BRITISH STANDARD

BS EN 12668-2:2010

Non-destructive testing — Characterization and verification of ultrasonic examination equipment

Part 2: Probes

ICS 19.100

British Standards

National foreword

This British Standard is the UK implementation of EN 12668-2:2010. It supersedes BS EN 12668-2:2001 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee WEE/46, Non-destructive testing.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

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This European Standard was approved by CEN on 25 December 2009.

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This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN Management Centre has the same status as the official versions.

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Contents

Page

Foreword

This document (EN 12668-2:2010) has been prepared by Technical Committee CEN/TC 138 "Non-destructive testing", the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by August 2010, and conflicting national standards shall be withdrawn at the latest by August 2010.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN 12668-2:2001.

EN 12668, *Non-destructive testing — Characterization and verification of ultrasonic examination equipment*, consists of the following parts:

— *Part 1: Instruments*

— *Part 2: Probes*

— *Part 3: Combined equipment*

Annex A is normative. Annex B is informative.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

1 Scope

This European Standard covers probes used for ultrasonic non-destructive examination in the following categories with centre frequencies in the range 0,5 MHz to 15 MHz, focusing and without focusing means:

a) single or dual transducer contact probes generating compressional or shear waves;

b) single transducer immersion probes.

Where material-dependent ultrasonic values are specified in this document they are based on steels having a sound velocity of (5 920 ± 50) m/s for longitudinal waves, and (3 255 ± 30) m/s for transverse waves.

Periodic tests for probes are not included in this document. Routine tests for the verification of probes using on-site methods are given in EN 12668-3.

If parameters in addition to those specified in EN 12668-3 are to be verified during the probe's life time, as agreed upon by the contracting parties, the methods of verification for these additional parameters should be selected from those given in this document.

2 Normative references

The following referenced documents are indispensable for the application 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.

EN 1330-4:2010, *Non-destructive testing — Terminology — Part 4: Terms used in ultrasonic testing*

EN 12668-1, *Non-destructive testing — Characterization and verification of ultrasonic examination equipment — Part 1: Instruments*

EN ISO 7963 [1)], *Non-destructive testing — Ultrasonic testing Specification for calibration block n° 2 (ISO 7963:1985)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 1330-4:2010 and the following apply.

3.1
dead zone
depth of the zone immediately beneath the coupling surface of the work piece, in which it is not possible to detect a given reflector

3.2
focal distance
near field length
point on the acoustical axis where the acoustic pressure is at its maximum

3.3
horizontal plane of a sound beam
<angle-beam probes> plane perpendicular to the vertical plane of the sound beam including the acoustical axis in the material

1) Under preparation.

3.4
operating frequency
f_o
centre frequency
arithmetic mean of upper and lower cut-off frequency

$$f_o = \frac{f_u + f_l}{2} \qquad (1)$$

NOTE In the frequency spectrum of an echo the upper and lower cut-off-frequencies are determined at -6 dB compared to the maximum amplitude.

3.5
peak-to-peak amplitude
h
maximum deviation between the largest positive and the largest negative cycles of the pulse

NOTE See Figure 1.

3.6
probe data sheet
sheet containing the information required by this standard

NOTE The data sheet need not necessarily be a test certificate of performance.

3.7
pulse duration
time interval over which the modulus of the unrectified pulse amplitude exceeds 10 % of its maximum amplitude, as shown in Figure 1

3.8
reference side
reference side is the right side of an angle beam probe looking in the direction of the beam, unless otherwise specified by the manufacturer

3.9
relative bandwidth
Δf_{rel}
ratio of the difference between the upper and lower cut-off frequencies f_u and f_l and the centre frequency f_o

$$\Delta f_{rel} = [(f_u - f_l)/f_o] \times 100 \%$$

NOTE The relative bandwidth is expressed in percent (%).

3.10
squint angle for straight-beam probes
δ
deviation between the axis of the beam and a perpendicular to the coupling surface at the emission point

NOTE 1 See Figure 2.

<angle-beam probes> angle between the sides of the probe housing and the measured beam axis, projected onto the plane of the probe face

NOTE 2 See Figure 3.

3.11
vertical plane of a sound beam
<angle-beam probes> plane in which the sound beam axis in the probe wedge and the sound beam axis in the inspected component both lie

4 General requirements for compliance

An ultrasonic probe complies with this standard if it satisfies the following conditions:

a) the probe shall comply with Clause 7;

b) either a declaration of conformity, issued by a manufacturer operating a certified quality management system, or issued by an organization operating an accredited test laboratory shall be available;

NOTE It is recommended that the certification is carried out in accordance with EN ISO 9001, or that the accreditation is carried out in accordance with EN ISO/IEC 17025.

c) the probe shall be clearly marked to identify the manufacturer, and carry a unique serial number, showing operating frequency, transducer size, angle, or a permanent reference number from which this information can be traced;

d) a technical specification (data sheet) for the appropriate type and series of probe which defines the performance criteria in accordance with Clause 5 shall be available.

The quality of probes will be assured in one of the following ways:

e) by issuing a declaration of conformity based on statistical analysis where a number of identical probes are manufactured under a quality management system. The manufacturer shall supply a data sheet which includes the values of the specified parameters with tolerances;

f) by issuing a declaration of conformity quoting the results of measurements made on each probe.

5 Technical specification for probes

Table 1 gives the list of information to be reported in a data sheet for all probes within the scope of this standard (I = Information, M = Measurement, C = Calculation). The data sheet shall also contain information concerning the ultrasonic instrument used for the test, its settings and coupling conditions, etc.

The operating temperature range of the probe, and any special conditions for storage or protection during transport shall also be stated in the data sheet.

For probes intended for use at elevated temperatures, the manufacturer shall provide information on the maximum operating temperature in relation to the time of use, and the effect of temperature on the sensitivity and on the beam angle.

Table 1 — List of information to be given in a data sheet

Information to be given	Category of probe														
	Contact													Immersion	
	Straight beam					Angle beam								Straight	
	Compressional				Shear	Compressional				Shear				Compressional	
	Single		Double		Single	Single		Double		Single		Double		Single	
	non-f.	focus.	non-f.	focus.	non-f.	non-f.	focus.	non-f.	focus.	non-f.	focus.	non-f.	focus.	non-f.	focus.
Manufacturer's name	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
Type of probe	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
Weight and size of probe	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
Type of connectors	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
TR connectors interchangeable?			I	I				I	I			I	I		
Material of transducers	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
Shape and size of transducers	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
Material of wedge, delay	I	I	I	I		I	I	I	I	I	I	I	I		
Material of wear plate	I														
Wear allowance	I	I	I	I		I	I	I	I	I	I	I	I		

I = Information;

M = Measurement;

C = Calculation.

continued

Table 1 *(continued)*

Parameters to be measured or calculated	Category of probe														
	Contact													Immersion	
	Straight beam					Angle beam								Straight	
	Compressional				Shear	Compressional				Shear				Compressional	
	Single		Double		Single	Single		Double		Single		Double		Single	
	non-f.	focus.	non-f.	focus.	non-f.	non-f.	focus.	non-f.	focus.	non-f.	focus.	non-f.	focus.	non-f.	focus.
Cross talk damping			M	M				M	M			M	M		
Pulse shape (time and frequency)	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
Centre frequency, band width	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
Pulse-echo sensitivity	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
Distance-amplitude curve	M,C	M,C	M,C	M,C	M,C	M,C	M,C	M,C	M,C	M,C	M,C	M,C	M,C	M,C	M,C
Impedance, static capacitance	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M

I = Information;

M = Measurement;

C = Calculation;

M,C = Measurement or calculation.

continued

Table 1 *(end)*

Parameters to be measured or calculated	Category of probe														
	Contact													Immersion	
	Straight beam					Angle beam								Straight	
	Compressional				Shear	Compressional				Shear				Compressional	
	Single		Double		Single	Single		Double		Single		Double		Single	
	non-f.	focus.	non-f.	focus.	non-f.	non-f.	focus.	non-f.	focus.	non-f.	focus.	non-f.	focus.	non-f.	focus.
Probe index						M	M	M	M	M	M	M	M		
Beam angle						M	M	M	M	M	M	M	M		
Angles of divergence	M				M	M				M				M	
Beam axis offset	M	M	M	M	M	M	M	M	M	M	M	M	M		
Squint angle	M	M	M	M	M	M	M	M	M	M	M	M	M		
Focal distance, near field	M,C	M,C	M,C	M,C	M,C	M,C	M,C	M,C	M,C	M,C	M,C	M,C	M,C	M,C	M,C
Focal width	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
Focal length	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
Physical aspects	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M

I = Information;

M = Measurement;

C = Calculation;

M,C = Measurement or calculation;

Non-f. = Non-focusing.

6 Test equipment

6.1 Electronic equipment

The ultrasonic instrument (or laboratory pulser/receiver) used for the tests specified in Clause 7 shall be of the type designated on the probe data sheet, and shall comply with EN 12268-1 as applicable. Where more than one type of ultrasonic instrument is designated the tests shall be repeated with each of the additional designated types.

Testing shall be carried out with the probe cables and electrical matching devices specified on the probe data sheet for use with the particular type of ultrasonic instrument.

NOTE Probe leads more than about 2 m long could have significant effect on probe performance.

In addition to the ultrasonic instrument or laboratory pulser/receiver the items of equipment essential to assess probes in accordance with this standard are as follows:

a) an oscilloscope with a minimum bandwith of 100 MHz;

b) a frequency spectrum analyser with a minimum bandwith of 100 MHz, or an oscilloscope/digitiser or computer capable of performing Discrete Fourier Transforms (DFT);

c) an impedance analyser.

The following additional equipment is optional:

d) For contact probes only:

   1) an electromagnetic-acoustic probe (EMA) and receiver;

   2) a plotter to plot directivity diagrams;

e) For immersion probes only:

   1) hydrophone receiver with an active diameter less than two times the central ultrasonic wavelength of the probe under test but not less than 0,5 mm. The bandwidth of the amplifier should be higher than the bandwidth of the probe under test.

6.2 Test blocks and other equipment

The following test blocks shall be used to carry out the specified range of tests, for contact probes only:

a) semi-cylinders with different radii (*R*) in the range from 12 mm to 200 mm. Steps of $R\sqrt{2}$ are recommended. Steel quality is as defined in EN ISO 7963. The thickness of each block shall be equal to or larger than its radius, up to a maximum thickness of 100 mm;

b) steel blocks with parallel faces and side-drilled holes of 3 mm diameter as shown in Figure 4. The dimensions of the blocks shall meet the following requirements:

   1) length, l, height, h, and width, w, shall be such that the sides of the blocks shall not interfere with the ultrasonic beam;

   2) depths of the holes, d_1, d_2, etc., shall be such that at least three holes shall fall outside the near field;

   3) the distance between the holes, s, shall be such that the amplitude profile across the holes shows an amplitude drop of at least 26 dB between two adjacent holes;

   4) steel quality is as defined in EN ISO 7963.

c) steel blocks with inclined faces with a notch as shown in Figure 5, and steel blocks with hemispherical holes as in Figure 6. Steel quality is as defined in EN ISO 7963. These blocks are used to measure the beam divergence in the vertical and horizontal plane respectively;

d) an alternative steel block to measure index point, beam angle and beam divergence for angle beam probes is given in Annex B;

e) ruler;

f) feeler gauges starting at 0,05 mm.

NOTE Not all blocks are required if only special kinds of probes are to be checked, e.g. blocks to measure the index point and beam angle are not necessary if only straight-beam probes have to be measured.

For testing immersion probes the following reflectors and additional equipment shall be used:

g) a steel ball or semi-spherical ended rod with smooth reflective surface. For each frequency range the diameter of ball or rod to be used is given in Table 2.

Table 2 — Steel ball (rod) diameters for different frequencies

Probe centre frequency MHz	**Diameter d of ball or rod** mm
$3 < f \leq 15$	$d \leq 3$
$0,5 \leq f \leq 3$	$3 < d \leq 5$

h) a large plane and flat reflector target. The target's lateral size shall be at least ten times wider than the diameter of the beam of the probe under test at the end of focal zone, as defined in 7.7.2.2.

Thickness is at least five times the wavelength of the probe under test, calculated using the velocity of ultrasound in the material of the target.

i) immersion tank equipped with a manual or automatic scanning bridge with five free axes:

— three linear axes X, Y, Z;

— two angular axes Θ and Ψ;

j) automatic recording means: If the amplitudes of ultrasonic signals are recorded automatically, then it is the responsibility of the manufacturer to ensure that the system has sufficient accuracy. In particular, consideration shall be given to the effects of the system bandwidth, spatial resolution, data processing and data storage on the accuracy of the results.

Typical set-ups to measure the sound beam of immersion probes are shown in Figures 15, 16 and 17.

The scanning mechanism used with the immersion tank should be able to maintain alignment between the target and the probe in the X and Y directions, i.e. within ± 0,1 mm for 100 mm distance in the Z direction.

The temperature of the water in the immersion tank shall be maintained at (20 ± 2) °C during the beam characterization of immersion transducers described in 7.7.

Care shall be taken about the influence of sound attenuation in water, which, at high frequencies, causes a downshift of the echo frequency when using broadband probes.

Table 3 shows the relation between frequency downshift and water path.

Table 3 — Frequency downshift in percent of centre frequency f_0 depending on total water path length, for relative bandwidths (b.w.) 50 % and 100 %

f_0	b.w.	Total water path mm															
MHz	%	10	20	30	40	50	60	70	80	90	100	150	200	250	300	350	400
5	50	0	0	0	0	0	0	1	1	1	1	1	2	2	2	3	3
	100	0	1	1	1	2	2	2	3	3	3	5	6	7	9	10	11
10	50	0	1	1	1	2	2	2	3	3	3	5	6	7	9	10	11
	100	1	3	4	5	6	7	8	9	10	11	16	21	24	28	31	34
15	50	1	1	2	3	4	4	5	6	6	7	10	13	15	18	20	23
	100	3	6	8	10	13	15	17	19	21	23	30	37	42	47	50	54
20	50	1	3	4	5	6	7	8	9	10	11	16	21	24	28	31	34
	100	5	10	13	17	21	24	27	29	32	34	44	51	56	61	64	67
25	50	2	4	6	7	9	11	12	14	15	17	23	29	34	38	41	45
	100	7	14	20	24	29	33	36	39	42	45	55	62	67	70	74	76
30	50	3	6	8	10	13	15	17	19	21	23	30	37	42	47	50	54
	100	10	19	26	32	37	41	45	48	51	54	64	70	74	78	80	82

7 Performance requirements for probes

7.1 Physical aspects

7.1.1 Method

Visually inspect the outside of the probe for correct identification and assembly and for physical damage which can influence its current or future reliability. In particular, for contact probes measure the flatness of the contact surface of the probe using a ruler and feeler gauges.

7.1.2 Acceptance criterion

For flat faced probes, over the whole probe face the gap shall not be larger than 0,05 mm.

7.2 Radio frequency pulse shape

7.2.1 Method

The amplitude and pulse duration of the echo is determined with a measurement set-up as in Figure 7 (contact probe) or Figure 17 (immersion):

a) for contact probes with a single transducer the echo out of a semi-cylinder is used whose radius is larger than 1,5 times of the near field length of the probe or within the focal range of focused probes;

b) for dual-element probes a semi-cylinder is used whose radius is nearest to the focal point of the probe;

c) for immersion probes a large flat reflector is used at the focal distance for focused probes or at more than one nearfield length for flat transducers.

The pulser setting shall be recorded, and the peak-to-peak amplitude of the transmitter pulse V_a shall be measured. It is recommended to plot the transmitter pulse shape and it is preferable that the plot of the transmitter pulse be included in the results of this test.

7.2.2 Acceptance criterion

The pulse duration shall not deviate by more than ± 10 % from the manufacturer's specification.

7.3 Pulse spectrum and bandwidth

7.3.1 Method

Use the same set-up as used in 7.2. Gate the reflector echo and determine the frequency spectrum using a spectrum analyser or a Discrete Fourier Transform.

Spurious echoes from the probe's wedge, housing, damping block, etc. shall not be analyzed together with the echo from the semi-cylinder. The gate width shall be twice the pulse duration as a minimum and centred on the maximum of the pulse.

The lower and upper frequencies for a -6 dB drop of echo amplitude shall be measured. For the immersion technique the values shall be corrected according to Table 3.

From these upper and lower frequencies f_u and f_l the centre frequency f_o is calculated:

$$f_{\mathrm{o}} = \frac{f_{\mathrm{u}} + f_{\mathrm{l}}}{2} \tag{2}$$

The bandwidth is:

$$\Delta f = f_{\mathrm{u}} - f_{\mathrm{l}} \tag{3}$$

and the relative bandwidth is calculated in percent (%), as:

$$\Delta f_{\mathrm{rel}} = \left(\Delta f \,/\, f_{\mathrm{o}}\right) \times 100\ \% \tag{4}$$

7.3.2 Acceptance criteria

The centre frequency has to be within ± 10 % of the frequency quoted in the data sheet.

The -6 dB bandwidth has to be within ± 15 % of the nominal bandwidth.

For broadband probes with a relative bandwidth exceeding 100 %, the lower frequency shall not be higher than $f_{\mathrm{l}} + 10\ \%$ and the upper frequency shall not be lower than $f_u - 10\ \%$.

If the spectrum between f_{l} and f_{u} has more than one maximum, the amplitude difference between adjacent minima and maxima shall not exceed 3 dB.

7.4 Relative pulse-echo sensitivity

7.4.1 Method

Relative pulse-echo sensitivity is defined as:

$$S_{\mathrm{rel}} = 20 \log_{10} \left(V_{\mathrm{e}} \,/\, V_{\mathrm{a}}\right) \tag{5}$$

where

V_{e} is the peak-to-peak voltage of the echo from a specified reflector, before amplification as measured in 7.2;

V_{a} is the peak-to-peak voltage applied to the probe with the ultrasonic instrument set to separate pulser/receiver mode.

Probe sensitivity comparisons made with different types of ultrasonic instruments can vary, because the probe sensitivity is influenced by the coupling conditions and by the impedances of pulser, probe, cable and receiver. Therefore, these parameters have to be specified in the data sheet.

7.4.2 Acceptance criterion

The relative pulse-echo sensitivity shall be within ± 3 dB of the manufacturer's specification.

7.5 Distance-amplitude curve

7.5.1 Method

The amplitude of ultrasonic pulses varies with distance from the probe. Therefore, to evaluate echoes from reflectors, for all kinds of probes, distance-amplitude curves are needed using the reflectors in Table 4.

Table 4 — Reflectors for distance-amplitude curves

	Contact	Immersion
Disk-shaped reflectors	Flat-bottom holes	Flat-ended rod
Cylindrical reflectors	Side-drilled holes	Cylindrical rod
Spherical	Hemispherical bottom hole	Hemispherical ended rod or ball

Disk-shaped reflectors, side-drilled holes and hemispherical bottom holes are used as equivalent reflectors when using contact probes. With immersion probes, usually a small-sized steel ball is used to measure a distance-amplitude curve (see 7.7.2). For dual-element probes, the separation layer shall be perpendicular to the axis of the side-drilled holes.

Using a series of reflectors of constant size but at different distances from the probe the received echo amplitudes are plotted against distance. At least eight measurement points on each curve shall be available. The distances used shall cover the focal range of focusing probes or the range including the near field length of non-focusing probes.

Distances and amplitudes are determined on the calibrated screen of an ultrasonic instrument mentioned in the data sheet.

To generate a noise curve, at each position of a maximized reflector echo the difference between noise and the reflector echo is determined by increasing the gain until the noise reaches the former height of the reflector echo. The noise level is measured with the probe removed from the object and the surface of the probe cleaned of couplant.

If it is not possible to increase the gain by a sufficient amount, the difference between reflector echo amplitude and noise level can be estimated.

If for example the reflector echo was at 40 % of full screen height, if the noise level is:

— 20 % then add 6 dB;

— 10 % then add 12 dB;

— 5 % then add 18 dB

to the difference given by the attenuator readings.

A diagram showing at least one distance-amplitude curve shall be available for each probe type, attached to the manufacturer's specification. This diagram shall also include a distance-noise curve.

Figure 8 shows an example of different distance-amplitude curves, calculated for disk-shaped reflectors in steel (distance-gain-size diagram − DGS-diagram). Figure 9 shows an example of a measured distance-amplitude curve for 3 mm side-drilled holes.

7.5.2 Acceptance criterion

Within the focal range the dB-difference between the noise level and the DAC shall not deviate by more than 3 dB from the difference given in the manufacturer's specification.

7.6 Electrical impedance

7.6.1 Method

For probes with an electrical matching circuit, e.g. induction coils in parallel or in series with the transducer, there is no frequency interval with constant impedance or phase. Therefore the complete impedance/phase curve is necessary to characterize these probes. For probes without electrical matching circuits the impedance is predominantly capacitive and this value can be determined from the network analyser.

The impedance of the probe is determined with a network analyser or an impedance/gain/phase analyser as described in EN 12668-1. The probe shall be connected directly to the analyser with its fixed cable or, if the cable is removable, with a cable not longer than 100 mm.

An impedance modulus and phase curve shall be plotted against frequency within a band symmetrical about the centre frequency of the probe.

7.6.2 Acceptance criteria

The measured modulus shall be within ± 20 % and the measured phase shall be within ± 5° of the manufacturer's specification.

7.7 Beam parameters for immersion probes

7.7.1 General

The measurement technique consists of studying the probe acoustic beam in water, using a target. This target is a small, almost point source reflector, or a hydrophone receiver. The beam parameters are determined by scanning the reflector or hydrophone relative to the beam, either by moving the target or the probe.

If the target is a reflector, echo-mode is used. Both transmitter and receiver characteristics of the probe are verified. If the target is a hydrophone, transmission mode is used, and then only the transmitting characteristics of the probe are verified.

The same reflector or hydrophone shall be used for all the beam parameter measurements associated with one particular probe.

Small variations in the measured position of maximum responses occur as measured by a hydrophone or different reflector types. Consequently, for reasons of repeatability, the equipment and the parameters of the target used shall be recorded with the results.

Targets are listed in 6.1, f) and 6.2, g).

Settings of the ultrasonic instrument or pulser receiver (pulse energy, damping, bandwidth, gain) shall be the same as those defined in 7.2. However, if the settings are changed during the measurement (gain for example), the new values shall be recorded on the result sheet.

In the following paragraphs two methods are proposed for beam measurement. They differ only in the methods used to record the measurement results:

a) direct measurement of specific beam parameters:

   the first technique, described in 7.7.2, is based on direct readings at specific points within the beam (see Figures 10 to 14);

b) measurements performed with an automated scanning system:

the second technique, described in 7.7.3, is based on automated collection of data during scanning. The results are displayed as a C-scan image. A copy of this image shall be provided with the test results. This copy shall include a scale of the acoustic levels defined in 7.7.3.

Before performing beam measurements described in the following paragraph, the squint angle shall be compensated for, by setting the beam axis perpendicular to the XY-plane as shown on Figures 15, 16 and 17. This operation is performed by adjusting both angles Θ and Ψ of the probe holder to maximize the echo from a flat target in the XY-plane.

7.7.2 Beam profile − measurements performed directly on the beam

7.7.2.1 General

Ultrasonic echo peak voltage is recorded using two methods. Either one of the following methods shall be used to record the ultrasonic peak echo voltage:

a) manually recording the amplitude displayed on an oscilloscope;

b) automatically recording the amplitude on a paper recorder, plotter or equivalent, synchronized to scanner movements.

In this last case, focal distance, focal length, focal width, transverse profile and beam divergence are deduced from the graphs obtained.

Figure 16 shows the equipment set-up used when the target is a reflector and Figure 17 shows the equipment used when the target is a hydrophone.

The focal distance and focal length are measured from axial profiles and the focal width and beam divergence are measured from transverse profiles.

7.7.2.2 Axial profile − focal distance and length of the focal zone

7.7.2.2.1 Method

Place the target on the probe axis and place the target and probe in contact. The coordinate of the front face of the probe or its acoustic lens is Z_0, see Figure 18.

Move the target (or probe) along the Z-axis, increasing probe-target distance. Find the distance at which the signal is maximized.

Adjust the X- and Y-position to further maximize the signal amplitude. The distance coordinate is Z_p and the voltage is V_p.

The focal distance is given as:

$$F_D = |Z_p - Z_0| \tag{6}$$

Find the limits of the focal zone by increasing and reducing the distance between the probe and the reflector to find the two points where V_p is reduced by 6 dB, if a reflector is used, or by 3 dB, if a hydrophone is used. Z_{L1} and Z_{L2} are the coordinates of these points on the Z-axis.

The length of focal zone is given by:

$$F_L = |Z_{L2} - Z_{L1}| \tag{7}$$

7.7.2.2.2 Acceptance criterion

Focal distance and focal length shall be within ± 15 % of the manufacturer's specifications.

7.7.2.3 Transverse profile − focal width

7.7.2.3.1 Method

Use the same set-up and same mechanical settings as in 7.7.2.2. Place the target at the focal point of probe, as found in 7.7.2.2.

To measure the focal width in the X direction move the probe (or hydrophone) in the X direction and find the two points X_1 and X_2, where the amplitude from the target has decreased by 6 dB (by 3 dB when a hydrophone is used).

To measure the focal width in the Y direction return the X-axis to the focal point and repeat the measurement, but this time move in the Y direction to find the two points Y_1 and Y_2, where the amplitude of the signal from the target has decreased by 6 dB (by 3 dB when a hydrophone is used).

The focal widths on X-axis and on Y-axis at focal point are given by the differences:

$$W_{X1} = |X_2 - X_1| \quad (8)$$

$$W_{Y1} = |Y_2 - Y_1|$$

7.7.2.3.2 Acceptance criterion

The focal widths shall be within ± 15 % of the manufacturer's specifications.

7.7.2.4 Transverse profile − beam divergence

7.7.2.4.1 Method

The beam divergence is only required for probes that have no artificial focusing means, such as acoustic lenses or curved piezoelectric elements. The beam divergence is deduced from the measurement of the beam width, as defined in 7.7.2.3 but measured in the far field.

The measurement shall be performed as follows:

a) first measure the beam widths W_{X1} and W_{Y1} at the focal distance as described in 7.7.2.3;

b) place the target (or probe) at the end of the focal zone (Z_{L2}), as measured in 7.7.2.2.

Record X'_1, X'_2 and Y'_1, Y'_2, the target (or probe) positions on X-axis and on Y-axis where the peak voltage decreases by 6 dB (reflector) or 3 dB (hydrophone) from the maximum value V_L, which is obtained on beam axis.

The beam widths at the end of the focal zone are given by:

$$W_{X2} = |X'_2 - X'_1| \quad (9)$$

$$W_{Y2} = |Y'_2 - Y'_1|$$

The beam divergence in X and Y direction is calculated using the following equations:

$$\Omega_X = \arctan\left[\left(W_{X2} - W_{X1}\right)/2\left(Z_{L2} - Z_p\right)\right] \tag{10}$$

$$\Omega_Y = \arctan\left[\left(W_{Y2} - W_{Y1}\right)/2\left(Z_{L2} - Z_p\right)\right]$$

7.7.2.4.2 Acceptance criterion

The angles of divergence shall not differ from the manufacturer's specified values by either ± 10 % or by 1°, whichever is the larger.

7.7.3 Beam profile − measurements made using an automated scanning system

7.7.3.1 General

The ultrasonic echo peak voltage is recorded during an automatic scan of the probe (or the reflector) in different planes. The variations of amplitude with position shall be recorded under the following conditions:

a) the sensitivity, amplitude resolution of data processing, motion speed and motion resolution shall be sufficient to avoid any loss of information.

   The system shall have sufficient dynamic range to collect the high amplitude signals (obtained at the focal point) without saturation and the low amplitude signals with a sufficient signal-to-noise ratio.

b) the maximum peak voltage V_p, detected at the focal point, defines the 0 dB level. The coding used for the 0 dB, -3 dB, -6 dB, -12 dB levels shall appear on a scale on the scan recording.

The verification is based on performing three scans:

c) one scan in the XZ- or YZ-plane including the beam axis gives the focal distance and focal length;

d) two scans in the transverse plane XY at the focal distance and at the end of the focal zone. These scans give the focal width and the beam widths in the X and Y directions. The beam divergence is calculated from the beam widths measured in the XY-plane.

7.7.3.2 Beam profile by scanning means − focal distance and focal length

7.7.3.2.1 Method

Use the same set up as described on Figure 16 when the target is a reflector, and Figure 17 when the target is a hydrophone.

The focal distance and the focal length are deduced from the scans in the plane containing the beam axis.

Adjust the position of the scanner so that:

a) its motion plane contains the beam axis;

b) the XZ- or YZ-plane covered by the scanning is wide enough to include the end of the focal zone, and the two points of transverse axes (X and Y) where the amplitude is 6 dB (reflector) or 3 dB (hydrophone) lower than on the beam axis.

From the C-scan images the following measurements are made:

c) the focal distance F_D, as defined in 7.7.2.2;

d) the focal length F_L, as defined in 7.7.2.2.

An example of this plot is given in Figure19.

7.7.3.2.2 Acceptance criteria

Focal distance and focal length shall be within ± 15 % of the manufacturer's specification.

7.7.3.3 Beam profile by scanning means − focal width and beam divergence

7.7.3.3.1 Method

The mechanical set-up is the same as in 7.7.3.2 and described in Figures 16 and 17.

The first scan is performed at the focal distance. The scanner is adjusted as follows:

a) adjust the Z-axis of the scanner so that the target is at the focal point, as it was determined in 7.7.3.2. The scanner displacements are in the XY plane containing the focal point, and perpendicular to the beam axis.

b) adjust the XY scanning area to include the positions where the amplitudes drop by 20 dB from V_p if using a reflector, or by 10 dB if a hydrophone is used.

At the focal distance, W_{X1} and W_{Y1} are the diameters of the zones measured in the X or Y direction where the displayed amplitudes are 6 dB (reflector) or 3 dB (hydrophone) lower than the value V_p measured on the beam axis (see Figure 20 for an example).

The second scan is performed at the end of the focal zone. The mechanical set up and the bridge adjustment are the same as for the previous scanning, except that the target is placed at the end of the focal zone (Z_{L2}), defined in 7.7.3.2.

From the image the focal widths W_{X2} and W_{Y2} are measured by the same method used to determine W_{X1} and W_{Y1} at the focal distance.

The angles of divergence in the X and Y direction are obtained by the same calculations used in 7.7.2.4.

7.7.3.3.2 Acceptance criteria

The angles of divergence shall not differ from the manufacturer's specified values by either ± 10 % or by ± 1°, whichever is the larger.

The focal widths shall be within ± 15 % of the manufacturer's specification.

7.8 Beam parameters for contact, straight-beam, single transducer probes

7.8.1 General

The procedures given in this clause are for probes with flat contact surfaces only. Probes with profiled shoes can only be evaluated on reference blocks having the same curvature as the sample the probe shoe was fitted to.

7.8.2 Beam divergence and side lobes

7.8.2.1 Methods

Different methods can be used to measure the directivity pattern:

a) using electromagnetic-acoustic (EMA) receivers.

   The probe is coupled to a semi-cylinder (see Figure 21).

   The EMA receiver measures the received signal when scanning the cylindrical surface of the block.

   The signal amplitude is plotted against the scanning angle of the EMA receiver. The plot shall include the main lobe and the adjacent side lobes. The angles for the -3 dB positions of the main lobe give the divergence angles (Figure 21).

   The angles of divergence have to be measured in two perpendicular planes.

   For rectangular transducers these planes shall be parallel to the larger side (a) and the smaller side (b) of the transducer.

b) using reference blocks with side-drilled holes.

   Test blocks with plane parallel sides containing 3 mm side-drilled holes at various distances, as shown in Figure 4, can be used to determine the angles of divergence and the side lobes in the two perpendicular planes.

   For each hole the position of the probe to receive the maximum echo and for the forward and backward position of the -6 dB drop and side lobe positions are marked in a final plot.

   The straight line through the marks of the maximum echo together with the normal to the surface of the block gives the beam angle. The straight lines fitted to the edge points of the beam together with the beam angle gives the -6 dB divergence angles.

   Note the change in echo amplitude in relation to probe movement as the beam is scanned over each hole in turn.

   If a side lobe is detected in the amplitude profile from two or more holes, maximize the side lobe and plot its position in relation to that of the main lobe. Also record the amplitude of the side lobe in relation to that of the main lobe.

c) using reference blocks with hemispherical holes.

   Test blocks with plane-parallel sides containing 10 mm hemispherical holes at various distances, as shown in Figure 6 can be used to determine the angles of divergence in two perpendicular planes. For each hole, mark in the final plot the position of the probe to receive the maximum echo and for the forward and backward position of the -6 dB drop.

7.8.2.2 Acceptance criteria

The angles of divergence shall not differ from the manufacturer's specified values by more than 10 % or by ± 1°, whichever is the larger.

Side lobes shall be ≥ 20 dB below the main lobe for reflection techniques and ≥ 10 dB below the main lobe for the EMA technique.

7.8.3 Squint angle and offset

7.8.3.1 Methods

With straight-beam probes the offset is the distance between the geometrical centre point of the probe and the measured acoustical centre point of the probe (Figure 2).

The following methods can be used:

a) using an electromagnetic-acoustic (EMA) receiver.

To measure the squint angle and the offset the set-up in Figure 2 is used.

First the probe is connected to the ultrasonic instrument and this is switched to the echo mode. By turning and moving the probe on a semi-cylindrical block the echoes of the multiple echoes series from the block are maximized. Then, at all reflections, the beam hits the cylindrical surface perpendicularly and the acoustical centre point of the probe is on the centre line of the block.

Staying at this position, in the second step, the EMA receiver is used with the probe acting only as a transmitter.

By moving the EMA receiver on the cylindrical surface the position of the maximum signal is found where the beam hits the cylindrical surface the first time. The measured angle is the squint angle δ.

The coordinates X_c and Y_c of the geometrical centre point of the probe together with the coordinates Y_m of the centre line of the block and X_m of the EMA receiver give the offset e:

$$e = \sqrt{(X_m - X_c)^2 + (Y_m - Y_c)^2} \qquad (11)$$

b) using reference blocks with side-drilled holes.

The displacements X_m and Y_m in two perpendicular directions are measured. They can be taken from the measurement of the beam axis in 7.8.2.1, b).

If X_c and Y_c are the coordinates of the geometrical centre point of the probe then the offset e can be calculated using the same equation as in 7.8.3.1, a).

Squint angles δ_x and δ_y are measured in the two perpendicular directions. The resulting angle δ is calculated as:

$$\delta = \arctan\left(\tan^2 \delta_y + \tan^2 \delta_x\right)^{\frac{1}{2}} \qquad (12)$$

7.8.3.2 Acceptance criteria

The squint angle shall be ≤ 2°. The offset shall be less than 1 mm away from the centre point of the probe.

7.8.4 Focal distance (near field length)

7.8.4.1 Method

For a non-focusing transducer the focal distance is identical with the near field length. For these probes it is difficult to directly measure the focal distance. It is therefore recommended that for these probes the near field length should be calculated using the methods given in Annex A from the measured centre frequency f_0 and the measured angles of divergence $\gamma_\perp$ and $\gamma_{//}$ in two perpendicular directions.

Focused straight-beam probes for direct contact shall be measured on reference blocks containing flat-bottom holes or side-drilled holes of constant diameter within the focal range of the probe.

Reflectors of 2 mm or 3 mm diameter shall be used to generate a distance-amplitude curve (best fit to the measurement points).

A measurement point shall be close to the peak of this curve, which gives the focal distance in the applied material. Focal distances caused by lenses or curved transducers are always shorter than the near field length of a plane transducer of the same shape and frequency.

7.8.4.2 Acceptance criterion

The focal distance shall be within ± 20 % of the manufacturer's specification.

7.8.5 Focal width

7.8.5.1 Methods

The focal width of focused straight-beam probes for direct contact can be determined using an EMA receiver or blocks with side-drilled holes and hemispherical holes, analogous to 7.8.2.

The following methods can be used:

a) using electromagnetic-acoustic (EMA) receivers.

   The probe is coupled to a semi-cylinder with a radius close to the focal distance of the probe. By moving the EMA on the surface in two perpendicular directions the angles of the 3 dB drop of signal amplitude are determined (see 7.8.2.1, a)). The focal widths of the probe can be calculated using these angles together with the known radius of the block.

b) using reference blocks with side-drilled holes.

   As shown in 7.8.2.1, b) for the divergence angles, the probe is moved in two perpendicular directions until the echo from a side-drilled hole close to the focal distance of the probe drops by 6 dB. This shift gives the focal widths of the beam.

c) using reference blocks with hemispherical bottom holes.

   As shown in 7.8.2.1, c) for the divergence angles, the probe is moved in two perpendicular directions until the echo from a hemispherical hole close to the focal distance of the probe drops by 6 dB. This shift gives the focal widths of the beam.

7.8.5.2 Acceptance criterion

The focal width shall be within ± 20 % of the manufacturer's specification.

7.8.6 Focal length

7.8.6.1 Method

From the distance-amplitude curve measured in 7.5 or 7.8.4 the points are determined where the amplitude drops by 6 dB as compared to the focal point.

The difference of their coordinates gives the focal length.

7.8.6.2 Acceptance criterion

The focal length shall be within ± 20 % of the manufacturer's specification.

7.9 Beam parameters for contact angle-beam single transducer probes

7.9.1 General

The procedures given in this clause are for probes with flat contact surfaces only. Probes with profiled shoes can only be evaluated on reference blocks having the same curvature as the sample the probe shoe was fitted to.

7.9.2 Index point

7.9.2.1 Method

To measure the index point a test block with a quadrant shall be used. The radius of the quadrant shall be large enough that the reflecting cylindrical surface is in the far field of the probe.

The probe is adjusted so that the echo from the cylindrical surface is maximized. At this position the index point corresponds to the engraved centre line of the quadrant.

7.9.2.2 Acceptance criterion

The index point shall be within ± 1 mm of the point marked by the manufacturer.

Angle beam probes with transducer size ≤ 15 mm and frequencies ≤ 2 MHz generate a broad sound beam where the position of the maximum echo can only be measured within a tolerance of ± 2 mm.

7.9.3 Beam angle and beam divergence

7.9.3.1 Methods

Similar methods to those used for straight-beam probes in 7.8 can be used to measure the divergence angles and side lobes of angle-beam probes:

a) using electromagnetic-acoustic (EMA) receivers.

   The probe is coupled to a semi-cylindrical block.

   The signal amplitude is plotted against the scanning angle of the EMA receiver.

   The plot shall include the main lobe and the adjacent side lobes. The angles for the -3 dB positions of the main lobe give the divergence angles (Figure 21).

   The angles of divergence have to be measured in two perpendicular planes (azimuthal and horizontal). The position of the maximum signal gives the angle of the acoustical axis (beam angle).

   Parameters of inclined beams can also be taken from a C-scan image in a plane perpendicular to the beam axis. Figure 22 shows an example of a C-scan image of a 45° angle beam probe measured with an EMA receiver on a test block with a 45° surface.

b) using reference blocks with side-drilled holes.

A test block with a series of 3 mm side-drilled holes at different depths, as shown in Figure 4, can be used to measure the beam angle, divergence angles and side lobes in the vertical plane.

For each hole the position of the probe to receive the maximum echo, and for the forward and backward position of the 6 dB drop and the side lobe positions are marked in a final plot.

The straight line through the marks of the maximum echo and the index point with the normal to the surface of the block gives the beam angle in the vertical plane. The straight lines fitted to the edge points of the beam together with the beam angle gives the -6 dB divergence angles in this plane.

Note the change in echo amplitude in relation to probe movement as the beam is scanned over each hole in turn. If a side lobe is detected in the amplitude profile from two or more holes, maximize the side lobe and plot its position in relation to that of the main lobe. Also record the amplitude of the side lobe in relation to that of the main lobe.

An alternative method of measuring the beam angles also using side-drilled holes is given in Annex B.

To measure the divergence angles in the horizontal plane a block with a notch is needed, as shown in Figure 5 (for 45° probes and 60° probes). The same procedure is used to determine the positions of the 6 dB drop, but the probe is moved sidewards.

c) using reference blocks with hemispherical holes.

A test block with a series of the 10 mm hemispherical holes at different depths, as shown in Figure 6 can be used to measure the beam angle and divergence angles in the vertical and horizontal planes.

For each hole the position of the probe to receive the maximum echo, and for the forward and backward position of the 6 dB drop are marked in a final plot.

The straight line through the marks of the maximum echo and the index point with the normal to the surface of the block gives the beam angle in the vertical and horizontal plane. The straight lines fitted to the edge points of the beam together with the beam angle give the -6 dB divergence angles in those planes.

7.9.3.2 Acceptance criteria

The beam angle shall be within ± 3° of the nominal angle for frequencies less than 2 MHz and ± 2° of the nominal angle for frequencies equal to or greater than 2 MHz.

The angles of divergence shall not differ from the manufacturer's specification by more than 10 % or by more than ± 1°, whichever is the larger.

When using the reflection technique the side lobes shall be ≥ 20 dB below the main lobe for nominal beam angles between 45° and 65°, and ≥ 15 dB for higher nominal beam angles.

When using the EMA technique ≥ 10 dB and ≥ 8 dB apply.

7.9.4 Squint angle and offset

7.9.4.1 Methods

Methods to measure the squint angle and offset:

a) using an electromagnetic-acoustic (EMA) receiver.

To measure the squint angle and the offset for an angle-beam probe the same set-up is used as in 7.8.3 (Figure 3). The squint angle δ is the angle between the reference side of the probe and the measured beam axis projected onto the coupling surface (Figure 3).

First the probe is coupled to a semi-cylindrical block and the ultrasonic instrument is switched to echo mode. By turning and moving the probe the echoes of the multiple echo series from the blocks are maximized. Then, at all reflections, the beam hits the cylindrical surface perpendicularly and the index point of the probe is on the centre line of the block.

At this position the angle between the sides of the probe and the sides of the block give the squint angle δ.

Secondly the EMA-receiver is used (the probe acting as a transmitter only). By moving the EMA-receiver the position of the maximum signal is determined where the beam hits the cylindrical surface for the first time.

X_m is the coordinate of this position of the EMA-receiver, and X_c is the coordinate of the intersection point of the centre line of the block with the centre line of the probe parallel to its reference side.

Using these coordinates the offset e can be calculated as:

$$e = \left(X_m - X_c\right)\cos\delta \quad (13)$$

b) using reference blocks.

With side-drilled holes, only the squint angle can be measured according to 7.8.3.

Adjust the position of the probe on the large flat surface of a suitable block to maximize the direct echo from a straight corner of the block, as shown in Figure 23. The corner reflector shall be in the far field of the probe.

Measure the direction in which the probe's reference side is pointing relative to the normal to the corner face by means of a straight edge and a protractor. This gives the squint angle.

If the squint angle exceeds 1° on the first measurement, make a total of three measurements and take the mean value.

7.9.4.2 Acceptance criteria

The squint angle shall be ≤ 2°. The offset shall be ≤ 1 mm from the centre point of the probe.

7.9.5 Focal distance (near field length)

7.9.5.1 Methods

Similar methods to those for straight beam probes are applied here (see 7.8.4). For unfocused angle-beam probes the near field length is calculated using the measured values of centre frequency f_0 and beam divergence angles $\gamma_\perp$ and $\gamma_{/\!/}$ using the equations given in Annex A.

With focused angle-beam probes for direct contact the same methods as for straight-beam probes are used (see 7.8.5).

A distance-amplitude curve generated with at least eight measurement points using small flat-bottom hemispherical or side-drilled holes is used. The point of peak amplitude gives the focal distance.

It is recommended that the measurement points are within the focal range of the transducer with a measurement point close to the peak.

They shall cover the 6 dB drop compared to the peak amplitude.

Focal distances caused by lenses or curved transducers are always shorter than the near field length of a plane transducer of the same shape and frequency.

7.9.5.2 Acceptance criterion

The focal distance shall be within ± 20 % of the manufacturer's specification.

7.9.6 Focal width

7.9.6.1 Methods

The boundaries of the focal length can be measured in a similar way to the angles of divergence (see 7.8.2) using an EMA receiver or side-drilled holes.

The measurement shall be made in two perpendicular directions with one of the following methods:

a) using electromagnetic-acoustic (EMA) receivers.

   The probe is coupled to a semi-cylinder whose radius is close to the focal distance of the probe. By moving the EMA on the surface the points are determined where the signal amplitude drops by 3 dB compared to the peak amplitude.

   With these angles and the known radius of the block the beam width at the focal distance can be calculated.

b) using reference blocks with side-drilled holes.

   As described in 7.8.2.1, b), the probe is moved until the echo from a side-drilled hole at the focal distance drops by 6 dB. This shift gives the focal widths of the beam in the vertical direction.

   The focal width in the horizontal plane can only be measured using the method described in 7.10.5.1, b).

c) using reference blocks with hemispherical holes.

   As described in 7.8.2.1, c), the probe is moved until the echo from a hemispherical hole at the focal distance drops by 6 dB. This shift gives the focal widths of the beam in the vertical and horizontal deviation.

7.9.6.2 Acceptance criterion

The focal widths shall be within ± 20 % of the manufacturer's specification.

7.9.7 Focal length

7.9.7.1 Method

From the distance-amplitude curve measured in 7.5 or 7.8.5 the points are determined where the amplitude drops by 6 dB compared to the focal point. The difference of their coordinates give the length of the focal range (focal length).

7.9.7.2 Acceptance criterion

The focal length shall be within ± 20 % of the manufacturer's specification.

7.10 Beam parameters for contact, straight beam, dual-element probes

7.10.1 General

The procedures given in this clause are for probes with flat contact surfaces only. Probes with profiled shoes can only be evaluated on reference blocks having the same curvature as the sample the probe shoe was fitted to.

7.10.2 Cross talk

7.10.2.1 Method

The measurements are made using an ultrasonic instrument meeting the requirements of EN 12668-1.

The ultrasonic instrument is switched to separate transmitter-receiver mode and the probe is connected to the transmitter and receiver sockets. The probe is coupled to a reference block whose dimensions allow a backwall echo to be obtained within the focal zone of the probe. This echo is adjusted to 80 % of screen height and the gain is noted. The echo from the coupling surface is visible on the display screen. The gain is increased until the amplitude reaches 80 % of screen height. The dB-difference to the first setting expresses the cross talk.

If the coupling echo is not visible, it is only possible to give a lower limit for the cross talk.

7.10.2.2 Acceptance criterion

The difference shall be better than 30 dB.

7.10.3 Distance to sensitivity maximum (focal distance)

7.10.3.1 Method

The point of maximum amplitude in the distance-amplitude-curve according to 7.5 gives the focal distance.

The echo heights from reflectors (see Table 4) at distances within the expected focal length are used to establish a distance-amplitude curve (at least eight points).

The separation layer of the probe shall be perpendicular to the axis of the side-drilled holes.

7.10.3.2 Acceptance criterion

The position of the maximum echo shall be within ± 20 % of the manufacturer's specification.

7.10.4 Axial sensitivity range (focal length)

7.10.4.1 Method

From the curve measured in 7.5, the -6 dB points can also be determined.

7.10.4.2 Acceptance criterion

The axial sensitivity range shall be within ± 20 % of the manufacturer's specification.

7.10.5 Lateral sensitivity range (focal width)

7.10.5.1 Methods

To determine the lateral sensitivity range the following methods can be used:

a) using an electromagnetic-acoustic (EMA) receiver.

This test uses the same set-up as that used for single-transducer probes (see 7.9.3). The beam profile for each transducer is measured separately and the combined profile is calculated from the product of the two beam profiles.

Select a semi-cylindrical test block with its radius close to the focal distance of the probe under test. Operating each transducer in turn, scan the EMA receiver over the cylindrical surface of the test block. Record the amplitudes of the signals from the two transducers for each position within the beam profile.

At each point within the beam multiply (dB are added) the amplitudes measured for each transducer. These products give the directional pattern of the dual-element probe. The -6 dB boundaries of the beam occur where these products are reduced by 6 dB from the maximum.

The measurement is made in two perpendicular directions, parallel and perpendicular to the separation layer.

b) using test blocks with 3 mm side-drilled holes.

A test block is used which has a 3 mm side-drilled hole close to the position of the focus of the probe.

The probe is shifted on the coupling surface until the echo of the side-drilled hole drops by 6 dB. These positions of the probe give the -6 dB boundaries of the focal length perpendicular to the acoustical axis.

The scanning has to be done parallel and perpendicular to the separation layer of the probe to give two perpendicular widths of the focal length.

c) using test blocks with hemispherical hole.

A test block is used which has a 10 mm hemispherical hole close to the position of the focus of the probe.

The probe is shifted on the coupling surface until the echo from the hemispherical hole drops by 6 dB. These positions of the probe give the -6 dB boundaries of the focal length perpendicular and parallel to the acoustical axis.

The scanning has to be done parallel and perpendicular to the separation layer of the probe to give two perpendicular widths of the focal length.

7.10.5.2 Acceptance criteria

The width of the focal length parallel and perpendicular to the separation layer has to be within ± 20 % of the manufacturer's specification.

7.11 Beam parameters for contact angle beam, dual-element probes

7.11.1 General

The procedures given in this clause are for probes with flat contact surfaces only. Probes with profiled shoes can only be evaluated on reference blocks having the same curvature as the sample the probe shoe was fitted to.

7.11.2 Cross talk

7.11.2.1 Method

The cross talk for a dual-element angle beam probe is measured in the same way as for a dual-element straight-beam probe (see 7.10.2).

7.11.2.2 Acceptance criterion

The difference shall be better than 30 dB.

7.11.3 Index point

7.11.3.1 Method

The index point is determined using a test block as for a single-transducer angle-beam probe (see 7.9.2).

7.11.3.2 Acceptance criterion

The index point has to be within ± 1 mm of the point marked by the manufacturer.

7.11.4 Beam angle and profiles

7.11.4.1 Methods

The beam angle of a dual-element probe can be determined using an EMA receiver reflecting side-drilled holes or hemispherical bottom holes:

a) using an electromagnetic-acoustic (EMA) receiver.

   This test uses the same set-up as that used for single-transducer probes (see 7.9.3). The beam profile of each transducer is measured separately and the combined profile is calculated from the product of the two beam profiles.

   Operating each transducer in turn, scan the EMA receiver over the cylindrical surface of the test block. Record the amplitudes of the signals from the two transducers for each position within the beam profile.

   At each point within the beam multiply (dB are added) the amplitudes measured for the two transducers. These products give the directional pattern of the dual-element probe.

   The 6 dB angles of divergence for the beam occur where these products reduce by 6 dB from the maximum. The beam angle is calculated from the arithmetic mean of the angles of divergence.

b) using side-drilled holes of 3 mm diameter.

   The set-up is the same as for a single-transducer probe (see 7.9.3).

c) using hemispherical bottom holes of 10 mm diameter.

   The set-up is the same as for a single-transducer probe (see 7.9.3).

7.11.4.2 Acceptance criterion

The beam angle shall be within ± 2° of the nominal angle.

7.11.5 Distance to sensitivity maximum (focal distance)

7.11.5.1 Method

The focal distance is determined as for a dual-element straight-beam probe (see 7.10.3), using at least eight points for the distance-amplitude curve.

7.11.5.2 Acceptance criterion

The focal distance shall be within ± 20 % of the manufacturer's specification.

7.11.6 Axial sensitivity range (focal length)

7.11.6.1 Method

The axial sensitivity range is determined as for a dual-element straight-beam probe (see 7.10.4).

7.11.6.2 Acceptance criterion

The axial sensitivity range shall be within ± 20 % of the manufacturer's specification.

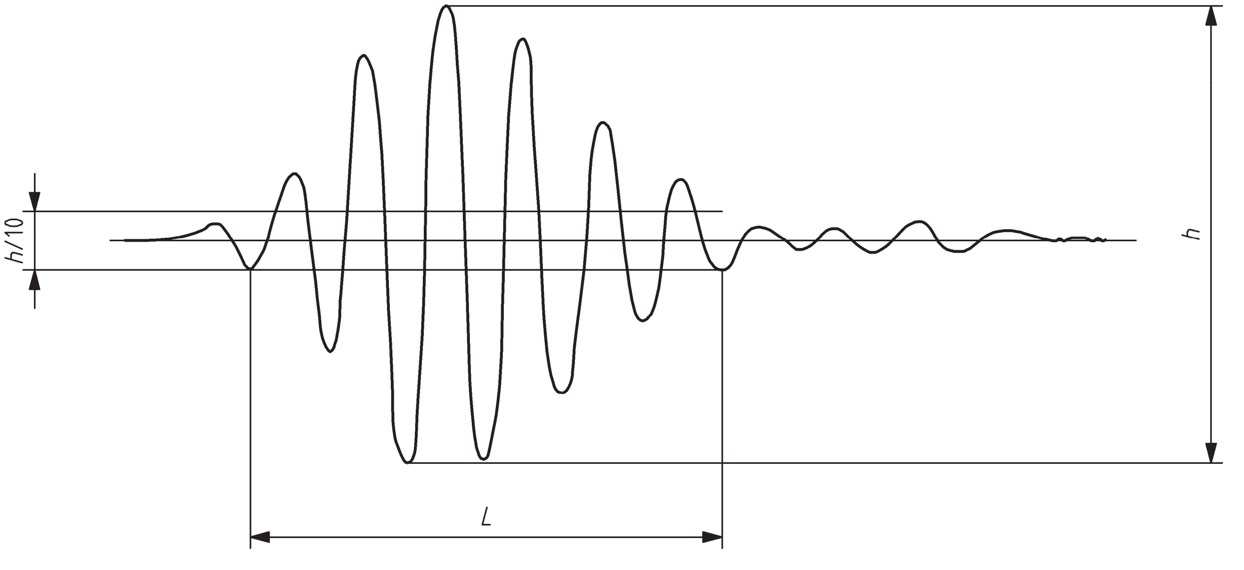
7.11.7 Lateral sensitivity range (focal width)

7.11.7.1 Method

The lateral sensitivity range is determined as for a dual-element straight-beam probe (see 7.10.5) using an EMA receiver, echoes from 3 mm side-drilled holes or 10 mm hemispherical bottom holes.

7.11.7.2 Acceptance criterion

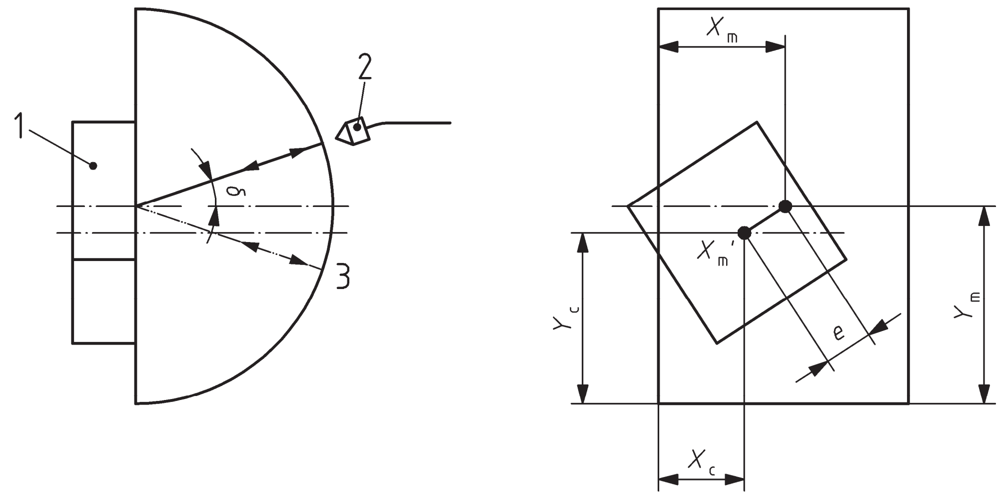
The width of the focal length shall be within ± 10 % of the manufacturer's specification.



Key

h peak-to-peak amplitude
L pulse duration

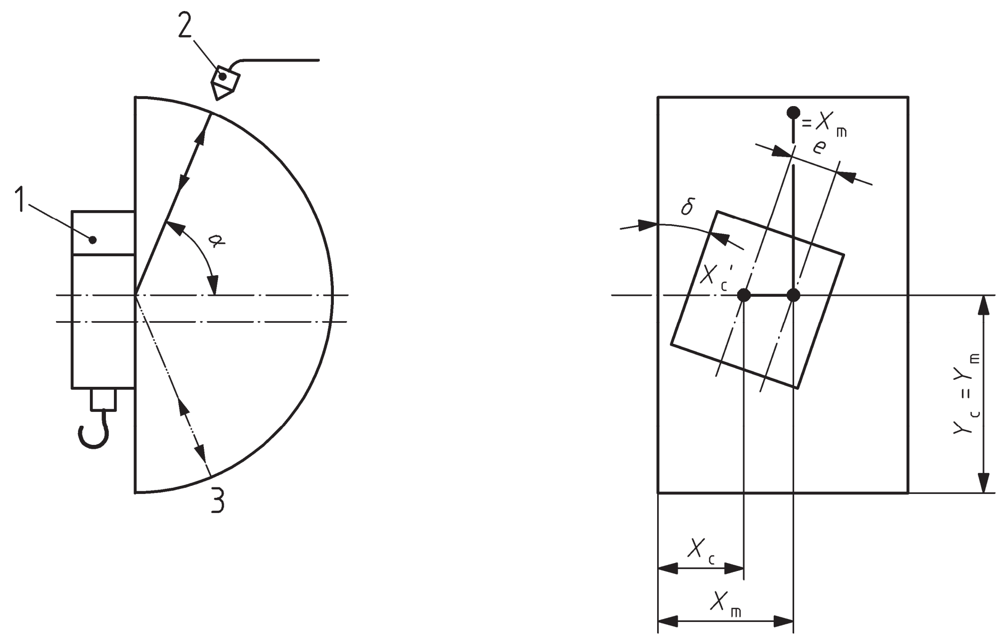
Figure 1 — Typical ultrasonic pulse



Key

1	ultrasonic probe	*e*	offset
2	EMA receiver	δ	squint angle
3	echo point	X_c, Y_c	coordinates of the centre of the probe
α	beam angle	X_m, Y_m	coordinates of the centre of the block

Figure 2 — Squint angle and offset with a straight-beam probe



Key

1	ultrasonic probe	*e*	offset
2	EMA receiver	δ	squint angle
3	echo point	X_c, Y_c	coordinates of the centre of the probe
α	beam angle	X_m, Y_m	coordinates of the centre of the block

Figure 3 — Squint angle and offset with an angle-beam probe

Dimensions in millimetres

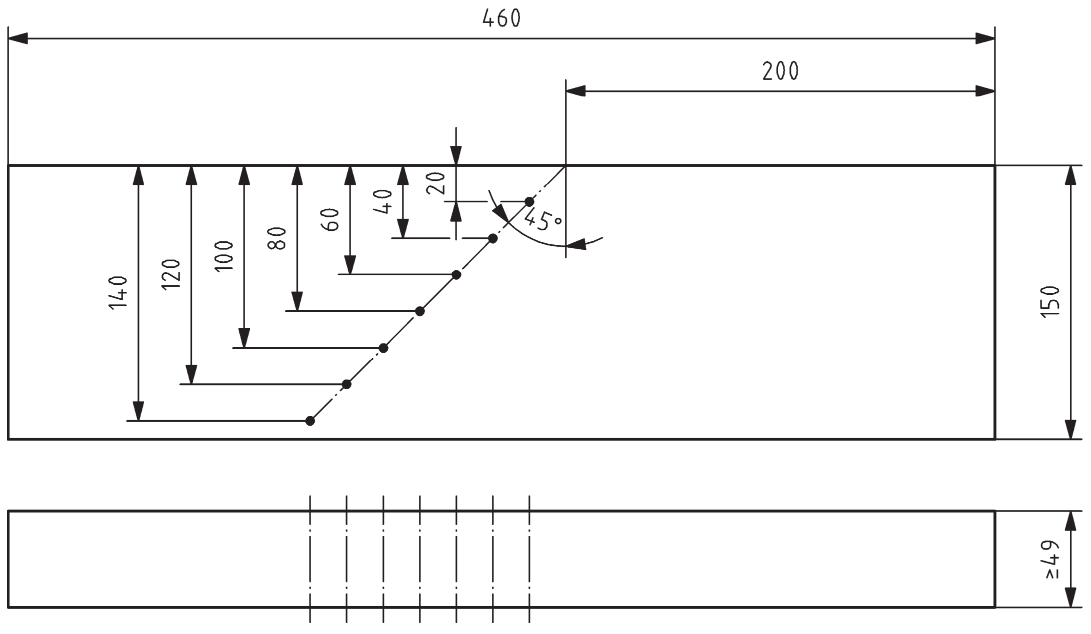
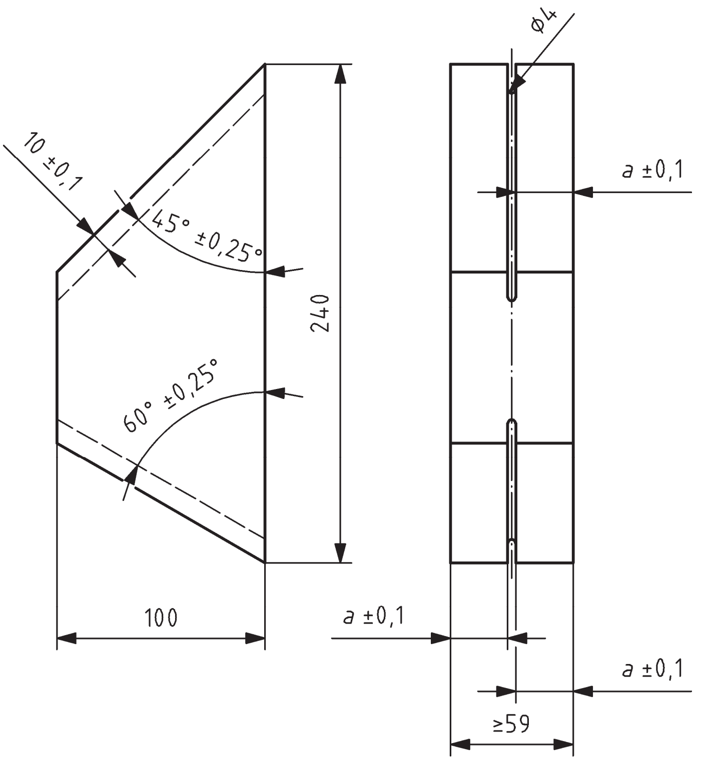


Figure 4 — Test block with 3 mm side-drilled holes

Dimensions in millimetres



Key

a tolerance of centre line position

Figure 5 — Test block with notches

Dimensions in millimetres

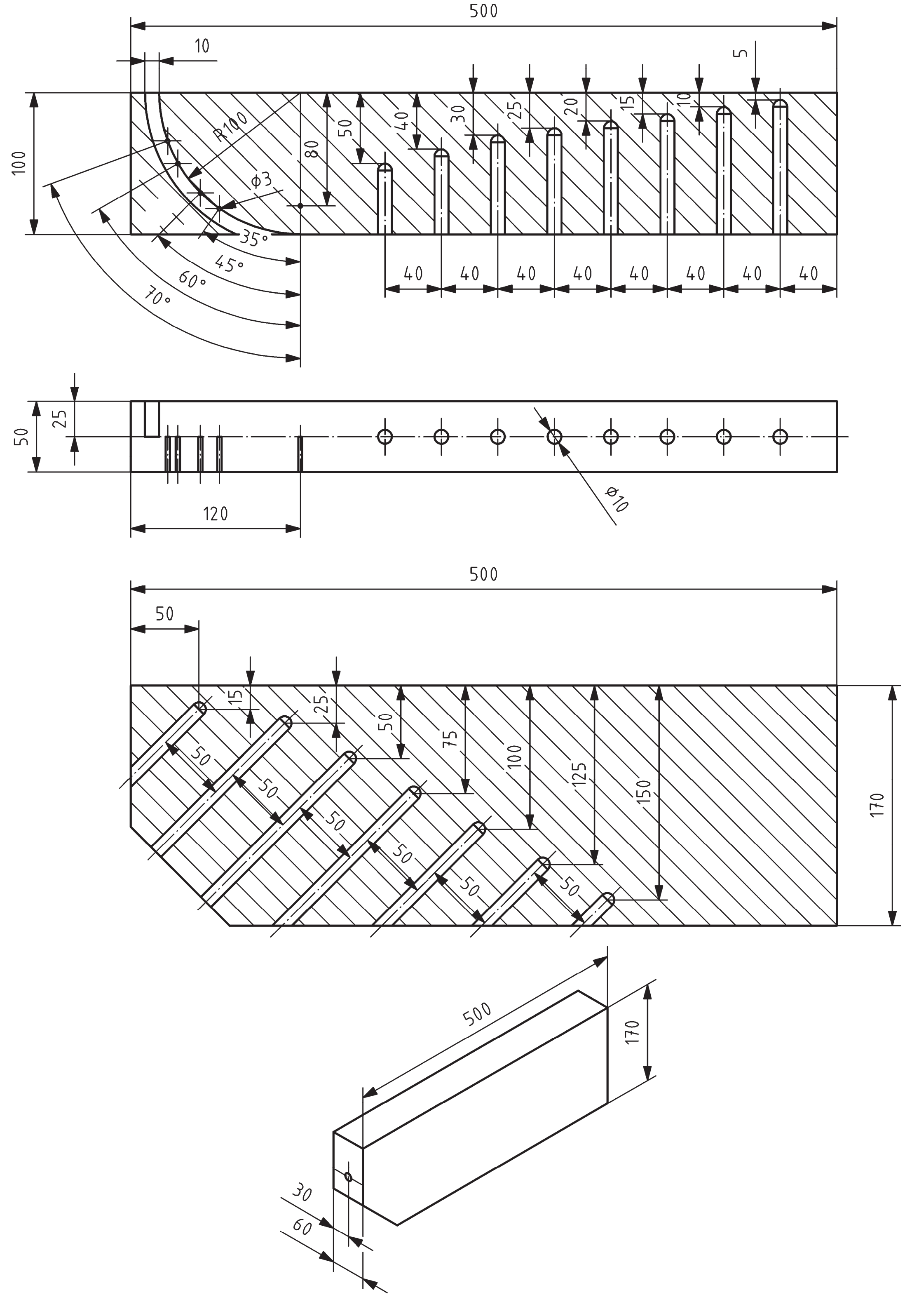
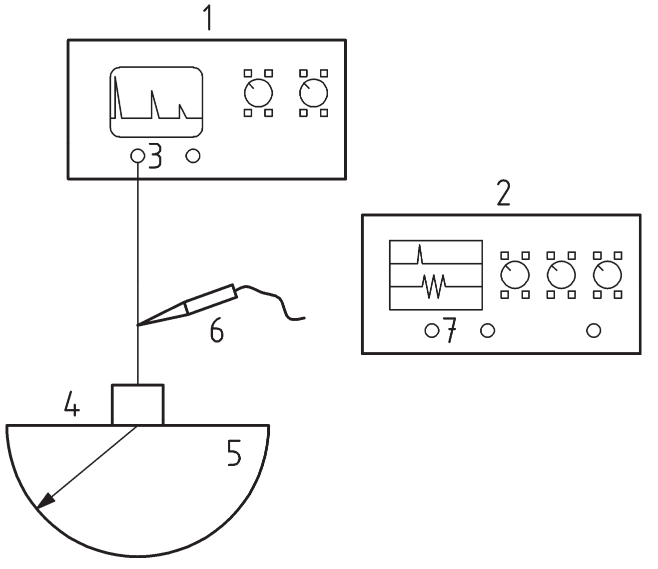


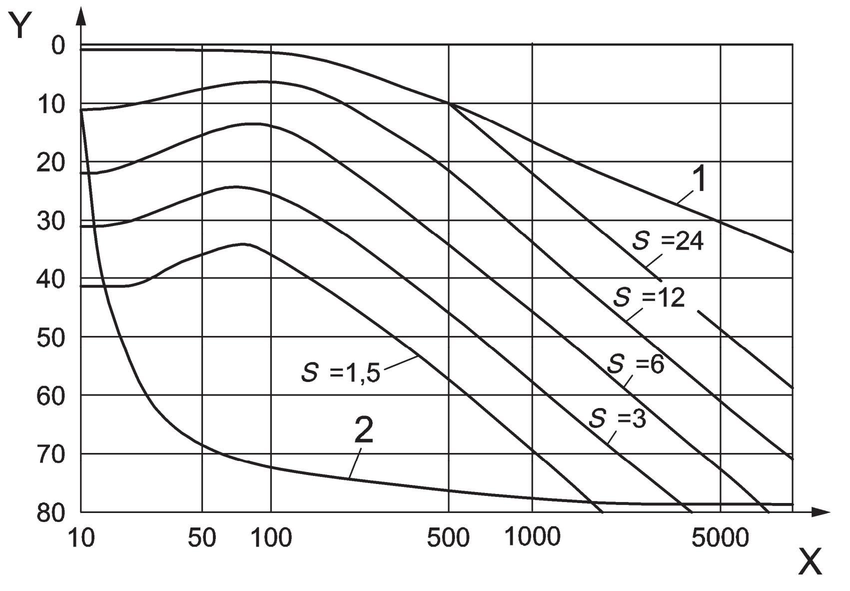
Figure 6 — Steel blocks with side-drilled and hemispherical holes



Key

1 transmitter
2 oscilloscope
3 connector
4 ultrasonic probe
5 reference block
6 oscilloscope probe
7 input connector

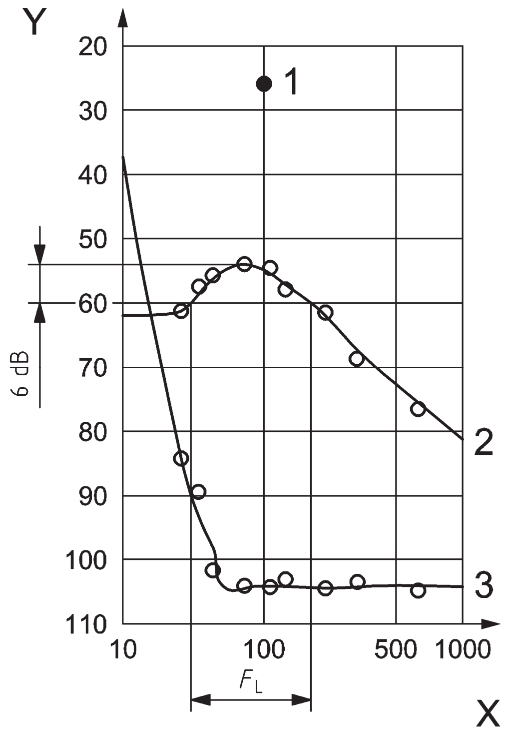
Figure 7 — Set-up for measuring the pulse duration of an echo



Key

1 backwall echo
2 noise level
X distance in mm
Y gain in decibels (dB)
S reflector size in millimetres (mm)

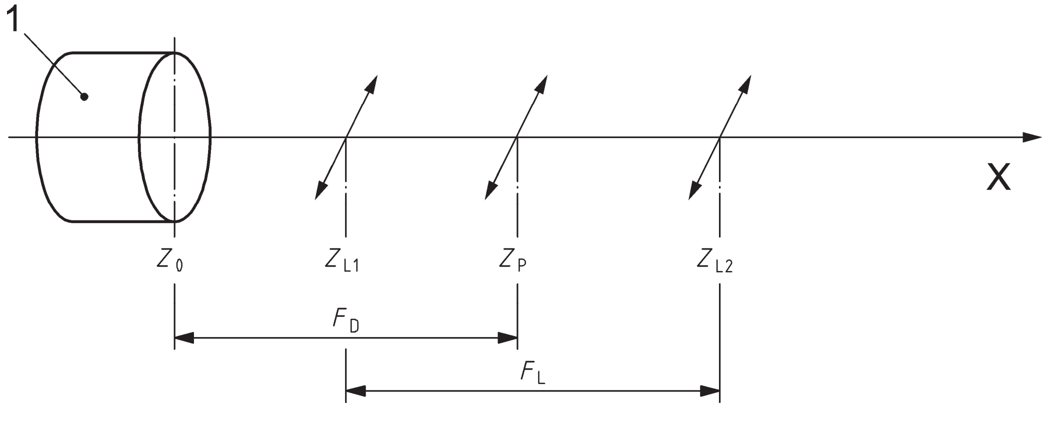
Figure 8 — Distance-amplitude curve for disk-shaped reflectors in steel



Key

1 backwall echo
2 3-mm side-drilled hole
3 noise level
X distance in millimetres (mm)
F_L focal length
Y gain in decibels (dB)

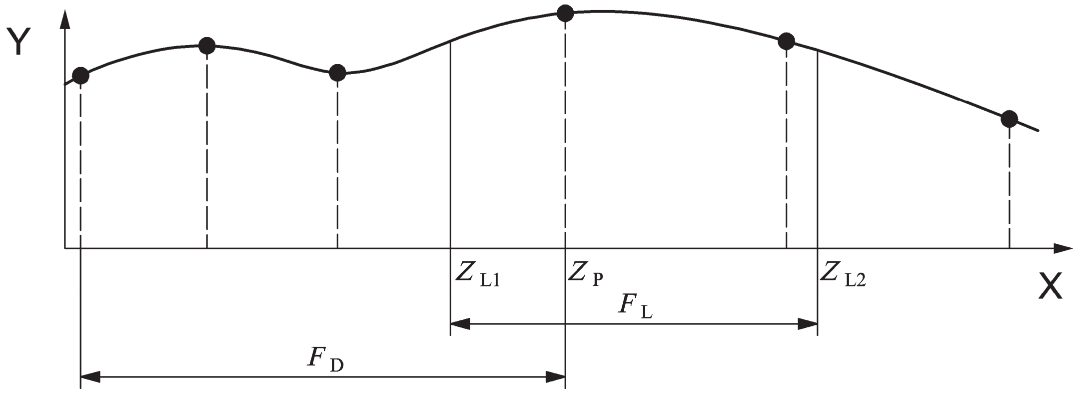
Figure 9 — Distance-amplitude curve and noise level for a 3-mm side-drilled hole



Key

1 probe
X distance in millimetres (mm)
F_D focal distance
Z_{L1}, Z_{L2} boundaries of focal range
F_L focal length
Z_P focal point

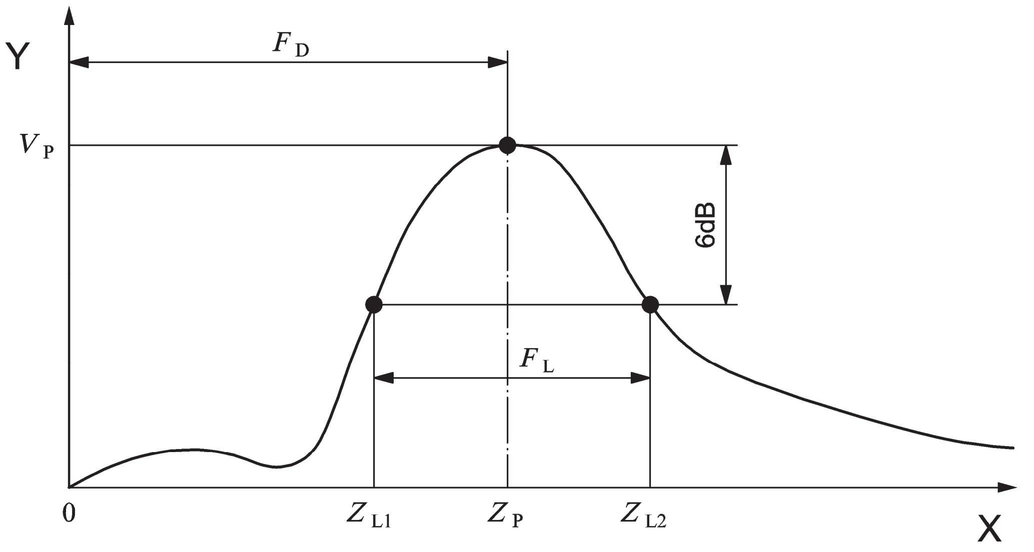
Figure 10 — Significant points on the beam axis of immersion probes



Key

Y amplitude in decibels (dB)
X distance in millimetres (mm)
F_D focal distance
F_L focal length
Z_{L1}, Z_{L2} boundaries of focal range
Z_P focal point

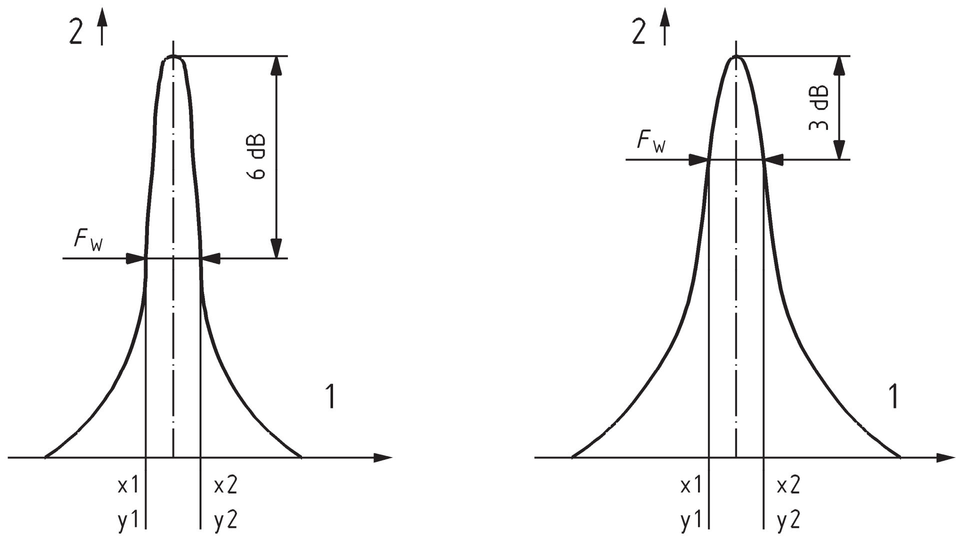
Figure 11 — Axial profile of a non-focused immersion probe



Key

Y amplitude in decibels (dB)
X distance in millimetres (mm)
F_D focal distance
F_L focal length
Z_{L1}, Z_{L2} boundaries of focal range
V_P amplitude at focal distance
Z_P focal point

Figure 12 — Axial profile of a focused immersion probe

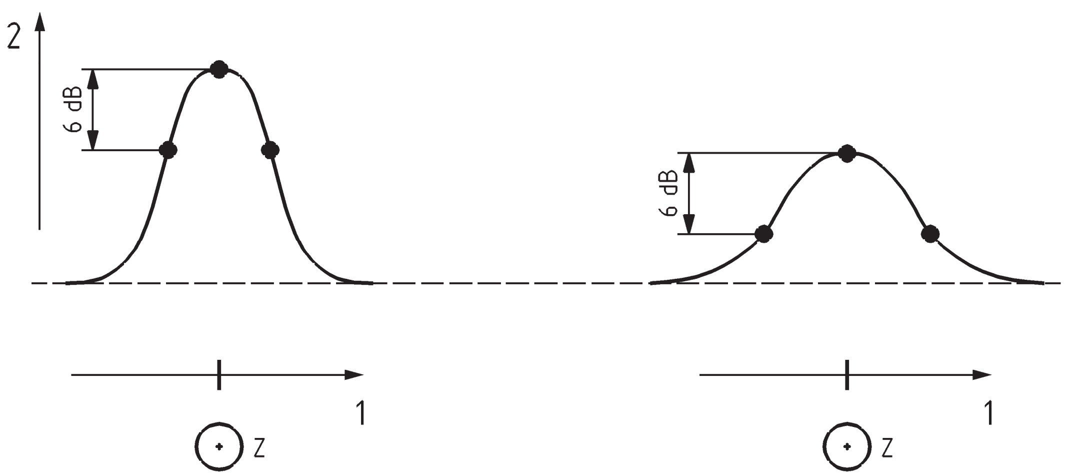


Key

1 X or Y axis
2 amplitude
F_W focal width

a) Pulse echo **b) Hydrophone technique**

Figure 13 — Transverse profiles of immersion probes

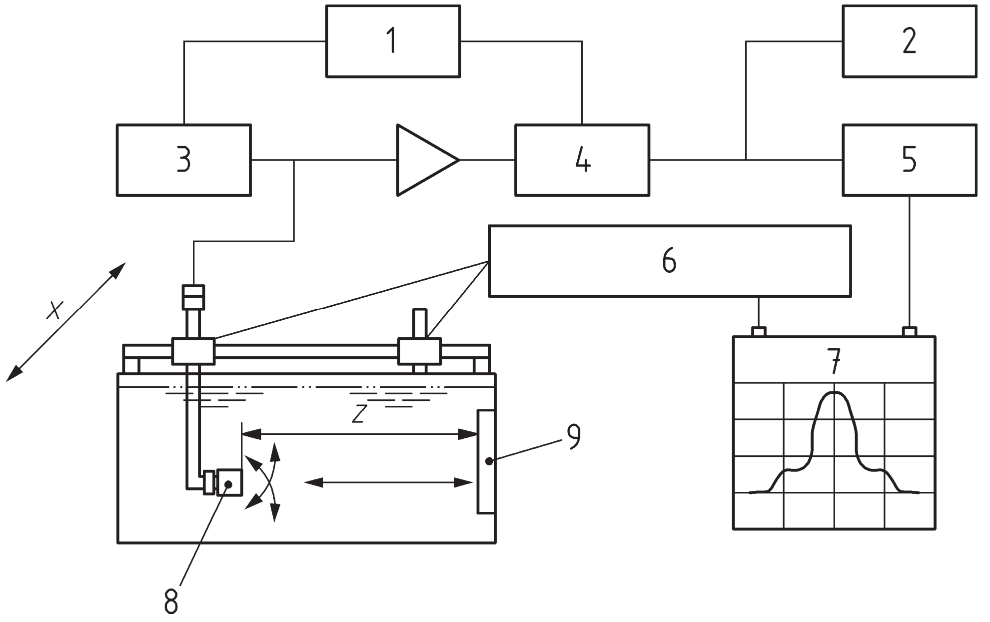


Key

1 X or Y axis
2 amplitude

a) At the focal point **b) At the end of the focal zone**

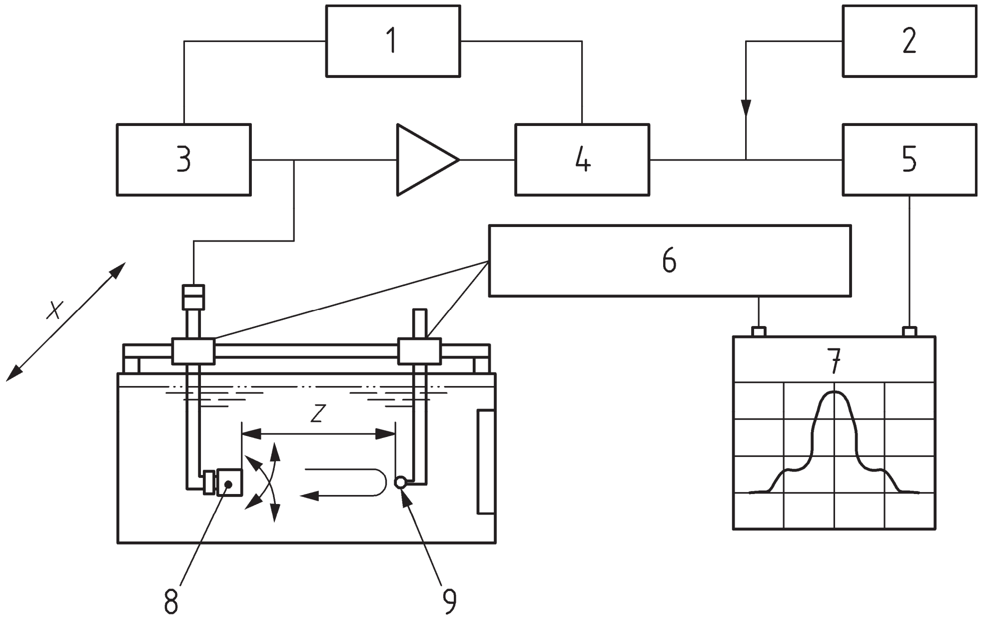
Figure 14 — Transverse profiles in the focal zone of an immersion probe



Key

1 delay
2 screen
3 pulse generator
4 gates
5 peak detector
6 positioning interface
7 recorder
8 probe
9 plate reflector

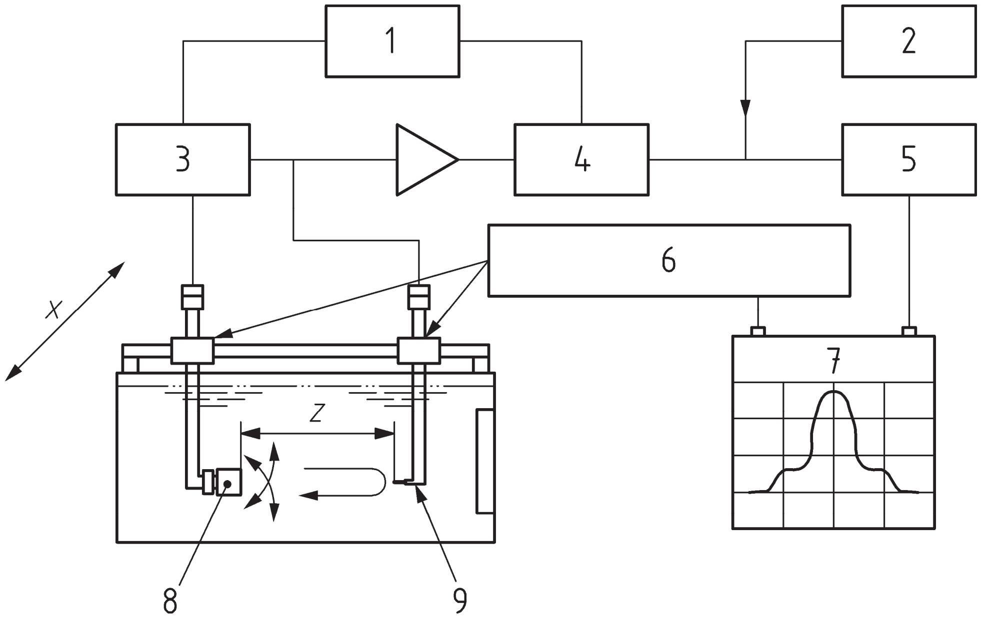
Figure 15 — Set-up to measure the sound beam of immersion probes − adjustment of the beam axis



Key

1 delay
2 screen
3 pulse generator
4 gates
5 peak detector
6 positioning interface
7 recorder
8 probe
9 ball reflector

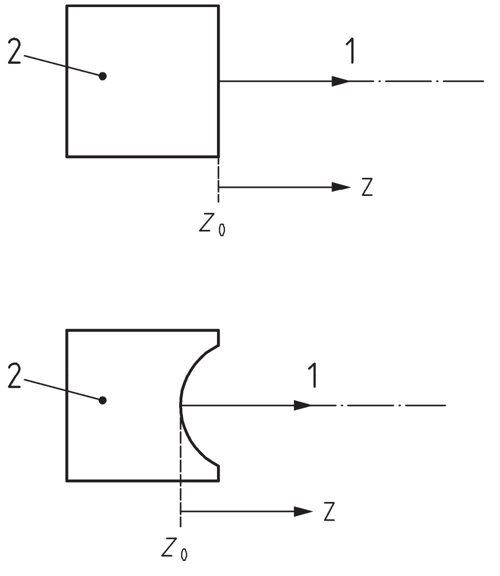
Figure 16 — Set-up to measure the sound beam of immersion probes using a ball reflector



Key

1 delay
2 screen
3 pulse generator
4 gates
5 peak detector
6 positioning interface
7 recorder
8 probe
9 hydrophone

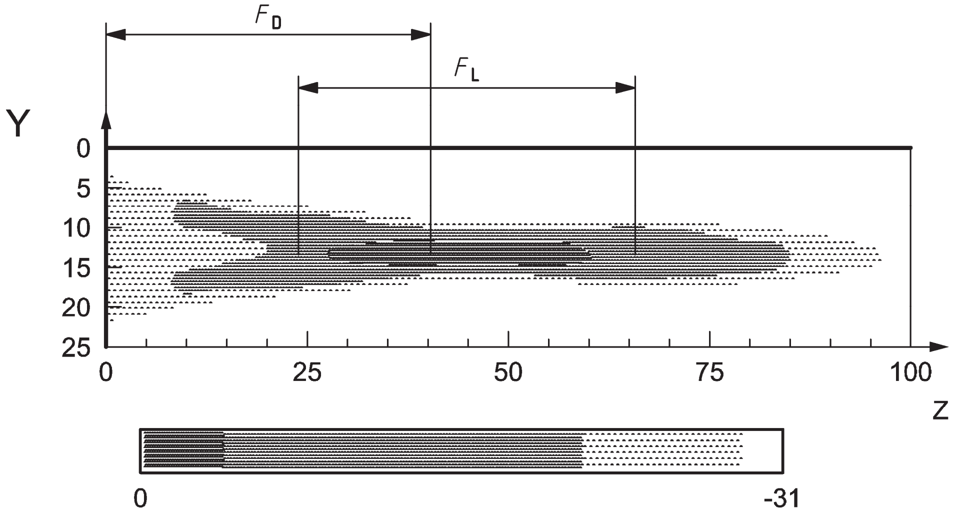
Figure 17 — Set-up to measure the sound beam of immersion probes using a hydrophone



Key

1 beam axis
2 probe
Z distance
Z_0 zero point

Figure 18 — Measurement of immersion probes finding the zero point, Z_0, of the coordinate system



Key

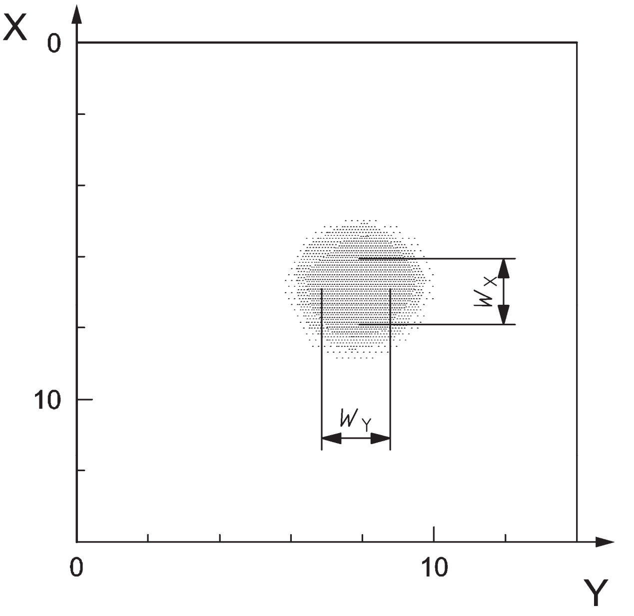
F_D focal distance

F_L focal length

Z distance on beam axis

Y distance perpendicular to beam axis

Figure 19 — C-scan image of a sound beam of a non-focusing immersion probe



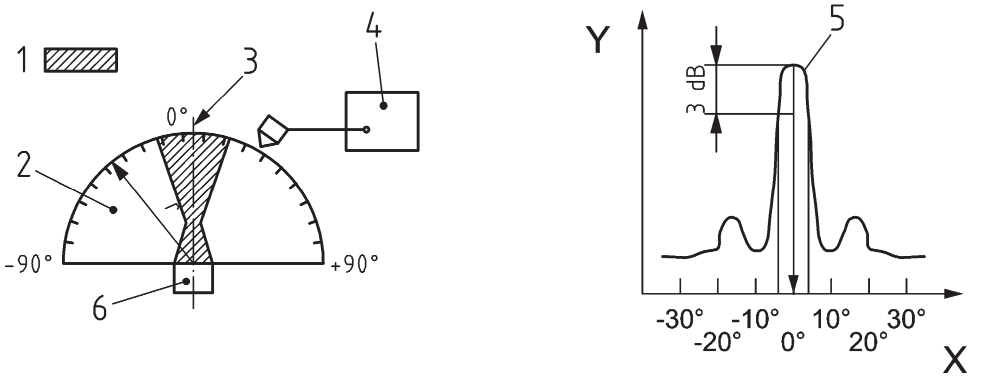
Key

W_X focal width on X axis

W_Y focal width on Y axis

X, Y distance perpendicular to beam axis

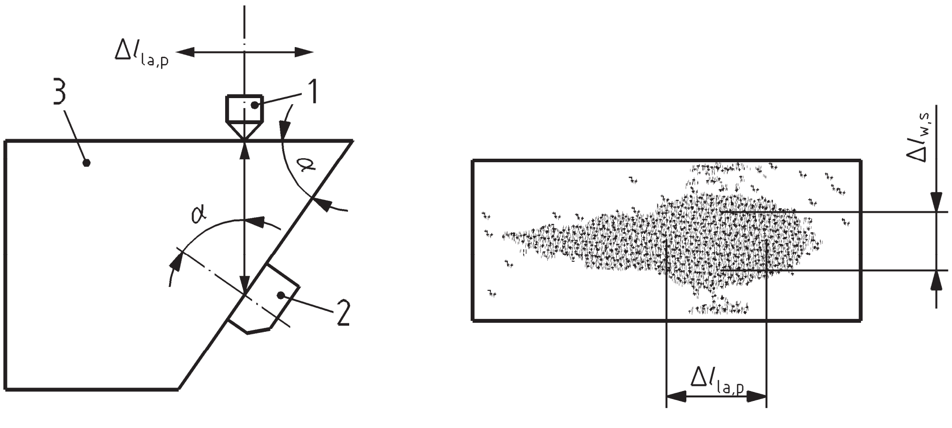
Figure 20 — C-scan image of a sound beam of a focusing immersion probe



Key

1 sound beam
2 half cylinder
3 axis
4 EMA receiver
5 main lobe
6 ultrasonic probe
X angle, degrees (°)
Y amplitude in decibels (dB)

Figure 21 — Measurement of beam divergence and beam angle



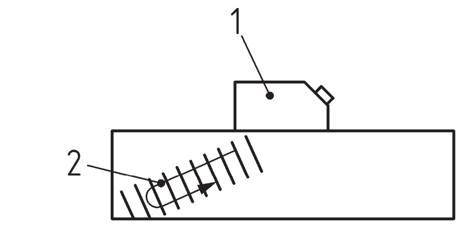
Key

1 EMA transducer
2 angle-beam probe
3 test block
α beam angle
$\Delta l_{la,p}$ projected focal length
$\Delta l_{w,s}$ projected focal width

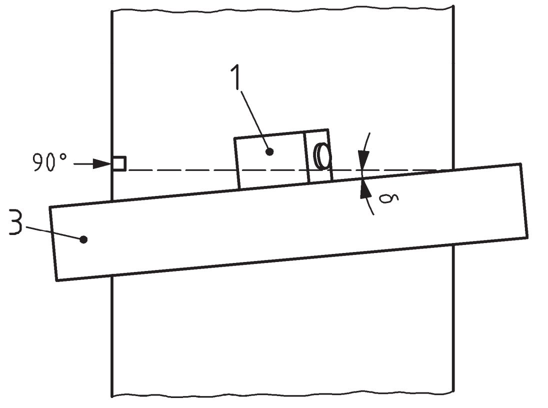
a) Reference block **b) C-scan image**

Figure 22 — Measuring beam parameters of an inclined sound beam using an EMA receiver

a)



b)



Key

1 probe
2 sound beam
3 ruler
δ squint angle

a) side view
b) top view

Figure 23 — Measuring the squint angle using the corner of a calibration block

Annex A
(normative)

Calculation of near field length of non-focusing probes

A.1 General

The near field length of a non-focusing transducer is calculated from the measured values of centre frequency f_o and of the measured angles of beam divergence γ in two perpendicular directions ($\gamma_\perp$ and $\gamma_{//}$). Usually in pulse echo mode the angles of divergence are defined by a 6 dB drop from maximum amplitude.

A.2 Straight beam probes

If $\gamma_{//}$ is the divergence angle parallel and $\gamma_\perp$ the angle perpendicular then for a circular transducer the near field length is calculated as:

$$N_0 = v_b / \left(15{,}16 f_0 \sin^2[\gamma]\right) \qquad \text{(A.1)}$$

for both angles $\gamma_\perp$ and $\gamma_{//}$

where

v_b is the sound velocity of the test block.

The larger N_0 is taken as the near field length of the circular transducer.

For rectangular transducers the angles of divergence are measured parallel to the sides a and b, where a ≥ b.

With the measured angle γ_a parallel to the larger side and the measured centre frequency f_0 the effective side a_{eff} of the rectangular transducer is calculated:

$$a_{eff} = (0{,}442 v_b)/(f_0 \sin[\gamma_a]) \qquad \text{(A.2)}$$

With the measured angle γ_b parallel to the smaller side and the centre frequency f_0 the effective side b_{eff} is calculated:

$$b_{eff} = (0{,}442 v_b)/(f_0 \sin[\gamma_b]) \qquad \text{(A.3)}$$

The aspect ratio is calculated as b_{eff}/a_{eff}. With this ratio the factor k can be taken from the diagram in Figure A.1.

Then the near field length of the rectangular transducer is:

$$N_0 = \left(k a_{eff}{}^2 f_0\right)/(4 v_b) \qquad \text{(A.4)}$$

where

v_b is the sound velocity in the test block.

A.3 Angle beam probes

The near field length shall be calculated for angle-beam probes with a plane transducer and a plane contact surface using the measured centre frequency f_o and the measured angles of divergence γ in two perpendicular directions (plane of incidence and plane perpendicular to it).

If γ_a is the angle measured in the plane of incidence and γ_h is the angle measured in the plane perpendicular to it, then the near field length of a circular transducer is calculated with the known sound velocity v_b in the reference block:

$$N_{0h} = v_b / \left(15{,}16 f_0 \sin^2[\gamma_h]\right) \tag{A.5}$$

(perpendicular to the plane of incidence)

$$N_{0a} = v_b / \left(15{,}16 f_0 \sin^2[\gamma]\right) \tag{A.6}$$

(in the plane of incidence)

where

$\gamma = \gamma_a \cos\beta / \cos\alpha$;

α is the beam angle in the wedge of the angle beam probe (angle of incidence);

ß is the beam angle in the material to be tested (angle of refraction).

The larger one of N_{0h} and N_{0a} is the near field length of the probe.

For rectangular transducers the effective sides a_{eff} and b_{eff} shall be calculated first. If a is the larger side and b the smaller one there are two cases:

a) large side a perpendicular to the plane of incidence:

$$a_{eff} = (0{,}442 v_b)/(f_0 \sin[\gamma_a]) \tag{A.7}$$

$$b_{eff} = (0{,}442 v_b)/(f_0 \sin[\gamma]) \tag{A.8}$$

with $\gamma = \gamma_h \cos\beta / \cos\alpha$;

b) large side a in the plane of incidence:

$$a_{eff} = (0{,}442 v_b)/(f_0 \sin[\gamma]) \tag{A.9}$$

$$b_{eff} = (0{,}442 v_b)/(f_0 \sin[\gamma_h]) \tag{A.10}$$

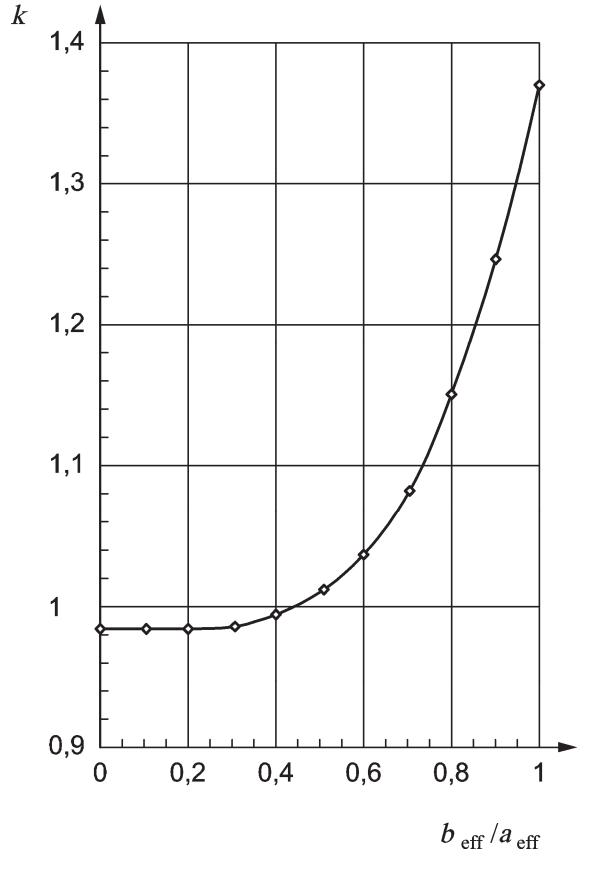
with $\gamma = \gamma_h \cos\beta / \cos\alpha$.

The aspect ratio (b_{eff}/a_{eff}) is calculated. Corresponding to this ratio there is a shape factor k shown in Figure A.1.

The near field length of the rectangular transducer is then calculated as:

$$N_0 = \left(k s_{eff}^{\ 2} f_0\right)/(4 v_b) \tag{A.11}$$

with s_{eff} being the larger out of a_{eff} and b_{eff} and v_b being the sound velocity of the block.



Key

k shape factor

b_{eff}/a_{eff} aspect ratio

Figure A.1 — Shape factor *k*, to calculate the near field length of rectangular transducers

Annex B
(informative)

Calibration block for angle-beam probes

This steel block according to Figure B.1 has a quarter cylinder and side-drilled holes of 4 mm diameter. Steel quality and heat treatment are as for calibration block EN ISO 7963.

Three different L-shaped scales for the interval of beam angles from

- 35° to 65°;
- 60° to 75°;
- 70° to 85°

can be attached to the same block (Figure B.1 and Figure B.2).

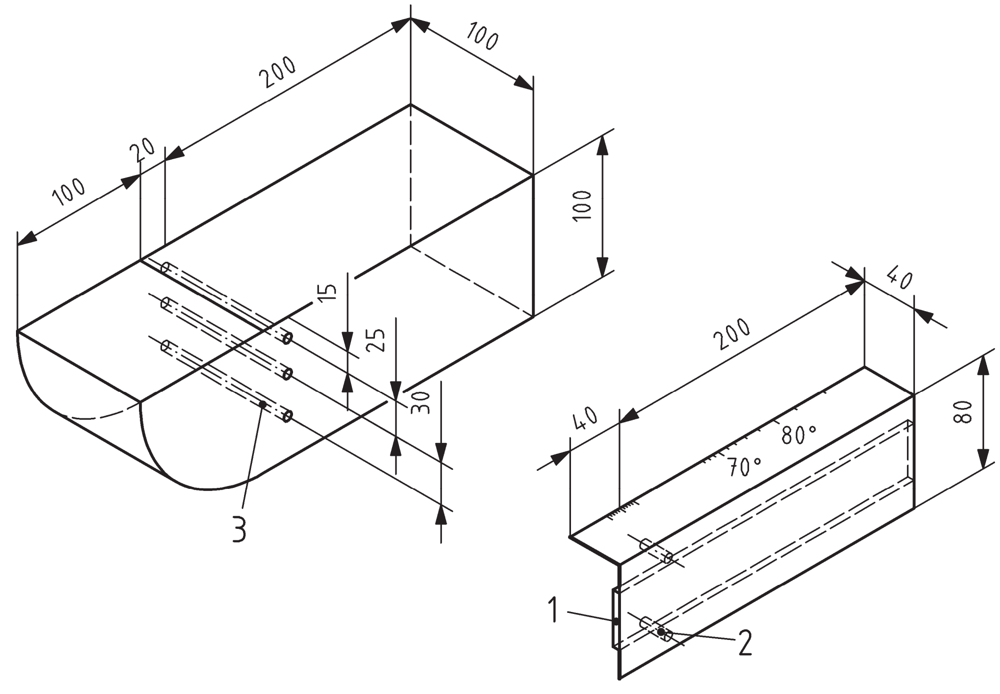
In a first step the scale suited to the probe's beam angle is chosen, e.g. for a 45° probe the scale no. 3 with a scale from 35° to 65° shall be used. This L-shaped scale is attached to the steel block, where the two bolts of the scale plug two of the three 4 mm side-drilled holes in the block.

The remaining hole is used as a cylindrical reflector to determine the beam angle. Additionally a magnetic pad on the scale fixes the scale to the steel block. The edge of the scale is used as a ruler to guide the probe.

The probe is then coupled to the block at the centre of the quadrant. By shifting the probe the echo from the 100 mm radius is maximized. The centre line of the quadrant then marks the index point (Figure B.3, a)).

In the next step the probe is coupled to the block so that the sound beam hits the 4 mm side-drilled hole (Figure B.3, b)). By shifting the probe the echo from the hole is maximized. The beam angle is then read from the scale at the position of the index point of the probe.

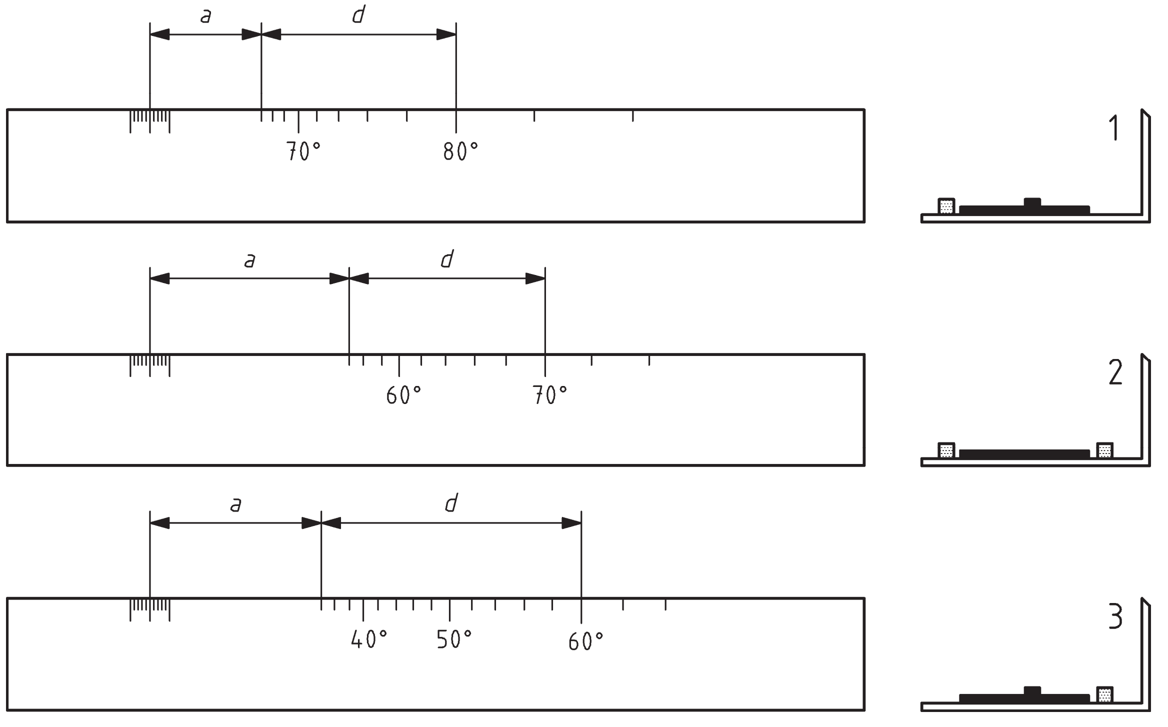
Dimensions in millimetres



Key

1 Magnetic pad
2 Two bolts which fit into the 4 mm holes
3 4 mm holes

Figure B.1 — Steel calibration block with detachable scales for contact, angle-beam probes



Key

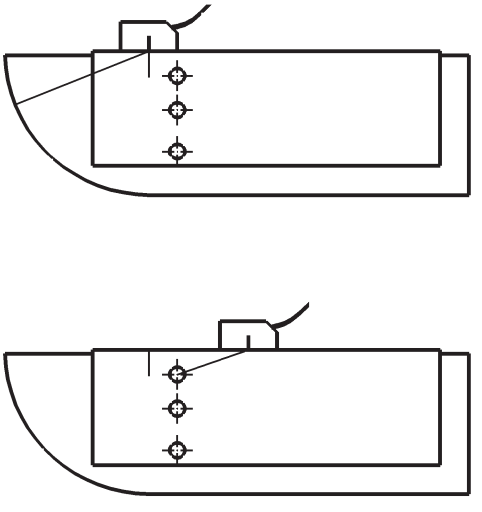
a distance between centre line of quadrant and start of scale engravings
b distance between start of scale and respective scale mark

NOTE For values of *a* and *d*, refer to Table B.1.

Figure B.2 — L-shaped scales 1, 2 and 3 to be attached to calibration block in Figure B.1

Table B.1 — Measures of the scale engravings in Figure B.2

Scale 1			Scale 2			Scale 3		
angle °	*a* mm	*d* mm	angle °	*a* mm	*d* mm	angle °	*a* mm	*d* mm
64	50,8	0	54	75,1	0	34	67,2	0
66		2,9	56		4,2	36		3,6
68		6,4	58		9,0	38		7,5
70		10,5	60		14,2	40		11,5
72		15,4	62		20,2	42		15,8
74		21,6	64		27,0	44		20,4
76		29,4	66		34,8	46		25,3
78		39,8	68		43,9	48		30,5
80		54,3	70		54,8	50		36,2
82		76,0	72		68,1	52		42,4
84		112,0	74		84,4	54		49,1
						56		56,6
						58		64,8
						60		74,0
						62		84,4
						64		96,3



a) Determination of the index point **b) Determination of the angle of incidence**

Figure B.3 — Determination of beam parameters of angle beam probes

Bibliography

[1] EN 12668-3, *Non-destructive testing — Characterization and verification of ultrasonic examination equipment — Part 3: Combined equipment*

[2] EN ISO 9001, *Quality management systems — Requirements (ISO 9001:2008)*

[3] EN ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories (ISO/IEC 17025:2005)*

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