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Ultrasonic non-destructive testing — Reference blocks and test procedures for the characterization of contact search unit beam profiles

Contrôles non destructifs par ultrasons — Blocs de référence et modes opératoires des essais pour la caractérisation des faisceaux des traducteurs utilisés dans les contrôles par contact

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

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

International Standard ISO 12715 was prepared by Technical Committee ISO/TC 135, *Non-destructive testing*, Subcommittee 3, *Acoustical methods*.

Annexes A and B form an integral part of this International Standard. Annex C is for information only.

Introduction

In ultrasonic non-destructive inspection, pulse/echo contact tests with a straight beam search unit (also known as a normal probe), an angle beam search unit (also known as an angle probe), or a dual element search unit (also known as a twin crystal probe) are often used. To reliably detect and characterize a flaw inside a structural material, a knowledge of the sound field (or the beam profile) produced by the search unit in contact testing is needed. This International Standard establishes two metal reference blocks to be adopted for various materials such as forged or rolled steel, aluminum and titanium alloy products. The frequency range of the search units used in this International Standard range from 1 MHz to 15 MHz. Depending on the microstructure of the materials under evaluation, in general, 1 MHz to 5 MHz is most suitable for steel products and 5 MHz to 15 MHz is most suitable for aluminum and titanium alloys.

The two reference blocks introduced are the hemi-step (HS) and the side-drilled-hole (SDH) blocks, from which the beam profiles produced by straight beam, focused beam, angle beam and dual element search units can be measured. This International Standard establishes the techniques and procedures to be used for the characterization of the search unit beam profiles in solids.

In pulse/echo ultrasonic tests, the reflected pulse (hereafter called echo) is used for the detection of discontinuities existing in a material. The discontinuities (hereafter called flaw or defect) such as porosity, voids or cracks in different sizes and shapes, may be located close to the surface or deep inside, or close together and oriented at different angles. A sound pulse incident on such flaws may reflect or refract into longitudinal (also known as compressional) or transverse (also known as shear) waves, or both, possibly with multiple reflections and refractions. In order to accurately characterize the location, size and shape of a flaw inside a material, the sound field produced and detected by the search unit and the instrument must be known.

The sound field inside a solid produced by a search unit in contact testing depends on the type, size, and frequency bandwidth of the search unit and other parameters such as focused, beam refraction angle in the test object, materials properties and the ultrasonic test instrument characteristics.

ISO 2400 establishes a reference block, known as the IIW No. 1 Block. For straight beam tests, this block is used for checking or establishing the near field resolution, far field resolution and time base (or horizontal) linearity of the test equipment. For angle beam tests, the block is used to determine the search unit index (hereafter called probe index) and the angle of refraction. This block also provides a means for checking the longitudinal (compressional) wave and transverse (shear) wave velocities of the test material.

ISO 7963 establishes a small calibration block, known as the IIW No. 2 Block, which is quite suitable for field use. It provides guidelines for material selection, preparation and mechanical tolerances of the reference block. It also provides procedures for testing the refraction angle and sensitivity settings of the signals.

The sound field of a straight beam search unit (normal probe) can be calculated or measured in immersion testing with the procedures given in ISO 10375.

In addition to the above International Standards, the present International Standard introduces two ultrasonic reference blocks and provides a general methodology of using these blocks in order to establish the sound fields or beam profiles in contact tests. The terminology used in this International Standard is in compliance with ISO 5577.

The objectives of this International Standard are the following.

— To determine search unit axes so that consistent tests can be performed.

— To establish a complete sound field or beam profile inside solid materials for search units of both straight beam and angle beam types, including focused beam and dual element search units.

— To provide a method for calculating the correct refraction angle when an angle beam search unit designed for use in steel is to be used in materials other than steel.

— To provide a beam profile measurement capability for future applications, such as an Electromagnetic Acoustical Transducer (EMAT).

— To provide a capability for lateral angle beam profile measurements.

— To provide means for time base calibration of angle beam search units to be used with ultrasonic imaging systems (see annex A).

— To provide means for time-of-flight (TOF) beam profile measurements for search units to be used with ultrasonic imaging systems (see annex B).

— To provide a technique, by hand held method and by using a mechanical scanner and UT imaging system to obtain both the amplitude and TOF beam profiles (see Figure B.1).

— To provide means for the determination of the skew (or squint) angle, far field and near field resolutions of angle beam search units (see annex C).

NOTE This document was initiated in the ISO/TC 135/SC3 meeting at Philadelphia, USA in 1985. The scope and contents of this document were discussed at Yokohama, Japan in 1987, at Berlin, Germany in 1989, at Ispra, Italy in 1991, at Pretoria, South Africa in 1993, at Berlin, Germany in 1995 and at Paris, France in 1997 among members of TC135/SC3/WG1.

Ultrasonic non-destructive testing — Reference blocks and test procedures for the characterization of contact search unit beam profiles

1 Scope

This International standard introduces two metal reference blocks, the hemi-step (HS) and the side-drilled-hole (SDH) blocks. This International Standard establishes procedures for measuring the sound field or beam profiles produced by search units in contact tests. The search units include straight beam, angle beam (refracted compressional and refracted shear), focused beam and dual element search units. The diameter or the side dimension of the search unit shall be no greater than 25 mm. The methodology of this International Standard provides guidelines for search units to be used for different metals including forged or rolled steel, aluminum or titanium alloy products. The frequency range of the search units used in this International Standard extends from 1 MHz to 15 MHz, where 1 MHz to 5 MHz is best suited for steels and 5 MHz to 15 MHz is best for fine grain structured alloys such as aluminum products. If this International Standard is to be used for material other than steels, users should be aware of the fact that the wave velocities in these materials may be different from that of steels and the angle beam search units are normally designed based on the steel applications. Snell's law of refraction is described in this International Standard so that correct refraction angles in other materials can be calculated. This International Standard applies to angle beam search units of all practical angles (0° to 70°), and to focused and dual element search units. This International Standard does not address the use of surface (Rayleigh) wave search units.

The procedures in this International Standard can be used in whole, or in part, with other standards. For testing materials which are very thick or very thin, the present reference blocks may be made proportionally larger or smaller to accommodate different search unit beam sizes. This International Standard does not address the estimation of equivalent defect sizes which will require reference blocks with flat-bottom-holes. This International Standard establishes no acceptance criteria; but does establish the technical basis for criteria that may be defined by user parties.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 7963:1985, *Welds in steel — Calibration block No. 2 for ultrasonic examination of welds*.

ISO 10375:1997, *Non-destructive testing — Ultrasonic inspection — Characterization of search units and sound field*.

3 Symbols and abbreviations

3.1 Symbols

Symbol	Designation	Unit
A	Peak echo amplitude	dB
d_{FL}	Beam diameter at focal length	mm
F_D	Depth of field	mm
F_L	Focal length	mm
H_i	Distance along the test surface from the beam index to the ith hole[a]	mm
L_x, L_y, L_z	Axes of search unit	–
P_i	Search unit position on the reference block[a]	–
R	Radius of the eight side-drilled holes[b]	mm
SDH_i	ith side drilled hole	–
T_1	Time from hemi-step surface 1	s
T_2	Time from hemi-step surface 2	s
T_d	Time delay	s
V_l	Longitudinal (compressional) wave velocity in the test object	ms^{-1}
V_s	Transverse (shear) wave velocity in the test object	ms^{-1}
V_w	Longitudinal (compressional) wave velocity in the wedge material	ms^{-1}
Y_i	Distance along Y-axis from the ith hole to the probe location of the peak echo amplitude[c]	mm
Y_{i1}, Y_{i2}	Locations along Y-axis of the two 6 dB drop points	–
Z_i	Depth of the ith hole centre to one of the side surfaces[d] of the SDH block[c]	mm
Z_β	Longitudinal beam axis of the angle beam search unit	–
$Z_{\beta i}$	Distance along the beam axis from the beam index to the ith hole centre[c]	mm
$Z_{\beta L}$	Lateral beam axis of the angle beam search unit	–
α_w	Incident angle (wedge angle)	°
β	Refraction angle	°
β_l	Refracted longitudinal (compressional) angle in the test object	°
β_s	Refracted transverse (shear) angle in the test object	°
γ	Skew (or squint) angle[e]	°

[a] $i = 1, 2, 3.....$

[b] Diameter = 1,5 mm.

[c] $i = 2, 3.....$

[d] T-, B-, R- and L-surfaces.

[e] See Figure 4 of ISO 10375:1997.

3.2 Abbreviations

FS	Full screen height or full scale of display graticule
HS	Hemi-step
IP	Initial pulse
P	Probes or search unit
R_v	Receiver connector
SDH	Side-drilled hole
B-surface	Bottom test surface of the SDH block
F-surface	Front test surface of the SDH block
L-surface	Left test surface of the SDH block
R-surface	Right test surface of the SDH block
T-surface	Top test surface of the SDH block
T_r	Transmitter connector
X, Y, Z	Axes of the reference block (plane of X-Y, test surface; Z, perpendicular to and below the test surface)

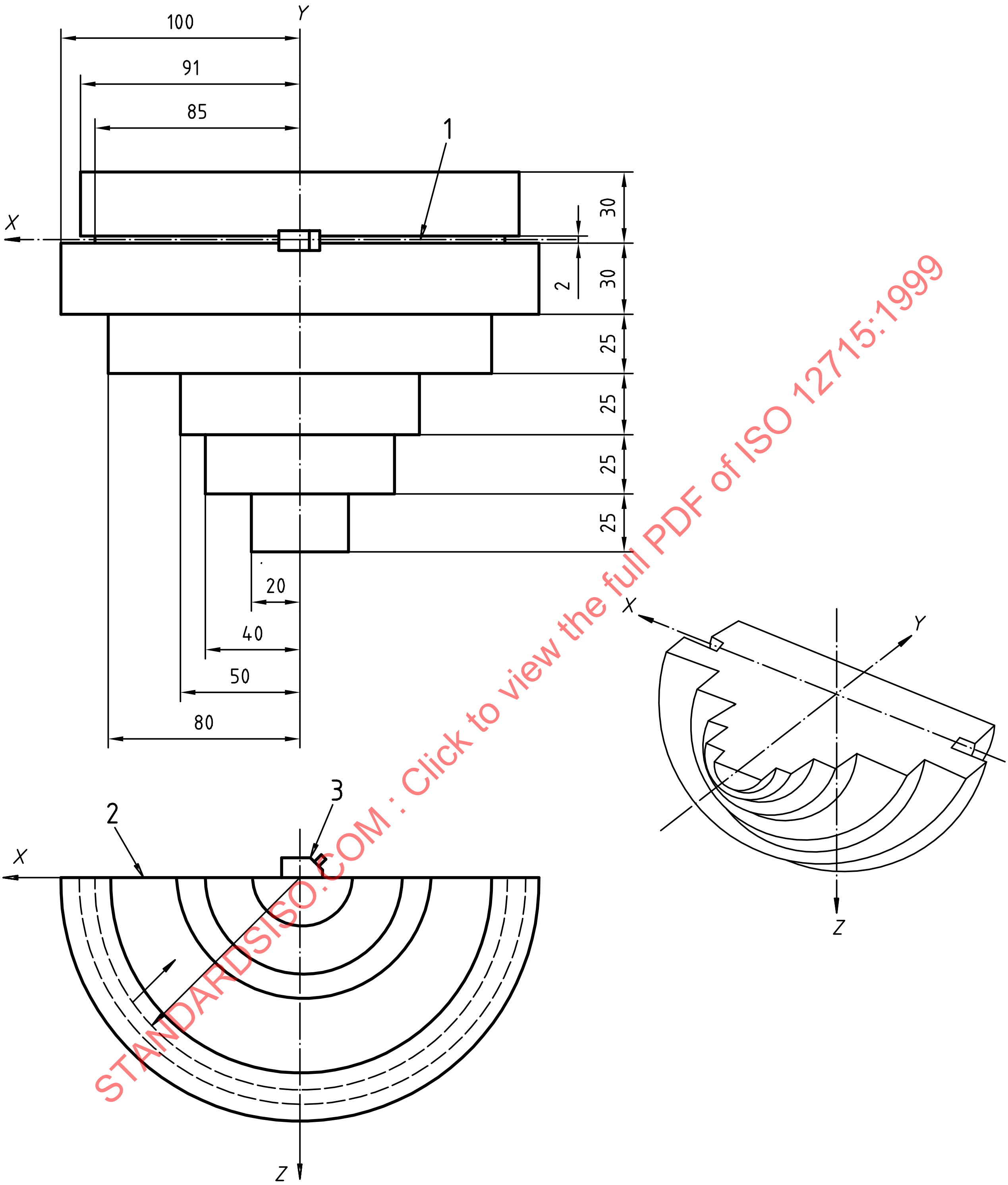
4 Descriptions of the reference blocks

The two reference blocks in this International Standard are made of metal. The reference blocks shall be fabricated using a material with acoustical characteristics similar or equivalent to that of the test object. The general requirements for the blocks' mechanical tolerance, surface roughness and engraved scale should be the same as stated in ISO 7963. The geometry and dimensions of the two blocks are described in 4.1 and 4.2.

4.1 Hemi-step (HS) block

Figure 1 shows the dimensions of the HS block in millimeters. It shall be machined from a solid cylinder. After it is machined into cylindrical step shape, it is cut along the longitudinal axis and machined to the required surface finish. The radii of the hemi-steps are 20 mm, 40 mm, 50 mm, 80 mm and 100 mm, a slot of 85 mm and 91 mm. The width of the 20 mm to 80 mm radial steps is 25 mm; the width of the 100 mm step is 30 mm; the width of the 85 mm slot is 2 mm and the width of the 91 mm radius step is 28 mm. A line along the centre section of the slot (the X-axis), a centre line dividing the HS block in symmetry (the Y-axis) and boundary lines between adjacent steps, on the flat surface, shall be engraved. When in use, the block should rest on an appropriate wood support. The support frame shall cause neither mechanical damage to the block nor any acoustical damping effect due to the support.

Dimensions in millimetres



Key

1 Centre line of slot

2 Front surface

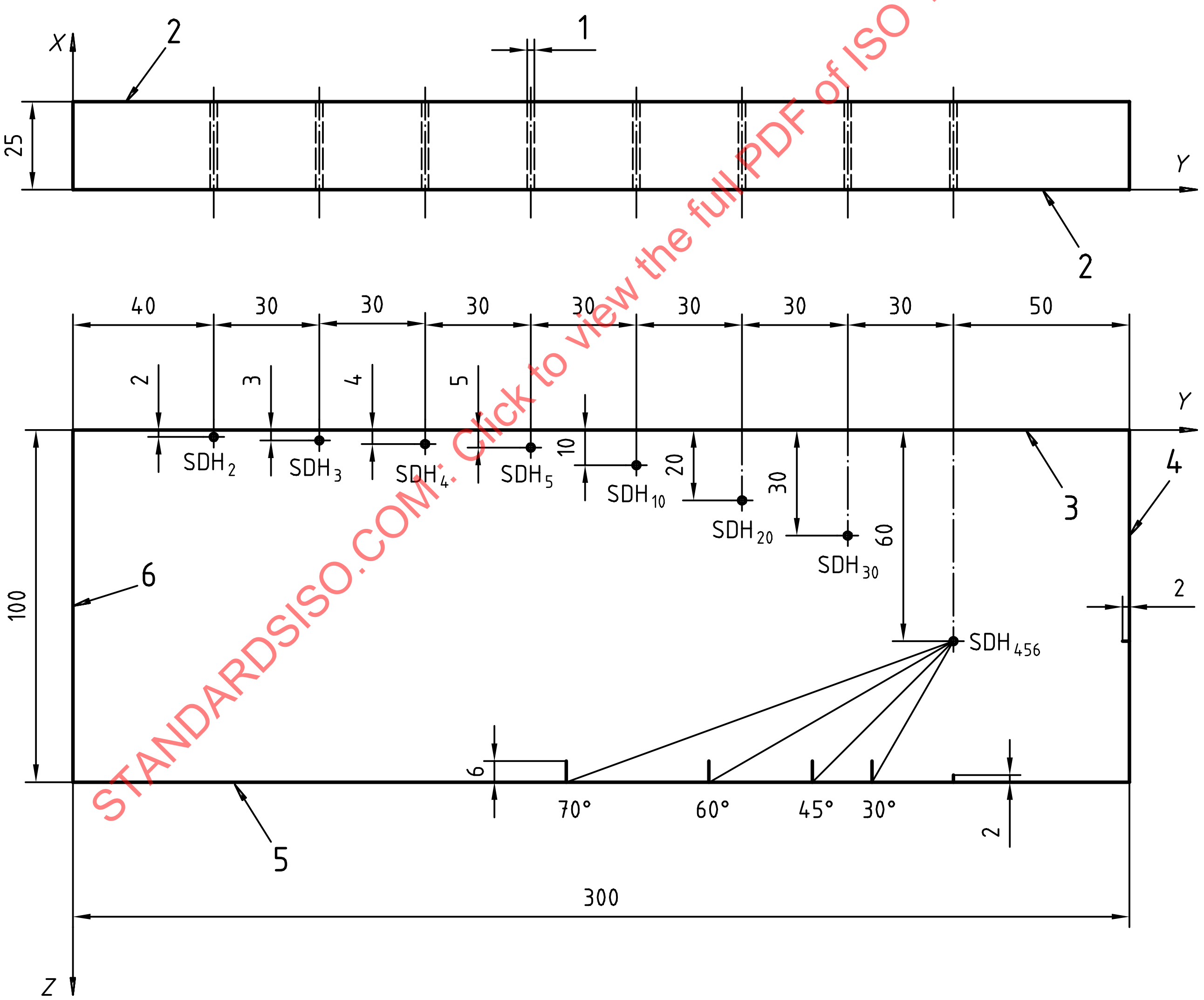
3 Angle probe

Figure 1 — Hemi-step (HS) block

4.2 Side-drilled hole (SDH) block

Figure 2 shows the dimensions of the SDH block in millimeters. It is 300 mm long by 25 mm wide by 100 mm high with eight identical side drilled holes 1,5 mm in diameter. They are identified as SDH2, SDH3, SDH4, SDH5, SDH10, SDH20, SDH30 and SDH456. The longitudinal axis of the holes shall be parallel to the top and bottom surfaces of the block. The surfaces of the block are identified as the T- (top), B- (bottom), R- (right) and L- (left), and F- (front) surface which refers to either side of the large surfaces. The location of the hole is measured from the centre of the hole to the top, bottom or end surface of the block. Short lines on the edge of the F- and T-surfaces are engraved indicating the locations of the SDH centre lines. The location of the SDH456 is engraved on all the T-, B-, R- and F-surfaces. Except for the SDH456 hole, the number affixed to the SDH indicates the distance of the hole centre to the T-surface. For example, the distance from the SDH2 hole centre to the T-surface is 2 mm. The distances from the SDH456 centre to the B-, R-, and T-surface are 40 mm, 50 mm and 60 mm respectively. The first hole, the SDH2 is 40 mm from the L-surface, and the distance between the adjacent holes is 30 mm. Refraction angles (0° to 70°) are indicated by short lines engraved on the F-surfaces at the edge between the F- and the B-surfaces. The nominal compressional and shear velocities of the material, determined empirically after the block has been made, may be engraved on one of the F-surfaces of the SDH block.

Dimensions in millimetres



Key

1 Side-drilled hole of diameter 1,5 mm
2 F-surface
3 T-surface
4 R-surface
5 B-surface
6 L-surface

Figure 2 — Side-drilled hole (SDH) block

5 Techniques and Procedures

5.1 Straight beam search units (normal probe)

5.1.1 Amplitude beam profile for straight beam search unit

Place the search unit on the T-surface, on top of the first SDH as shown in Figure 3. If the echo signal on the instrument's display screen is within the probe's dead zone, ignore this hole and proceed testing with the next hole until the echo signal is able to be resolved. Move the search unit such that the signal reflected from the hole is maximum. Adjust the gain such that the signal amplitude is about 80 % of full scale (hereafter called FS) of the instrument display graticule. The signal shall be at least 20 dB greater than the background noise level. Move the search unit along the Y-axis to and from the peak amplitude such that the signal amplitude drops 6 dB from the peak amplitude. Record the gain for the peak amplitude (A), the probe location (Y_i) of the peak amplitude, the two 6 dB drop (− 6 dB) points (Y_{i1}, Y_{i2}) and the depth (Z_i) of the hole in the test.

Repeat the above tests for all of the holes of interest on the SDH block. The depth (Z_i) of the SDH$_i$ is measured from the centre of the hole and the wave is reflected from the hole top surface. For engineering accuracy, no radius corrections are needed since the error source caused by this difference is relatively small compared to other error sources in ultrasonic tests. Figure 4 shows the beam profile in the test object produced by a straight beam search unit.

It should be noted that the amplitude varies in the near field due to diffraction from the probe edges. Beyond the near field is the far field where the amplitude decreases with increasing distance. The calculation of the near field length is given in ISO 10375.

5.1.2 Amplitude beam profile for focused straight beam search unit

Repeat the procedures stated in 5.1.1. The result is plotted as shown in Figure 5.

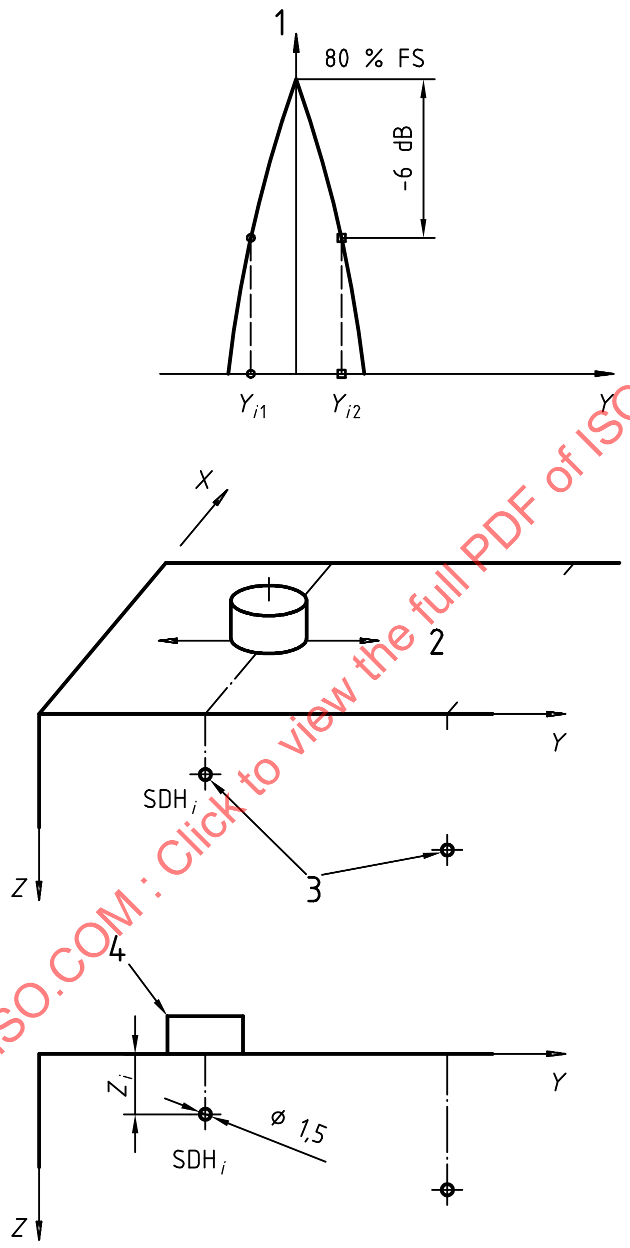
a) The line joining the peak amplitude at each depth is the sound beam axis.

b) The location of the signal at maximum amplitude is the focal point.

c) The distance from the test surface to the focal point is the focal length (F_L).

d) The distance between the two 6 dB drop points along the beam axis is the depth of field (F_D).

e) At the focal point, the distance between the two 6 dB drop points in a plane perpendicular to the beam axis is the focal beam diameter (d_{FL})



Key

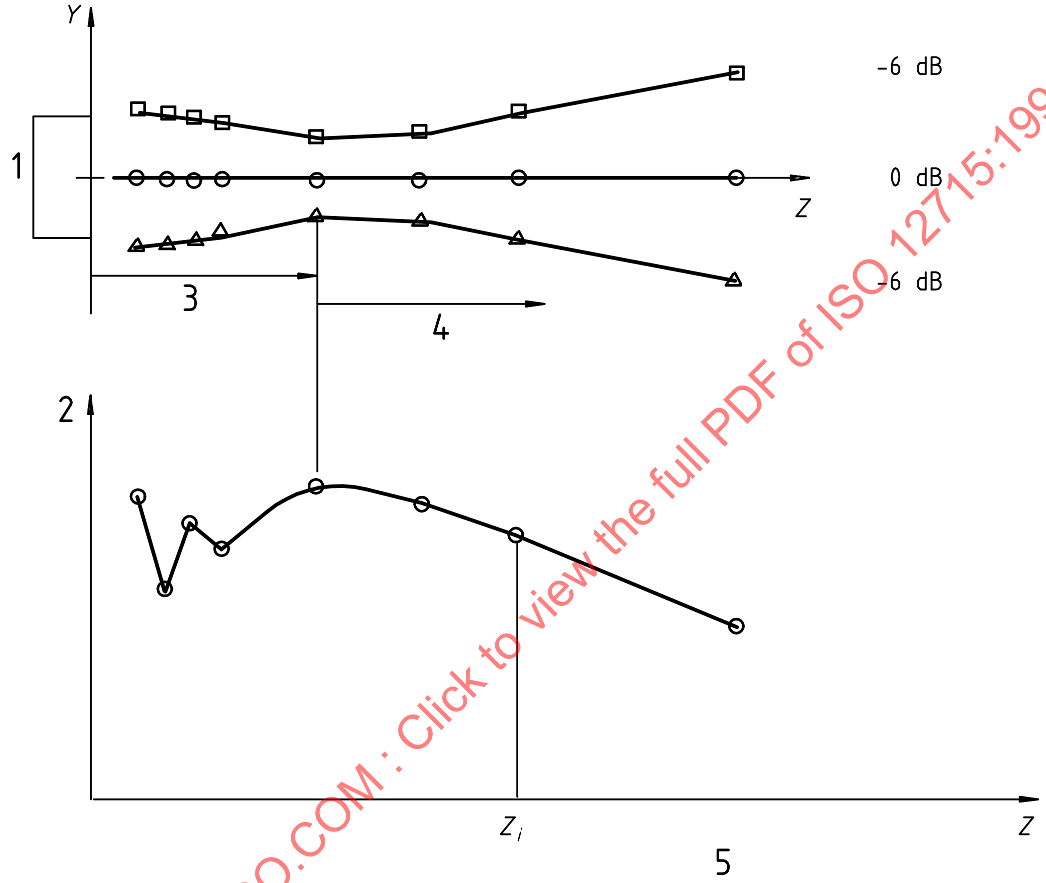
1 Echo amplitude A (dB)

2 T-surface

3 Side-drilled holes

4 Straight beam search unit

Figure 3 — Sound beam test for straight beam search unit



Key

1 Search unit

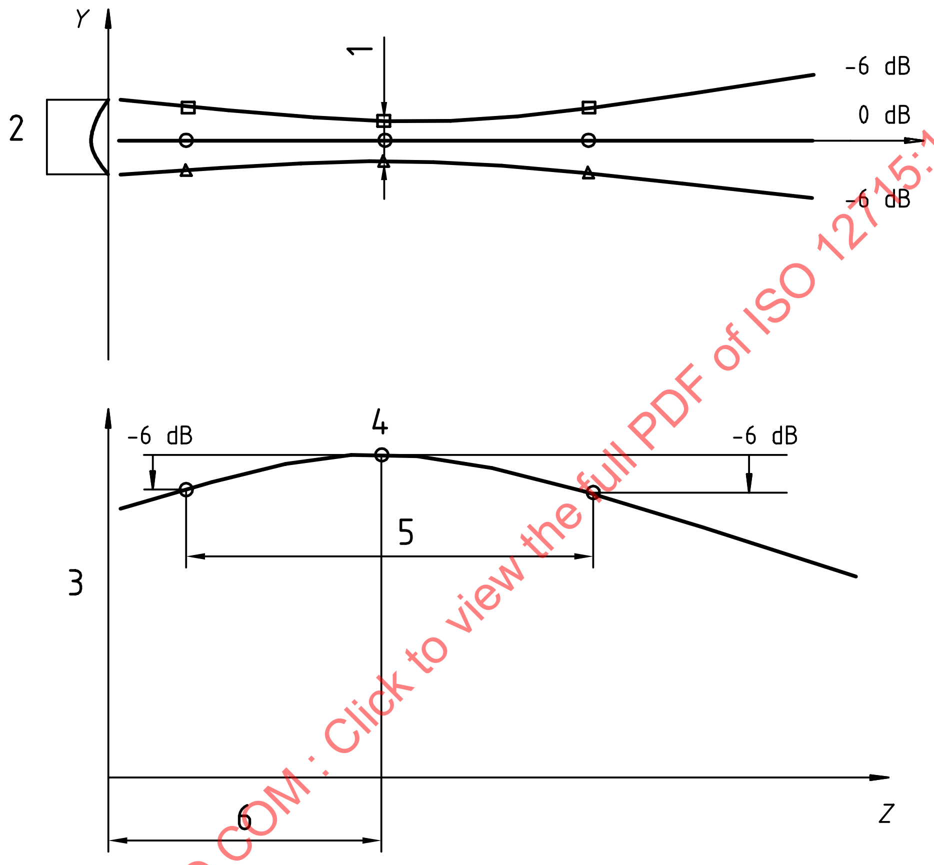
2 Echo amplitude A (dB)

3 Near field

4 Far field

5 Distance (mm)

Figure 4 — Beam profile for straight beam search unit



Key

1 Beam diameter (d_{FL}) at focal point

2 Focussing search unit

3 Echo amplitude A (dB)

4 Peak amplitude

5 Depth of field (F_D)

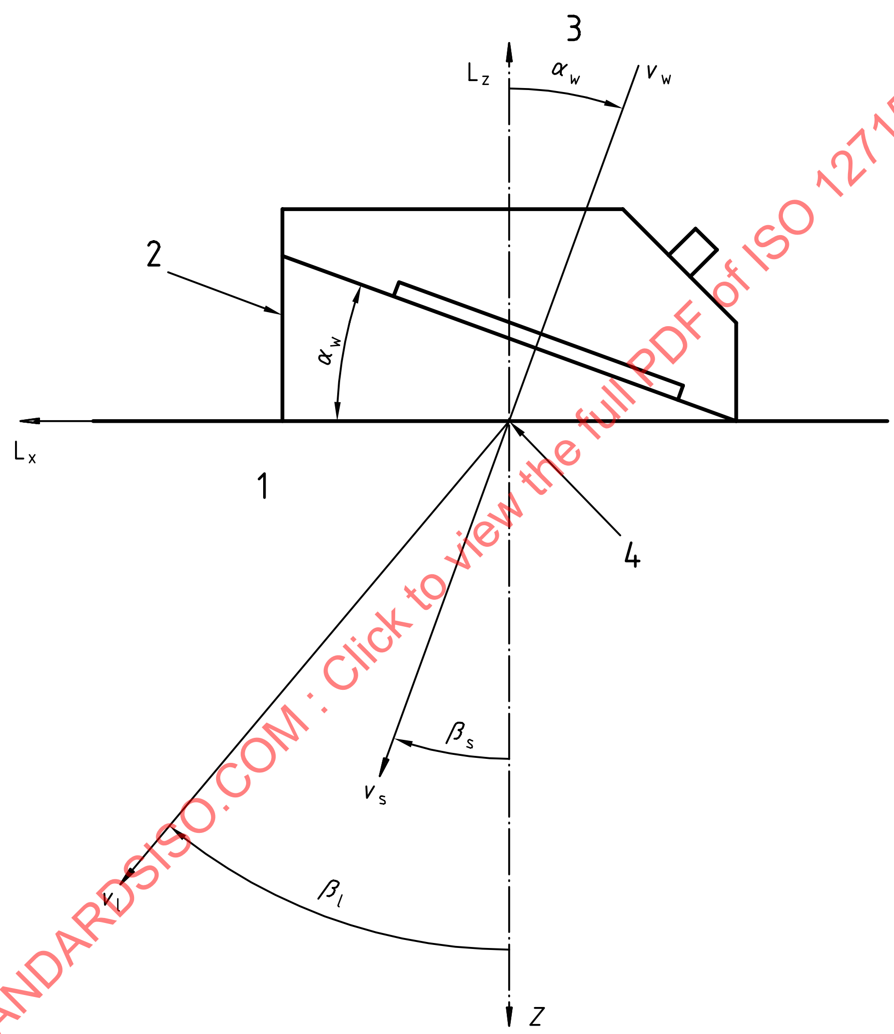
6 Focal length (F_L)

Figure 5 — Beam profile for focusing straight beam search unit

5.2 Angle beam search unit (angle probe)

Most angle beam search units are identified by their nominal size, nominal frequency, nominal beam angle and the velocity of propagation of transverse (shear) waves in steel. Angle beam search units used in different materials which have different wave velocities will yield different angles of refraction. An angle beam search unit can produce a refracted longitudinal (compressional) wave, a refracted transverse (shear) wave or both inside a test object.

The relationship between the incident (wedge) and the refracted angle in terms of the wave velocities in the wedge and in the test object is shown in Figure 6.



Key

1 Test object

2 Wedge

3 Incident angle

4 Beam index (I)

Figure 6 — Snell's law of refraction

Snell's Law of refraction is given as follows.

Refracted longitudinal (compressional) wave:

$$\frac{V_W}{V_l} = \frac{\sin \alpha_W}{\sin \beta_l} \quad (1)$$

Refracted Transverse (shear) wave:

$$\frac{V_W}{V_S} = \frac{\sin \alpha_W}{\sin \beta_S} \quad (2)$$

The above formulae provide a means for the calculation of correct refraction angle when the angle beam search unit designed for use in steel is to be used in materials other than steel.

5.2.1 Longitudinal amplitude beam profile for angle beam search unit

Place the search unit on the T -surface, on top of the first hole of the SDH block, with the longitudinal axis (L_x) of the search unit perpendicular to the longitudinal axis (X) of the hole as shown in Figure 7. Aim the angle beam toward the hole and obtain a peak signal. Adjust the gain such that the peak signal amplitude is about 80 % FS of the instrument. Move the search unit along the Y-axis on the block to and from the peak amplitude point such that the signal amplitude drops 6 dB from the peak amplitude. Record the peak echo amplitude (A), the probe location (Y_i) of the peak amplitude, the two 6 dB drop points (Y_{i1}, Y_{i2}) and the depth (Z_i) of the hole in the test. The distance along the beam axis from the beam index to the ith hole centre is $Z_{\beta i}$. It can be obtained as follows.

$$Z_{\beta i} = [(Z_i)^2 + (Y_i)^2]^{1/2} \quad (3)$$

Repeat the above tests for all of the holes of interest. The longitudinal beam profile in the test object, produced by an angle beam search unit is shown in Figure 8. In addition, the peak amplitudes vs depth (Z) below the test surface are plotted for practical applications and the peak amplitudes along the beam axis (Z_β) are plotted for theoretical analyses.

5.2.2 Lateral amplitude beam profile for angle beam search unit

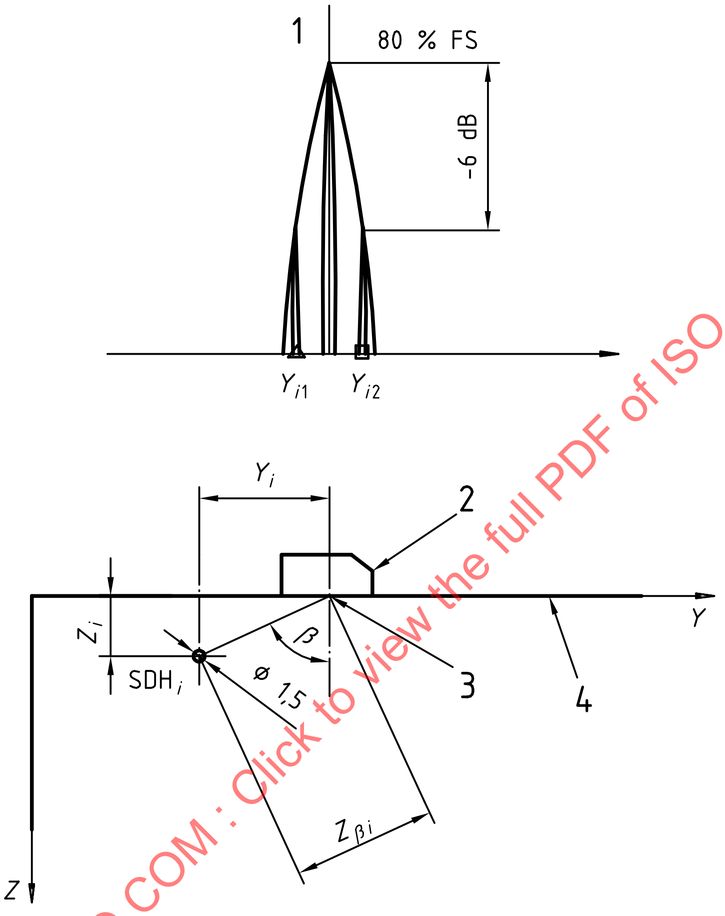
The lateral amplitude beam profile for the angle beam search unit can best be measured with the HS-block as shown in Figure 9.

Place the angle beam search unit on the HS-block with its beam toward the 100 mm radius surface, identified temporarily as step 2 surface. With the aid of a straight edge, the angle beam search unit is slid along the Y-direction. Record the position $Y = 0$, where the signal amplitude (A) is maximum at 80 % FS of the instrument. For position $Y < 0$, the amplitude from step 2 surface starts to fall; for position $Y > 0$, the amplitude remains at about the same level of 80 % FS.

Record the position Y_{i1}, where the amplitude (A) from step 2 surface (100 mm) is 40 % FS. The half lateral beam width, at Z_β = Step 1, is Y_{i1}.

Repeat the measurements for all adjacent steps, i.e. 80 mm to 50 mm, 50 mm to 40 mm, 40 mm to 20 mm, on both sides (sides 1 and 2) of the HS-block, without changing the receiver gain. Figure 10 is the lateral amplitude beam profile in the test object produced by an angle beam search unit.

It should be noted that, depending on the probe characteristics, the amplitude on each hemi-step can vary due to different interference. The signal amplitude, consisting of a main signal level, may contain several distinctive high amplitude peaks. In such cases, the distinctive high amplitude peaks are ignored and the main signal levels from each step surface are used for the amplitude beam profile measurements. Additionally, the time of flight (TOF) beam profiles should also be measured to supplement the amplitude beam profiles (see annex B).



Key

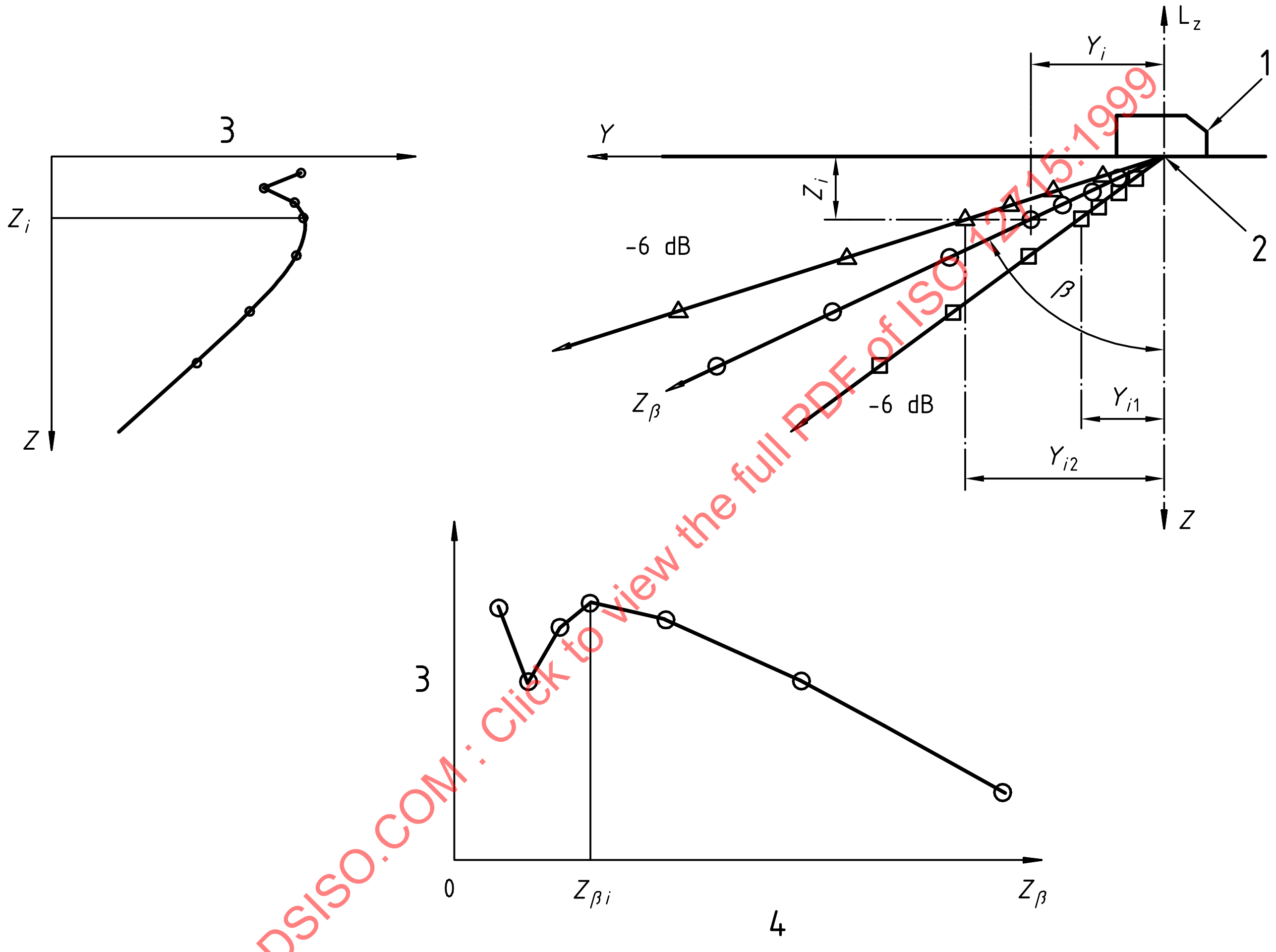
1 Echo amplitude A (dB)

2 Angle beam research unit

3 Beam index (I)

4 T-surface

Figure 7 — Longitudinal beam profile test of angle beam search unit



Key

1 Angle beam search unit

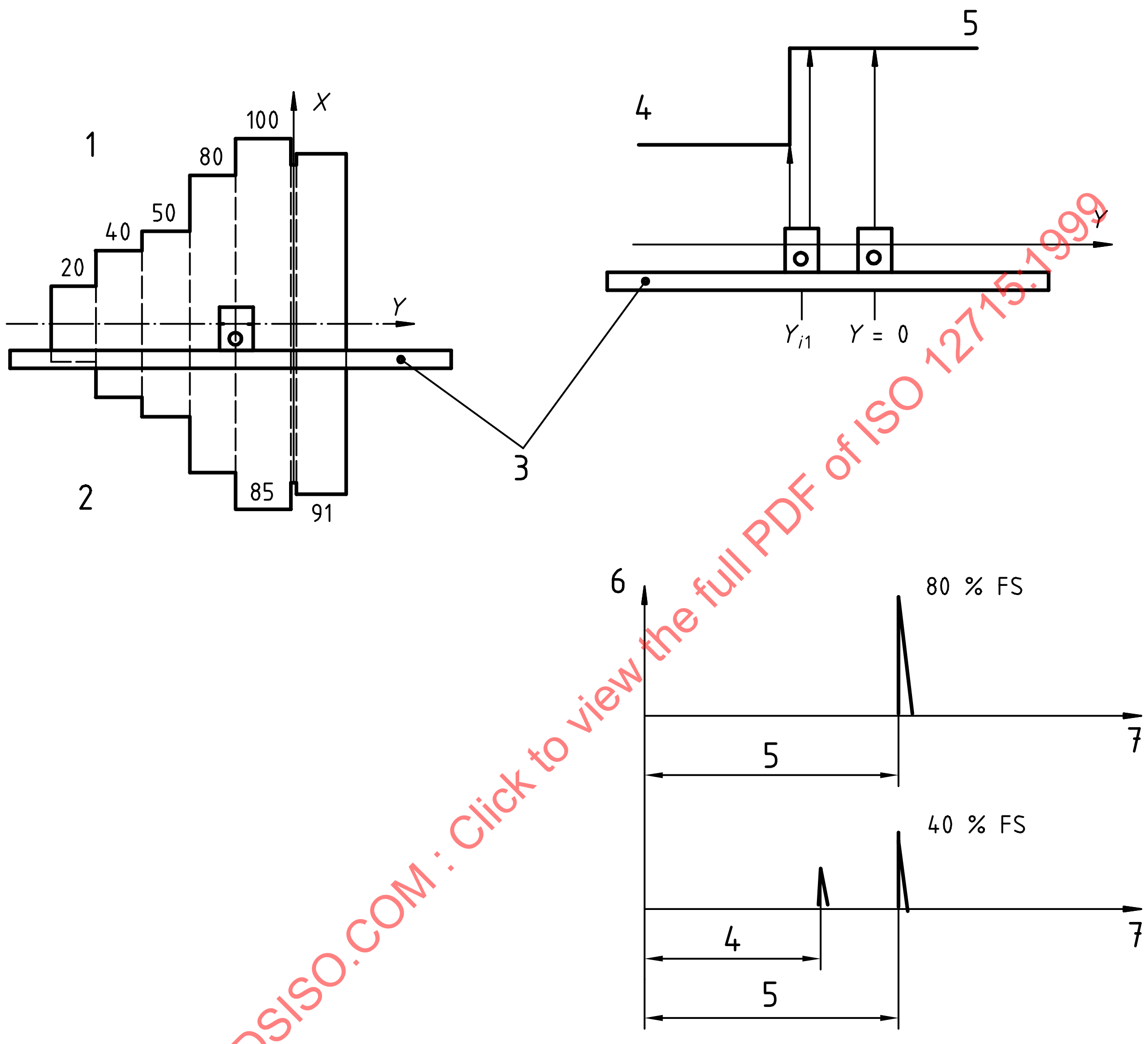
2 Beam index (I)

3 Echo amplitude A (dB)

4 Beam axis

Figure 8 — Longitudinal sound beam of angle beam search unit

Dimensions in millimetres



Key

1 Side 1

2 Side 2

3 Straight edge

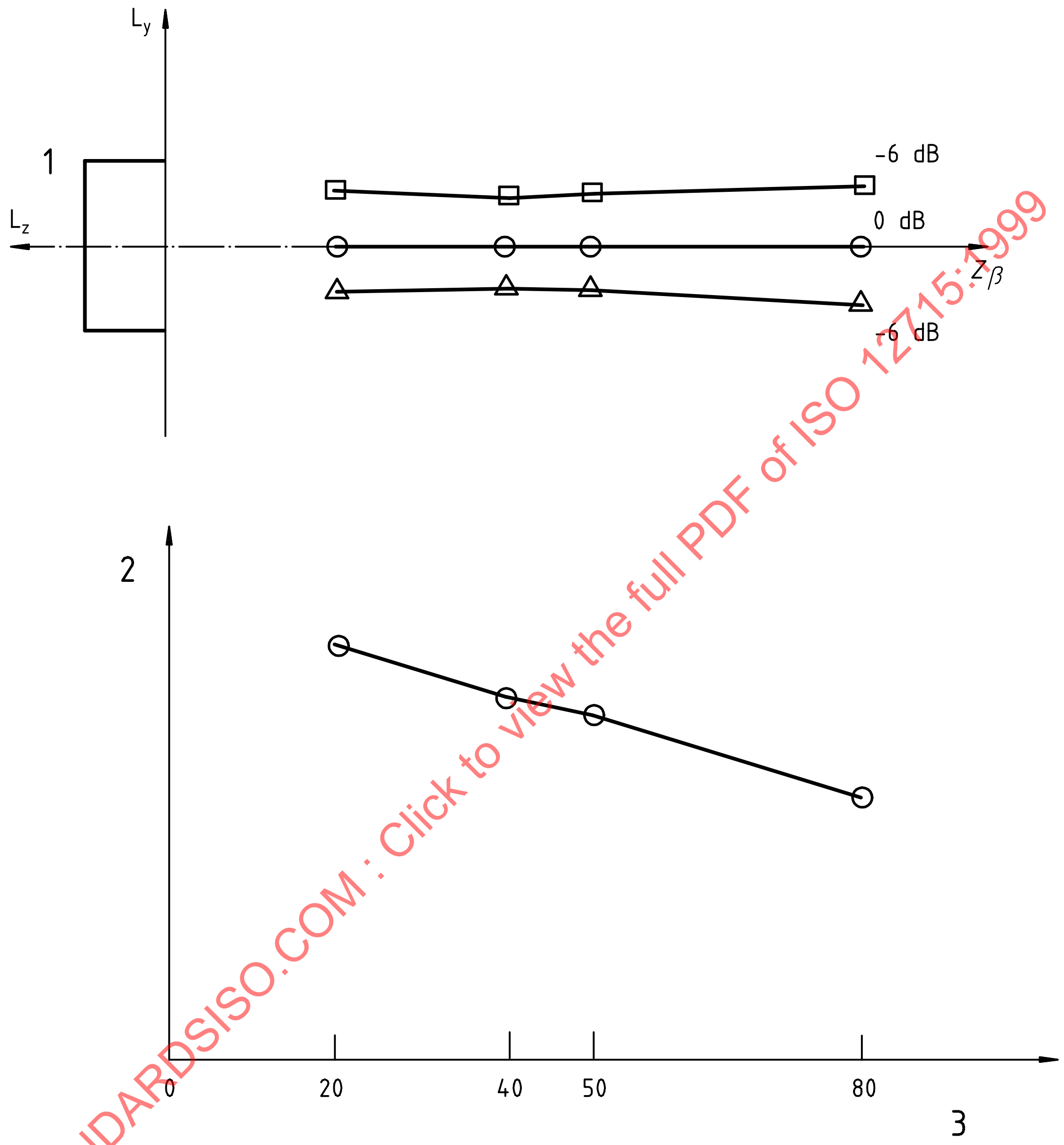
4 Step 1

5 Step 2

6 Amplitude A (%)

7 Time or distance

Figure 9 — Lateral half beam width of angle beam search unit at step 1



Key

1 Angle beam search unit

2 Echo amplitude A (dB)

3 Distance along axis Z_β (mm)

Figure 10 — Lateral beam profile of angle beam search unit

5.2.3 Longitudinal amplitude beam profile for focused beam angle beam search unit

Repeat the same procedures as stated in 5.2.1. The beam profile of the focused angle beam search unit is shown in Figure 11. The amplitudes vs depth (Z) and vs the beam axis (Z_β) are also plotted in Figure 11.

a) The line linking the peak amplitude at each depth is the longitudinal beam axis Z_β.

b) The location of the signal at maximum amplitude is the focal point.

c) The distance from the beam index to the focal point along the longitudinal beam axis is the focal length (F_L).

d) The distance between the two 6 dB drop points along the longitudinal beam axis is the depth of field (F_D).

e) At the focal point, the distance between the two 6 dB drop points on a plane perpendicular to the longitudinal amplitude beam axis is the focal beam diameter (d_{FL}).

5.2.4 Lateral amplitude beam profile for focused angle beam search unit

Repeat the same procedure as stated in 5.2.2. The result of the lateral beam profile for the focused angle beam search unit is shown in Figure 12.

a) The line linking the peak amplitude at each depth is the lateral beam axis $Z_{\beta L}$.

b) The location of the signal at maximum amplitude is the focal point.

c) The distance from the beam index to the focal point along the lateral beam axis is the focal length (F_L).

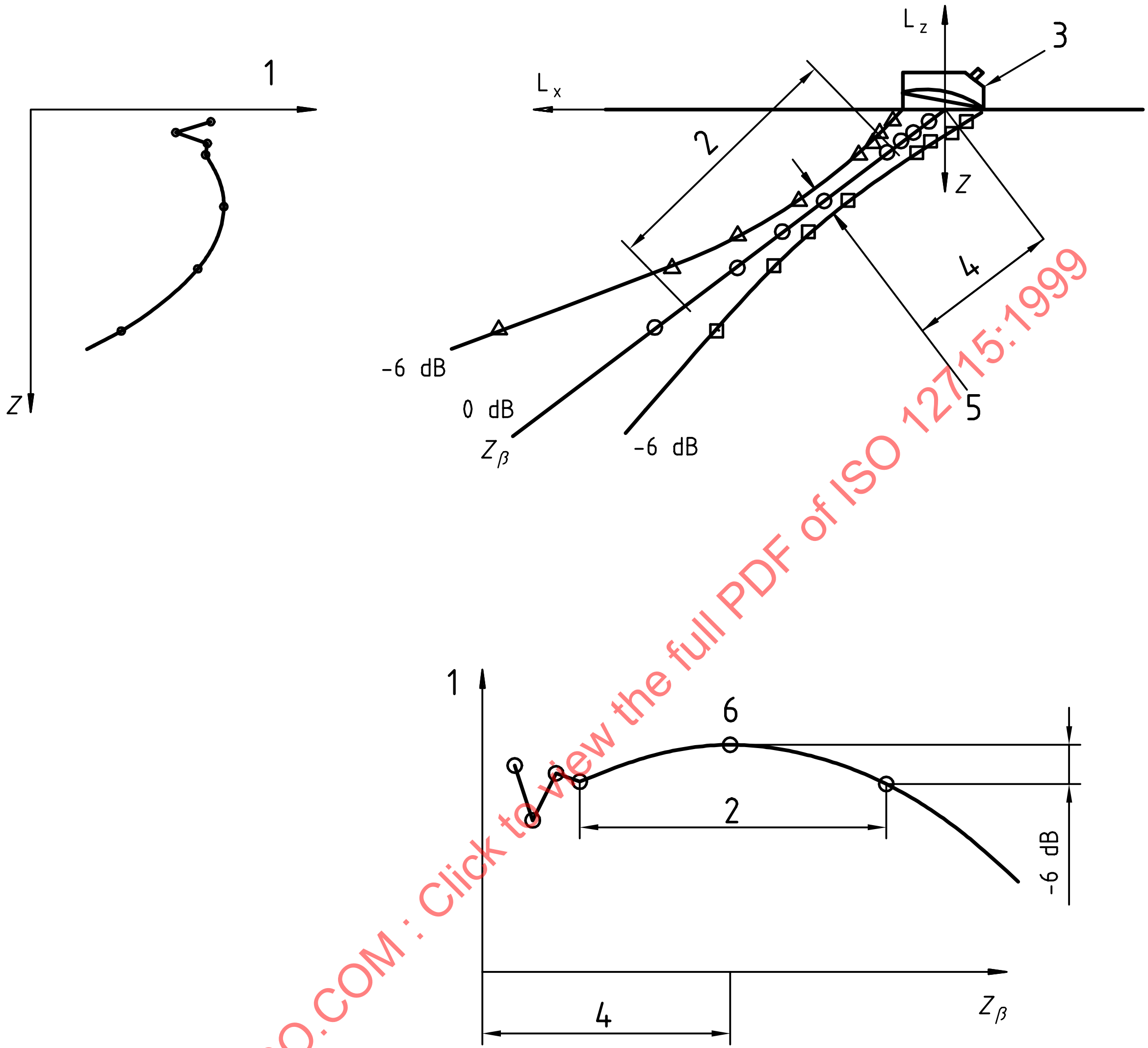
d) The distance between the two 6 dB drop points along the lateral beam axis is the depth of field (F_D).

e) At the focal point, the distance between the two 6 dB drop points on a plane perpendicular to the lateral beam axis is the focal beam diameter (d_{FL}).

5.3 Dual element search unit (twin crystal probe)

The straight beam dual element search unit is often used for testing thin materials or detecting flaws immediately beneath the surface of the test object or testing coarse grain materials. It is constructed with two elements mounted on a delay material inside one housing. Some dual element search units may have a slight angle, known as the roof angle. For best sensitivity and consistency, a dual element search unit should be marked with the longitudinal L_x axis and the lateral L_y axis as well as the transmitting (T_r) and receiving (R_v) connectors.

The procedures for determining the beam profiles for a straight dual element search unit and an angle dual element search unit are the same as given in 5.1.1 and 5.2.1, respectively. The orientation of the dual element search unit relative to the axis of the SDH as well as the ultrasonic test instrument used for the inspection shall be recorded.



Key

1 Echo amplitude A (dB)

2 Longitudinal depth of field (F_D)

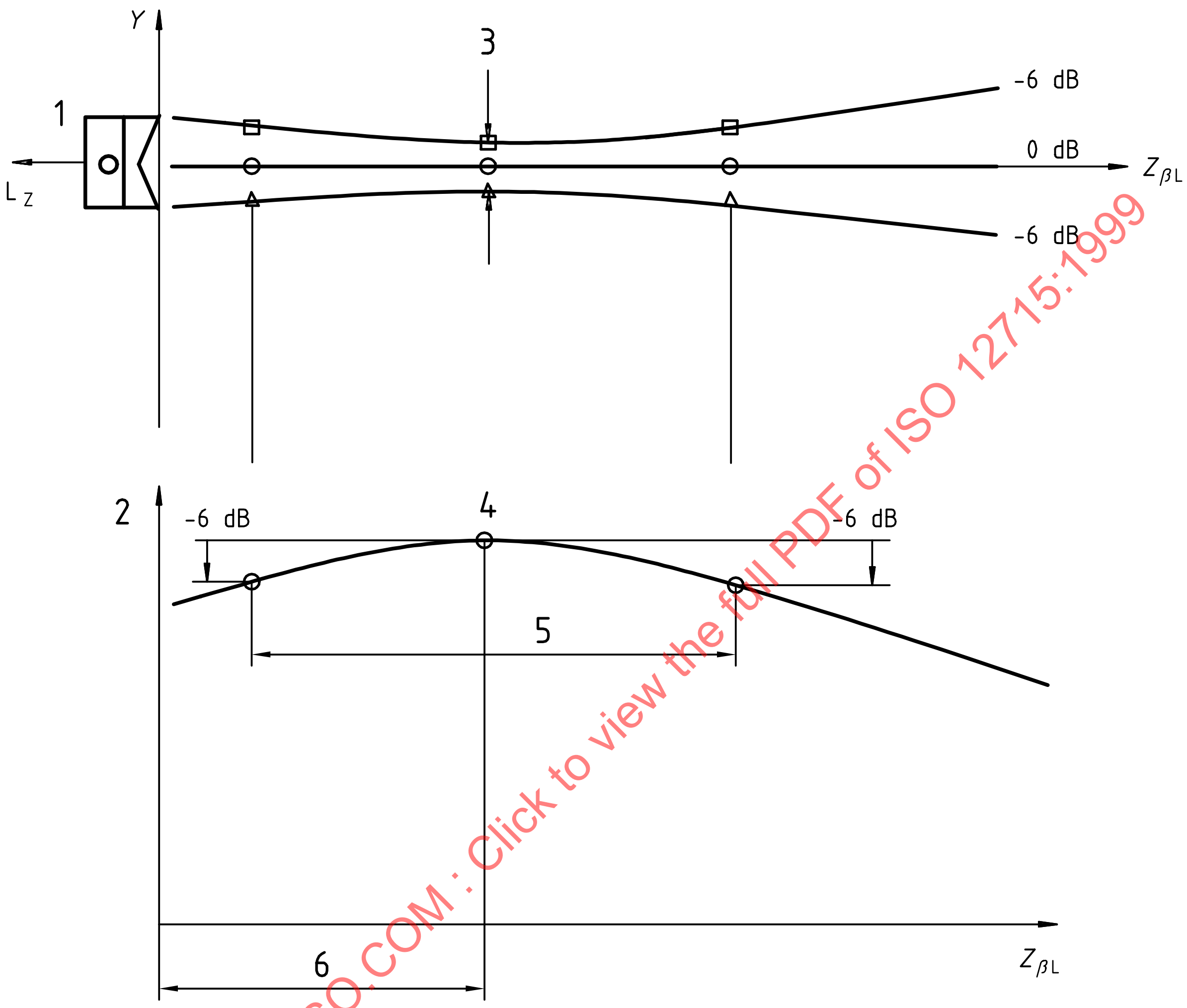
3 Focusing angle beam search unit

4 Longitudinal focal length (F_L)

5 Focal beam diameter d_{FL}

6 Focal point peak amplitude

Figure 11 — Longitudinal beam profile of focusing angle beam search unit



Key

1 Search unit
2 Echo amplitude A (dB)
3 Beam diameter (d_{FL}) at focal point
4 Lateral focal point (peak amplitude)
5 Lateral depth of field (F_D)
6 Lateral focal length (F_L)

Figure 12 — Lateral sound beam of focusing angle beam search unit (point focusing probe)

Annex A
(normative)

Time base calibration

The double distance features of the HS block shall provide a capability for the time base calibration for angle beam probes. The procedure is as follows.

Select maximum thickness range of interest, and test on two surfaces with double distance feature, for example, 20 mm and 40 mm, 40 mm and 80 mm or 50 mm and 100 mm.

Set the angle search unit on the HS block, with the probe index aligned with the centre-line of the HS block, with its beam direction toward the step surface.

Set the sensitivity level such that the signals are between 80 % and 100 % FS.

The signal reflected from the smaller step surface (hemi surface 1) of a step pair is noted as T_1 and the signal reflected from the larger step (hemi surface 2) of that pair is noted as T_2.

Adjust the time scale such that T_1 and T_2 are aligned on their corresponding divisions on the screen. Each division should correspond to 10 mm in sound path. The zero location on the horizontal scale is the front surface of the test material.

For ultrasonic imaging system, the time delay (T_d) is calculated by

$$T_d = 2\,T_1 - T_2$$

as shown in Figure A1.

The above procedure is also applicable to straight beam search units using the HS block tested along the centre-line.