-2d}\right)-\alpha\right\} \quad (10)$$

$$y_3 = \frac{\pi D}{180°}\left\{\arcsin\left(\frac{D\sin\alpha}{D-2d}\right)-\arcsin\left(\frac{D\sin\alpha}{D-2t_m}\right)\right\} \quad (11)$$



Key

D	external diameter of concentric surface
d	material thickness
t_m	depth of the intersection of the beam axes
y_1, y_2, y_3	distances on the test surface (arc lengths)
α	beam angle

Figure 6 — Scanning on a convex surface

6 Longitudinal-longitudinal-transverse wave technique

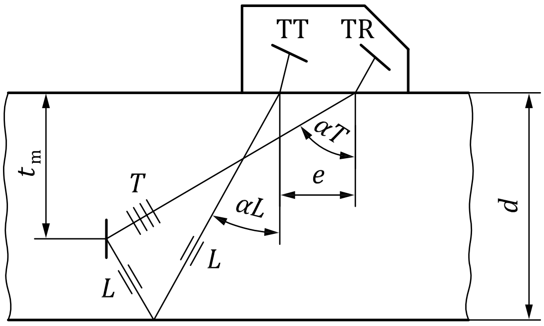
6.1 General

The principle of the longitudinal-longitudinal-transverse wave (LLT) technique is shown in Figure 7.

The transmitting transducer TT generates a longitudinal wave at an angle α_L between 7° and 45°.

This wave is reflected at the back wall of the test object and impinges on the discontinuity assumed to be oriented perpendicular to the test surface. Here, most of the energy is mode converted to a transverse wave, which travels back to the probe at an angle α_T and is detected by the receiver TR.

The relation between angles α_L and α_T is given by Formula (12).



Key

TT transducer transmitter

TR transducer receiver

e distance between the probe index points

t_m depth of the intersection of the beam axes

d material thickness

L sound path of the longitudinal wave

T sound path of the transverse wave

αT beam angle of the transverse wave beam

αL beam angle of the longitudinal wave beam

Figure 7 — Basic principle of LLT technique

$$\alpha_T = \arccos\left(\frac{c_T}{c_L}\cos\alpha_L\right) \tag{12}$$

where

α_T is the beam angle of the transverse wave beam;

α_L is the beam angle of the longitudinal wave beam;

c_T is the transverse wave velocity;

c_L is the longitudinal wave velocity.

For full through-wall testing, several probes normally should be used, each covering a specific test zone.

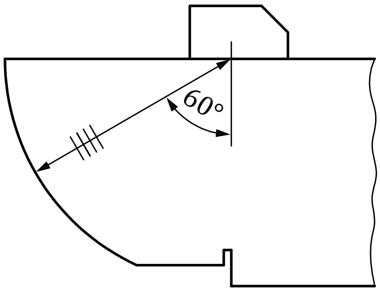
6.2 Time base setting and determination of depth of a discontinuity

a) The time base of the ultrasonic instrument shall be set for transverse waves using transducer TR of the LLT probe as transmitter and receiver (pulse–echo technique) (e. g. on calibration block no. 1 according to ISO 2400), see Figure 8a).

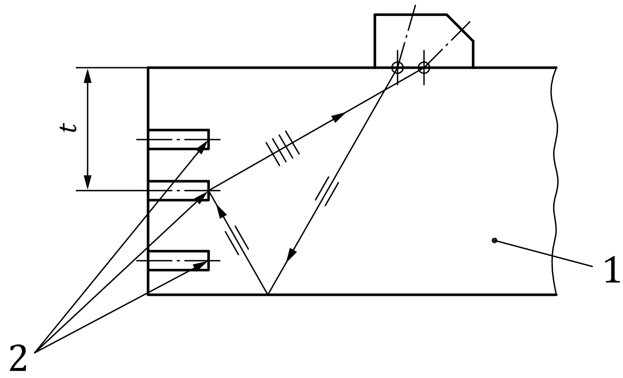
b) The probe shall then be used in the LLT mode (with transducer TT operating as transmitter, and transducer TR as receiver) on a reference block having the same thickness as the test object and containing a number of vertical disc-shaped reflectors at different depths, see Figure 8b).

c) The observed sound path distance along the time base for each of these reflectors should be noted in a table or a diagram against their depth from the scanning surface, see Figure 8c).

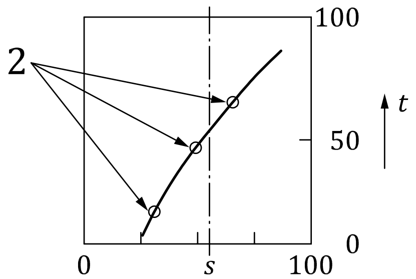
d) This table or diagram shall then be used to determine the depth, *t*, of a discontinuity from a measurement of its observed sound path distance, see Figure 8c) and 8d).



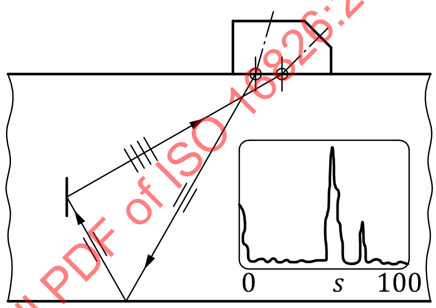
a) LLT probe on calibration block



b) LLT probe on reference block with disc-shaped reflectors



c) Diagram showing depth versus sound path



d) LLT probe on test object with typical evaluation

Key

1 reference block

2 flat bottom hole

t depth from the scanning surface, in mm

s sound path distance, in mm

Figure 8 — Determination of depth of a discontinuity

6.3 Sensitivity setting

The sensitivity setting shall be performed using one of the following reflectors:

a) the end face of a reference block perpendicular to the scanning surface;

b) a disc-shaped reflector perpendicular to the scanning surface (flat-bottomed hole).

6.4 Determination of the depth of the intersection of the beam axes

As with the tandem technique the LLT technique has the highest sensitivity at the intersection point of the beam axes of the transmitter and the receiver.

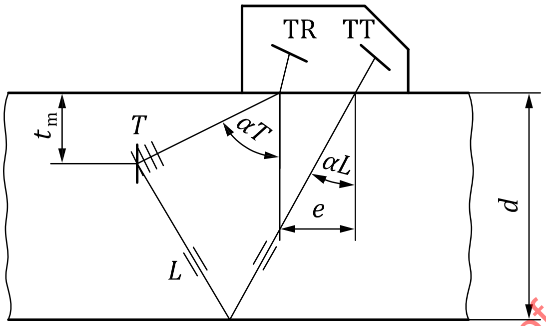
The depth t_m of this intersection point (see Figures 7 and 9) depends on the choice of the pair of angles α_L and α_T, on the thickness, *d*, of the test object and on the distance, *e*, between the probe index point of the transmitter (TT) and the probe index point of the receiver (TR).

If the probe index point of the transmitter (TT) is situated in front of the probe index point of the receiver (TR) (see Figure 7), this depth is given by Formula (13):

$$t_m = \frac{(2d \tan\alpha_L) + e}{\tan\alpha_L + \tan\alpha_T} \quad (13)$$

If the probe index point of the transmitter (TT) is behind the probe index point of the receiver (TR) (see Figure 9), t_m is given by Formula (14):

$$t_m = \frac{(2d \tan\alpha_L) - e}{\tan\alpha_L + \tan\alpha_T} \quad (14)$$



Key

TT transducer transmitter

TR transducer receiver

e distance between the probe index points

d material thickness

t_m depth of the intersection of the beam axes

L sound path of the longitudinal wave

T sound path of the transverse wave

αT beam angle of the transverse wave beam

αL beam angle of the longitudinal wave beam

Figure 9 — Depth of the intersection of the beam axes, TR in front of TT

Formula (13) and Formula (14) are also valid if the transmitter and receiver are contained in separate housings.

As with the tandem technique, the height of the test zone t_z can be determined by using a reference block with reflectors at different depths or be approximately determined by geometrical superposition of the transmitter and receiver beams, using the 6 dB beam edges of the individual beams (using pulse–echo technique).

6.5 Sensitivity diagram for LLT technique

The evaluation of the echo height can be performed using sensitivity diagrams that are calculated, determined experimentally or supplied by the probe manufacturer.

6.6 Correction of sensitivity

In addition to the transfer corrections (for losses caused by coupling and sound attenuation), a sensitivity correction factor of 6 dB shall be added to compensate for the sensitivity losses at the borders of the test zones.