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Non-destructive testing — Ultrasonic testing — Specification for a calibration block for phased array testing (PAUT)

Essais non destructifs — Contrôle par ultrasons — Spécifications relatives au bloc d'étalonnage pour la technique multiéléments

Reference number
ISO 19675:2017(E)

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Foreword

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This document was prepared by Technical Committee ISO/IIW, *International Institute of Welding*, Commission V.

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Non-destructive testing — Ultrasonic testing — Specification for a calibration block for phased array testing (PAUT)

1 Scope

This document specifies requirements for the dimensions, material and manufacture of a steel block for calibrating ultrasonic test equipment used in ultrasonic testing with the phased array technique.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

EN 16018, *Non-destructive testing — Terminology — Terms used in ultrasonic testing with phased arrays*

EN 10025-2, *Hot rolled products of structural steels — Part 2: Technical delivery conditions for non-alloy structural steels*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5577 and EN 16018 apply.

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

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

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

4 Abbreviated terms

ACG angle-corrected gain

FSH full-screen height

RF radio frequency

SDH side-drilled hole

SNR signal- to-noise ratio

TCG time-corrected gain

5 Manufacture

5.1 Steel

Blocks shall be manufactured from steel grade S355J0, in accordance with EN 10025-2, or equivalent.

5.2 Pre-machining and heat treatment

5.2.1 Raw blocks

Raw blocks shall be rough-machined to a dimension of 320 mm × 120 mm × 30 mm before heat treatment.

5.2.2 Heat treatment

The heat treatment shall consist of:

1) austenitizing at 920 °C for 30 min;

2) rapid cooling (quenching) in water;

3) tempering by heating to 650 °C for 3 h;

4) cooling in still air.

5.2.3 Checking prior to final machining

It is recommended to pre-machine the block to the following dimensions: 305 mm × 101 mm × 26,5 mm.

All external surfaces shall be pre-machined to a roughness value not greater than 1,6 µm R_a.

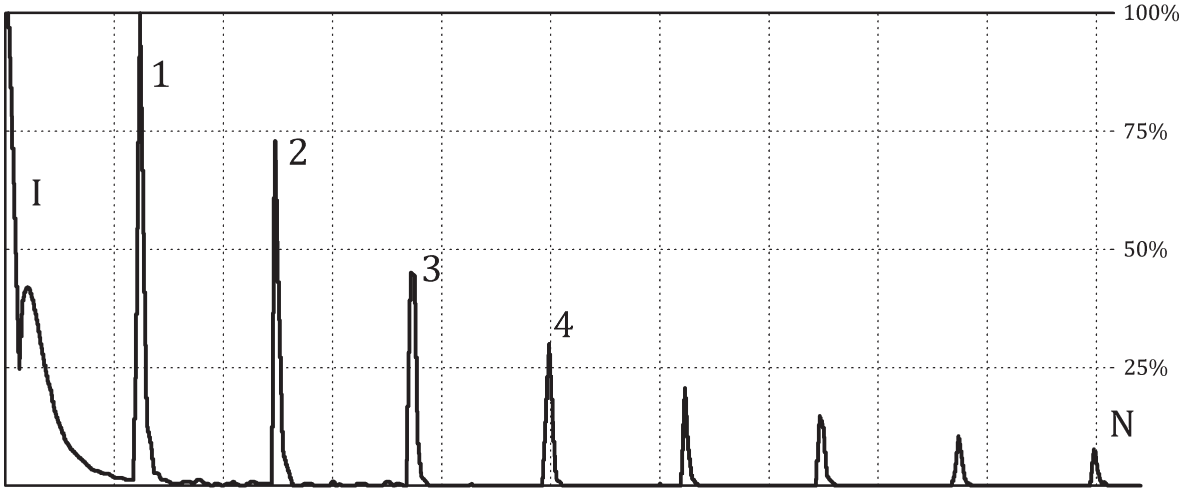
The pre-machined block shall be in accordance with the following.

a) It shall be free from internal discontinuities. For this purpose, an ultrasonic test shall be carried out after heat treatment, with a longitudinal wave straight-beam probe of at least 10 MHz nominal centre frequency and having a transducer size of 10 mm to 15 mm. The block shall be checked on all four long faces to cover the complete volume. With the probe positioned on the largest face of the block, the instrument's gain shall be set to achieve a grain scatter noise of 10 % of full screen height. No echo shall have an amplitude greater than that of the grain scatter noise;

b) It shall be isotropic for transverse and longitudinal waves proved by velocity measurements in accordance with Annex A (see A.3). Probes shall be located around the mid-position of each of the three faces;

c) It shall present low sound attenuation.

NOTE Absolute measurements of attenuation may be difficult to obtain because echo amplitudes depend on many factors. The significance of attenuation can be estimated by simple qualitative tests. Relative attenuation measurements can be made by examining the exponential decay of multiple back wall reflections [a satisfactory attenuation generally is proven by the observation of at least four echoes above of 25 % of FSH when a probe as recommended in 5.2.3 a) is used]. See Figure 1.



Key

I initial pulse

1, 2, 3, 4.... N multiple back wall echoes

Figure 1 — Acceptable sound attenuation

5.3 Final machining

5.3.1 Dimensions and surface finish

The dimensions and tolerances of the phased array calibration block shall be determined and recorded in accordance with Annex A (see A.2) and shall be in accordance with Figure 2. All external surfaces shall be machined to a roughness value not greater than 0,8 µm R_a.

5.3.2 Reference marks

Permanent reference marks shall be engraved on the block in accordance with Figure 3 and Table 1.

Reference marks shall be regular and not too deep (approx. 0,1 mm max.) and shall not be generated by a metal deformation process. Stamping shall not be used. Etching or laser engraving are the preferred marking processes.

5.3.3 Velocity checks

The velocities of longitudinal and transverse waves shall be determined and recorded in accordance with Annex A (see A.3).

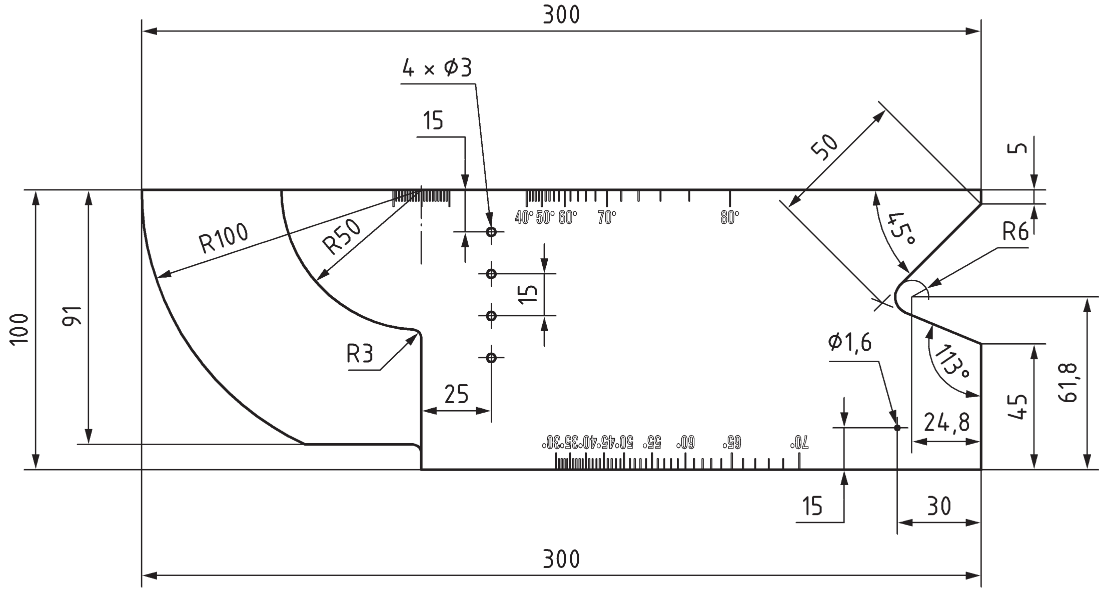
6 Marking

The block shall be permanently marked, in the area shown in Figure 2 c), with the following:

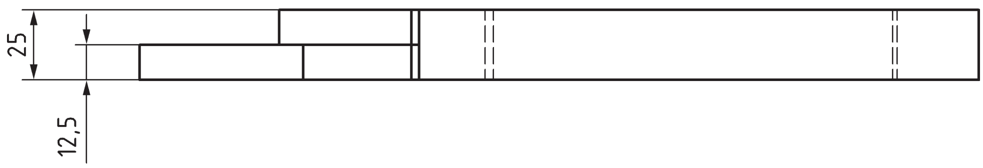
a) a reference to this document (i.e. ISO 19675:2016);

b) the manufacturer's serial number and trade mark;

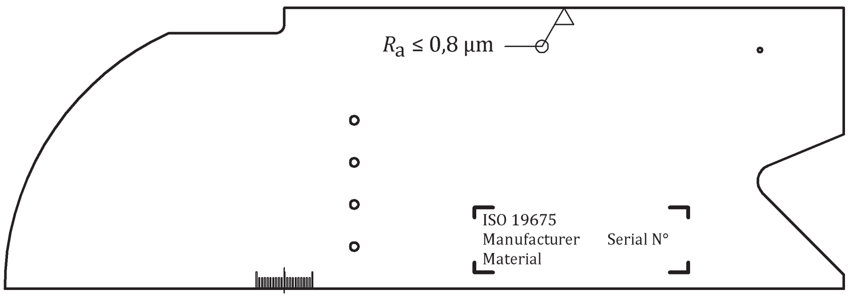
c) the steel grade used to make the block.



a) Front view



b) Bottom view



c) Back view

Tolerances:

Reflector tolerance per chart, Overall block size tolerance ±0,1 mm.

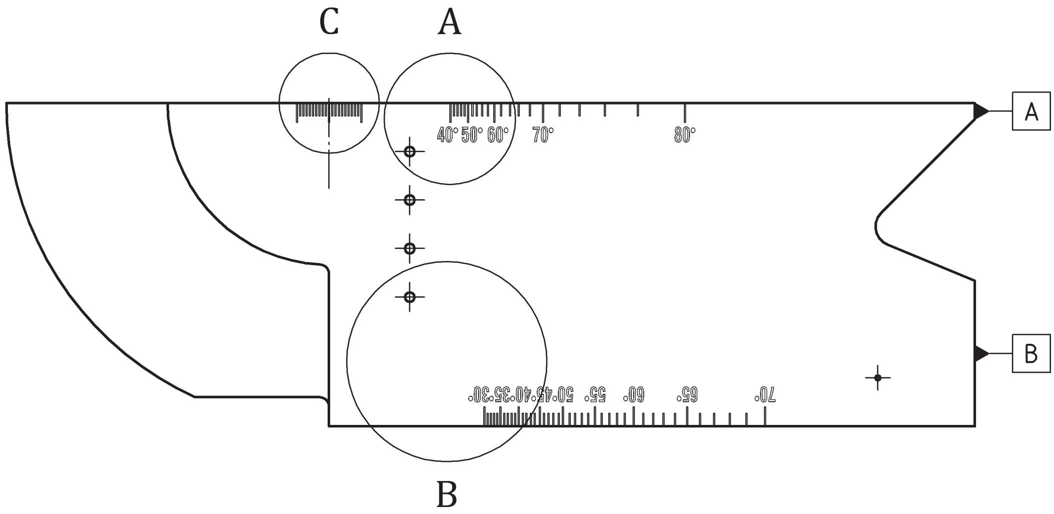
Remove all burrs, break all edges, no sharp corners. Mill all surfaces, surface finish, all over R_a ≤ 0,8 µm.

Machining Tolerances for reflectors and marks

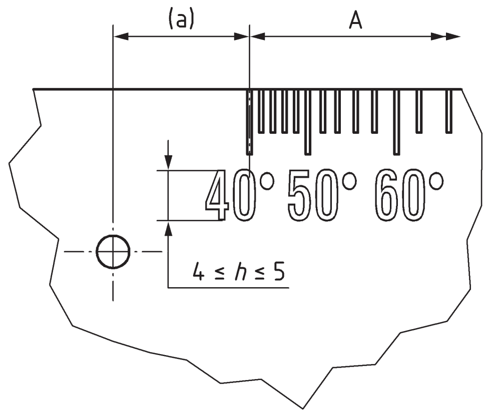
a) hole diameters, ±0,2 mm c) central position of reference reflectors, ±0,1 mm

b) all pertinent angles, ±1 ° d) angle identification and index mark lengths, ±0,4 mm

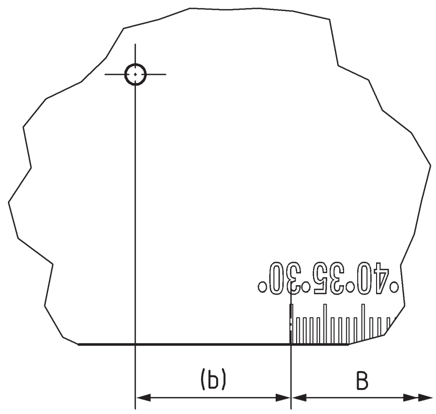
Figure 2 — Block dimensions with tolerances



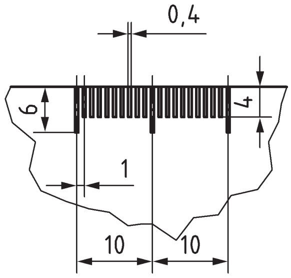
a) Side view



b) Detail A



c) Detail B



d) Detail C

NOTE See Table 1 for dimensions.

Figure 3 — Reference marks — Dimensions and positions

7 Declaration of conformity

A declaration of conformity shall be issued by the manufacturer for each block, containing:

a) a statement that the block complies with this document;

b) main physical dimensions of the block and hole diameters as measured;

c) attenuation results measured in accordance with 5.2.3;

d) results of all velocity measurements in accordance with Annex A (see A.3).

8 Possible modifications to phased array calibration block

Blocks of thickness greater than 25 mm are permitted to accommodate probes with larger active apertures.

Table 1 — Distances of indents

Distance (a) mm	**Distance from datum "A"** mm	**Indent with label** degrees	**Indent without label** degrees	**Distance (b)** mm	**Distance from datum " B"** mm	**Indent with label** degrees	**Indent without label** degrees
12,6	162,4	40		23,1	151,9	30	
13,5	161,5		42	24,0	151,0		31
14,5	160,5		44	25,0	150,0		32
15,5	159,5		46	26,0	149,0		33
16,7	158,3		48	27,0	148,0		34
17,9	157,1	50		28,0	147,0	35	
19,2	155,8		52	29,1	145,9		36
20,6	154,4		54	30,1	144,9		37
22,2	152,8		56	31,3	143,7		38
24,0	151,0		58	32,4	142,6		39
26,0	149,0	60		33,6	141,4	40	
28,2	146,8		62	34,8	140,2		41
30,8	144,2		64	36,0	139,0		42
33,7	141,3		66	37,3	137,7		43
37,1	137,9		68	38,6	136,4		44
41,2	133,8	70		40,0	135,0	45	
46,2	128,8		72	41,4	133,6		46
52,3	122,7		74	42,9	132,1		47
60,2	114,8		76	44,4	130,6		48
70,6	104,4		78	46,0	129,0		49
85,1	89,9	80		47,7	127,3	50	
				49,4	125,6		51
				51,2	123,8		52
				53,1	121,9		53
				55,1	119,9		54
				57,1	117,9	55	
				59,3	115,7		56
				61,6	113,4		57
				64,0	111,0		58
				66,6	108,4		59
				69,3	105,7	60	
				72,2	102,8		61
				75,2	99,8		62
				78,5	96,5		63
				82,0	93,0		64
				85,8	89,2	65	
				89,8	85,2		66
				94,2	80,8		67
				99,0	76,0		68
				104,2	70,8		69
				109,9	65,1	70	

Annex A
(normative)

Determination of material anisotropy

A.1 Material anisotropy

Acoustic anisotropy is generally considered a characteristic defined by a material having different sound velocities in different directions.

In general, three types of waves can be transmitted in an unbounded solid medium. In an isotropic material, these are longitudinal waves with particle motion along the direction of propagation and two transverse waves with particle motions perpendicular to the direction of propagation. Anisotropic materials also support three waves but particle motions are not usually along or at right angles to the direction of propagation. As a result, in anisotropic materials, no wave is exclusively transverse or longitudinal.

Longitudinal mode velocities are easily assessed; however, these do not tend to vary by a significant amount in most carbon steels even if they have a quite great amount of anisotropy.

Transverse mode velocities can display a more noticeable degree of anisotropy. Variation in transverse wave velocity in mechanical vibration has its equivalent in optical birefringence. This acoustic birefringence effect is illustrated in Figure A.1.

By rotating a straight-beam transverse wave probe, at the same location of an anisotropic medium, the fast and slow transverse wave velocities can then be easily determined for two perpendicular directions.

A.2 Determination of block dimensions

The physical dimensions of the block are determined by means of a mechanical measuring instrument capable of determining the physical dimensions of the block to the stated accuracy (see Figure 2). The accuracy of the dimensional checks shall be provided as part of the block documentation.

A.3 Determination of velocities

A.3.1 General

An ultrasonic instrument in conjunction with two different straight-beam probes (longitudinal and transverse) is then used to measure the time of flight of back wall echoes. Velocities (V) are then calculated, using the measured thickness (d) and the time of flight (t) at the same measuring point.

Formula (A.1) is used:

$$V = 2d/t \quad (A.1)$$

The time of flight is measured in three perpendicular directions (X, Y, Z) at three positions in accordance with Figure A.2.

The measurements shall be carried out within the temperature range from 17 °C to 23 °C.

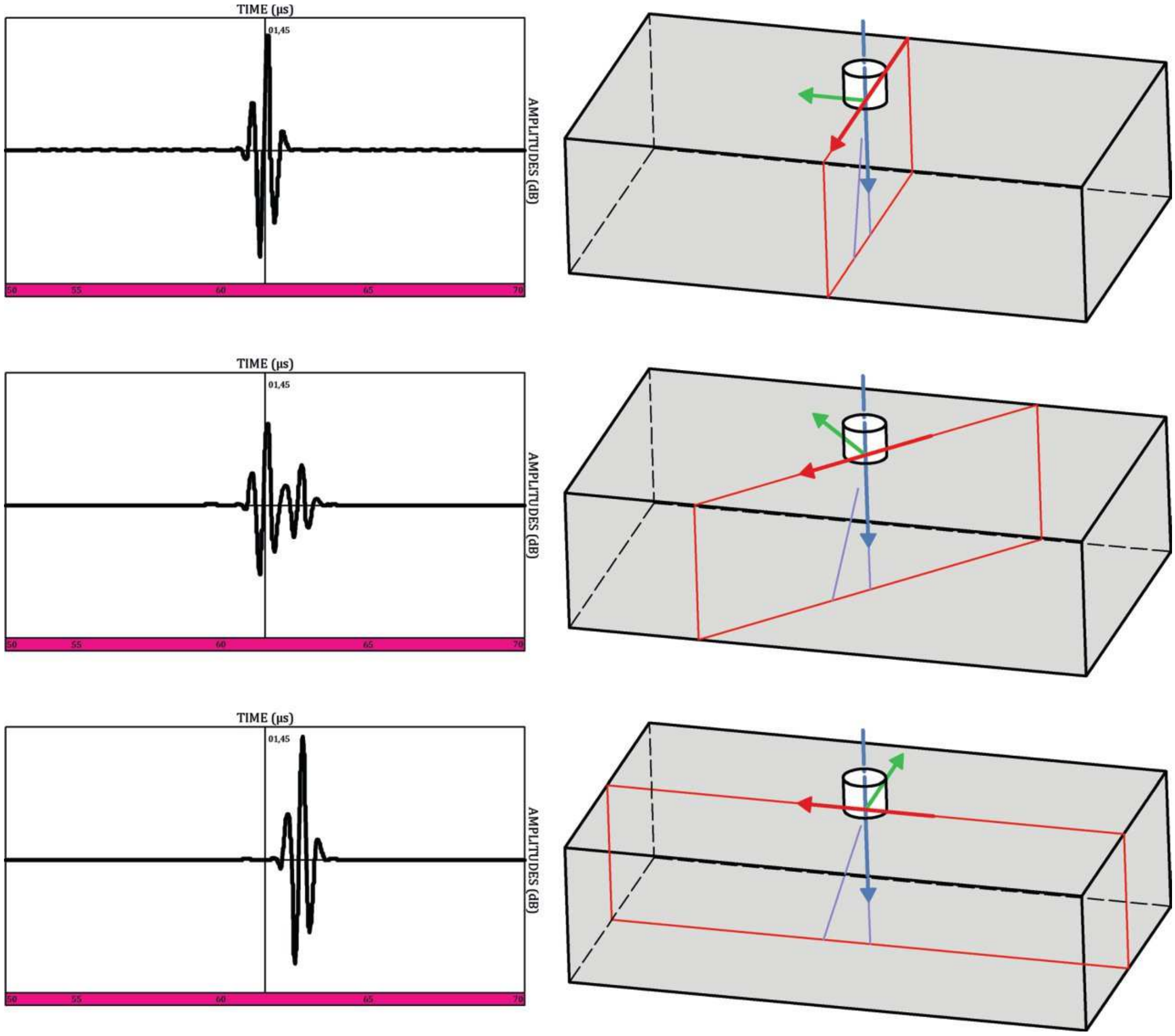
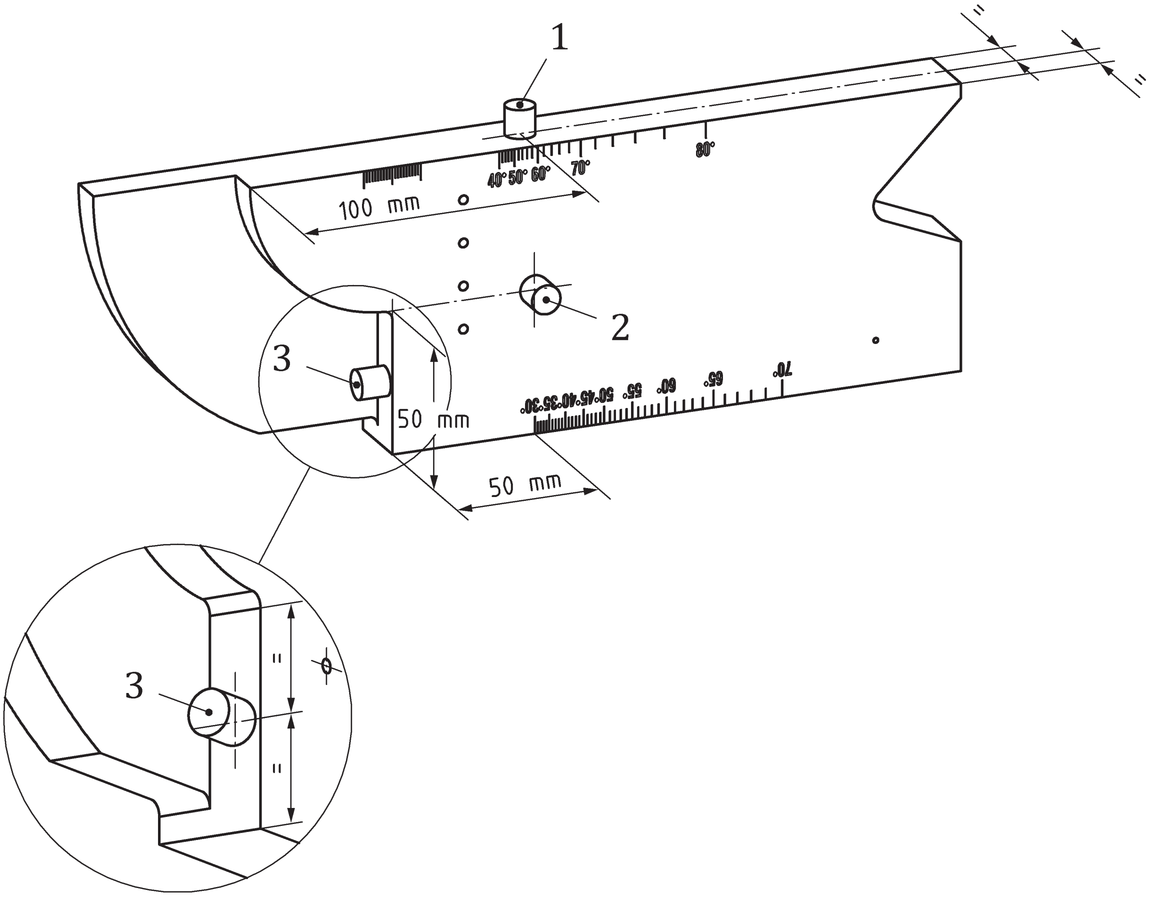


Figure A.1 — Illustration of the birefringence effect observed in an anisotropic medium with transverse waves, when rotating the probe in one position



Key

1, 2, 3 probe positions - opposite side may be used

Figure A.2 — Probe positions for velocity determination

A.3.2 Longitudinal waves

Use a probe with a nominal centre frequency of at least 5 MHz, broadband pulse and a transducer size of 10 mm to 12,5 mm in diameter. Measure the time difference between the first and the second back wall echo at three positions in accordance with Figure A.2 (see note).

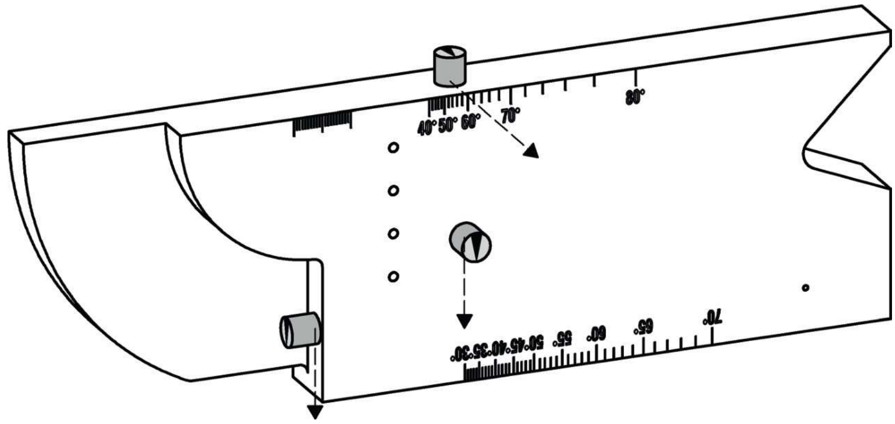
A.3.3 Transverse waves

To couple transverse waves, suitable coupling media of high viscosity are required. For the three positions defined in Figure A.2, use a transverse wave straight-beam probe of frequency 4 MHz to 5 MHz, broadband pulse and a transducer size of 10 mm to 12,5 mm in diameter. Measure the time difference between the first and the second back wall echo (see note).

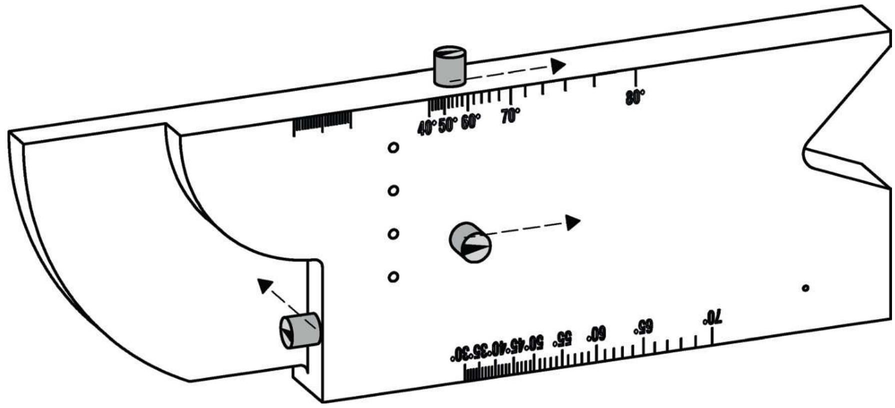
Because transverse waves are polarized, make two measurements in each location of the probe with the plane of polarization in the second measurement perpendicular to the first measurement in accordance with Figures A.2 and A.3.

Thus, for each calibration block, there are at least six values for transverse wave velocity.

NOTE Multiple back wall echoes may be used, 1 mm/μs ≡ 1 000 m/s.



a) First polarization plane to determine V_{T1}



b) Second polarization plane to determine V_{T2}

Figure A.3 — Probe positions and orientation for transverse wave velocity determination

A.3.4 Report of determination of velocities and acceptance criteria

The velocities shall be determined within a maximum permissible error of ±0,2 %, i.e. with an uncertainty of ±6 m/s for transverse waves and ±12 m/s for longitudinal waves.

The reference velocities[1] are:

— V_{L0}: 5 920 m/s;

— V_{T0}: 3 255 m/s.

The determined:

— longitudinal wave velocity, V_L shall be V_{L0} ± 30 m/s;

— transverse wave velocities, V_{T1} and V_{T2} shall be V_{T0} ± 15 m/s;

Results of velocity determination shall be recorded in accordance with Table A.1.

Table A.1 — Template to report measurement results

Position	Longitudinal L		Transverse T			
	V_L (m/s)	Deviation from reference velocity value (m/s)	V_{T1} (m/s)	Deviation from reference velocity value (m/s)	V_{T2} (m/s)	Deviation from reference velocity value (m/s)
1						
2						
3						

All calculated velocities of longitudinal waves shall stay within the interval (5 890; 5 950) m/s.

All calculated velocities of transverse waves shall stay within the interval (3 240; 3 270) m/s.

Any block having a velocity value outside these intervals shall be scrapped.

Annex B
(informative)

Description of possible uses of the PAUT calibration block

This annex does not replace standards that are specific to testing phased array instruments, phased array probes or combined systems. The goals of this annex are to compare the usage of this PAUT calibration block with that of the ISO 2400 block, and to briefly illustrate some of the other possible usages of this block. See Tables B.1 to B.4.

Table B.1 — Examples of phased array ultrasonic test system functions that can be checked by the PAUT calibration block

Function	Existing mono-element (ISO 2400)	Recommended PAUT
Probe index (angle beam probes)	Centre of 100 mm radius	Same process
Beam angle (angle-beam probes)	Index aligns with engraving with beam directed at 50 mm or 1,5 mm diameter holes	Same process using 3 mm SDHs nearest to the engraving used
Beam squint angle	Probe casing angle with respect to block wedge when corner reflection peaked	Same process possible using protractor and straight edge
Linearity of time base	Graticule spacing interval for 25 mm multiples	Same process
Calibration of time base	Range-delay adjustments with extra option to calibrate with 91 mm step from longitudinal mode to equal 50 mm transverse mode	Same process but the plastic insert is not available for compression mode to 50 mm equivalent
Linearity of attenuator	Adjust 1,6 mm diameter SDH to 80 % and then add 2 dB and subtract, 2 dB, 6 dB, 18 dB and 24 dB	Same process with 1,6 mm SDH
Linearity of screen height	Ratio of two signals maintained with increasing dB to put larger signal at 10 % steps of FSH	Same process
Pulse duration	RF pulse duration at 10 % of peak amplitude from back wall	Same process
Measurement of dominant frequency	Convert to time base and use signal from radius or thickness and count number of cycles in 1 µs	Same process
Signal-to-noise ratio (SNR)	Set 1,6 mm SDH peaked to 10 % of FSH. Remove and dry probe and add gain until noise reaches 10 % of FSH	Same process with side-drilled hole now 1,6 mm

Table B.2 — Examples of additional functions for the PAUT calibration block

Function	Existing mono-element	Recommended PAUT
Wedge delay	—	Wedge delay can be determined at a fixed depth or to a fixed distance, such as the 100 mm radius.
Assess for grating lobes	—	Assessment of potential grating lobes is done by comparing the amplitude of off-axis responses of a SDH at shallowest depths to the same SDH on main axis.
Active element assessment	—	Any single element 1-step E-scan displayed with the probe on a wedge or the calibration block should indicate lack of ringing in inactive elements on B-scan or uncorrected S-scan display.
Sensitivity equalization for E-scans	—	Uniform sensitivity for E-scans, set using SDH.
Sensitivity equalization for S-scans (ACG)	—	Uniform sensitivity for S-scans, set using 50 mm or 100 mm radius.
Plotting check	—	Aligned position of 3 mm SDH on an S-scan can provide an indication of position plotting accuracy and delay law generation.
Element assignment	—	Single element step E-scan with reflection on sloped surface. With refracting wedge the wedge provides the sloped surface. For 0° linear array (without wedge) an inclined slope is required. Monitor for monotonic increase in arrival time of back wall echoes.
Anisotropy assessment	Done for block as opposed to UT system using comparison of longitudinal and transverse velocities	Done for block as opposed to UT system using comparison of longitudinal and transverse velocities.

Table B.3 — Examples of possible practices (common functions) using the PAUT calibration block

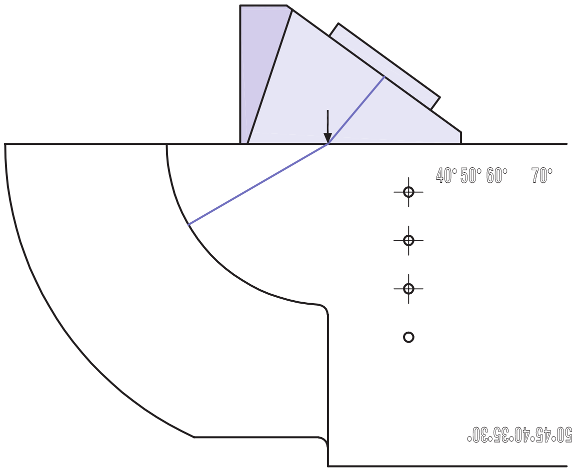
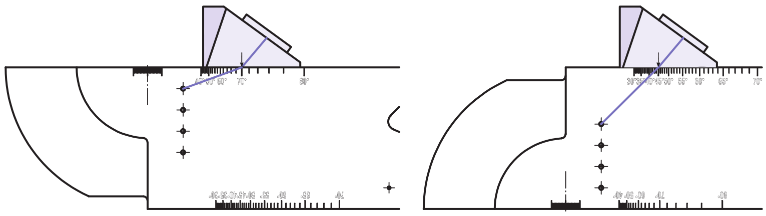
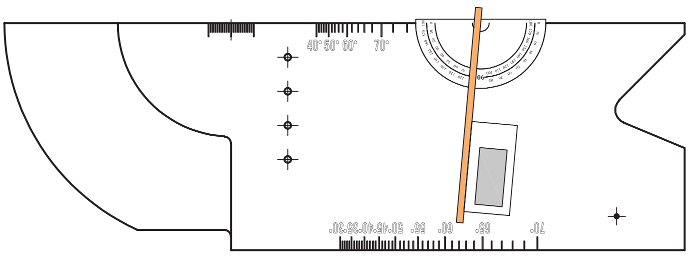
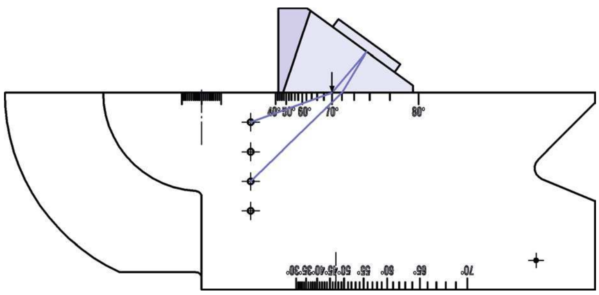
Function	Recommended practice
Probe index (angle-beam probe)	
Beam angle (angle beam probe)	 70° and 45° positions
Beam squint	 Maximize corner echo, use a protractor to assess squint angle
Linearity of time base	Interval to peaks using multiples of 25 mm (or thinner) thickness
Calibration of time base	Longitudinal mode - 25 mm and 100 mm intervals (maybe more) Transverse mode, 50 mm and 100 mm radii
Linearity of attenuator	Fixed signal from 3 mm diameter SDH
Linearity of screen height	Ratio of any two signals remains fixed (e.g.) 

Table B.3 *(continued)*

Function	Recommended practice
Pulse duration	RF back wall signal from any surface including 100 mm radius and measure either the time from 10 % levels or the equivalent sound path for either longitudinal or transverse mode.
Measurement of dominant frequency	Count cycles in a known 1 µs time interval (use same signal as pulse-duration assessment signal)
Signal-to-noise ratio (SNR)	Set 1,6 mm SDH peaked to 10 % of FSH. Remove and dry probe and add gain until noise reaches 10 % of FSH.

Table B.4 — Examples of possible practices (additional functions) using the PAUT calibration block

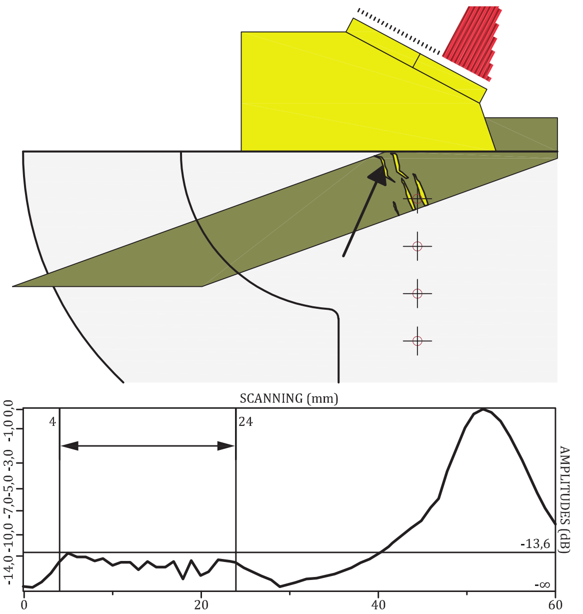
Functions	Recommended practice
Wedge delay	Any SDH or even the radius can be used to check a constant distance or depth to a known target.
Sensitivity equalization for E-scans	Any SDH can be used to monitor for attenuation effects of the changes in wedge path in order to be compensated, if possible by the system.
Sensitivity equalization for S-scans (ACG)	A constant sound path in the steel is required to ensure suitable correction for S-scans where the effects of echo-transmittance and increasing wedge path cause amplitude loss. Only the radius can be used because an SDH will have increasing sound path to the target and this introduces another variable to the process that is only supposed to be correcting for wedge and angle losses.
Assess for grating lobes	 Collect B-scan Assess lobe amplitude Specify dB level to which a grating lobe should be below peak signal on intended refracted axis to be acceptable (e.g. −20 dB)

Table B.4 *(continued)*

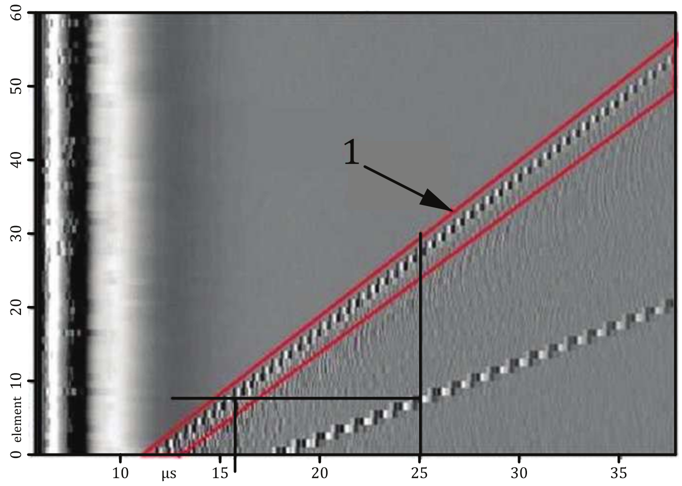
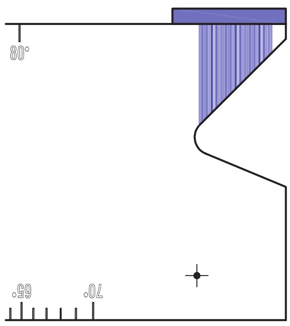
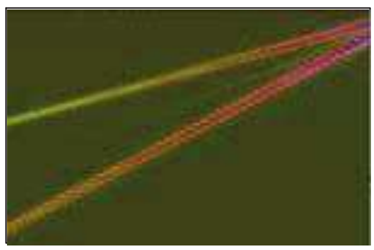
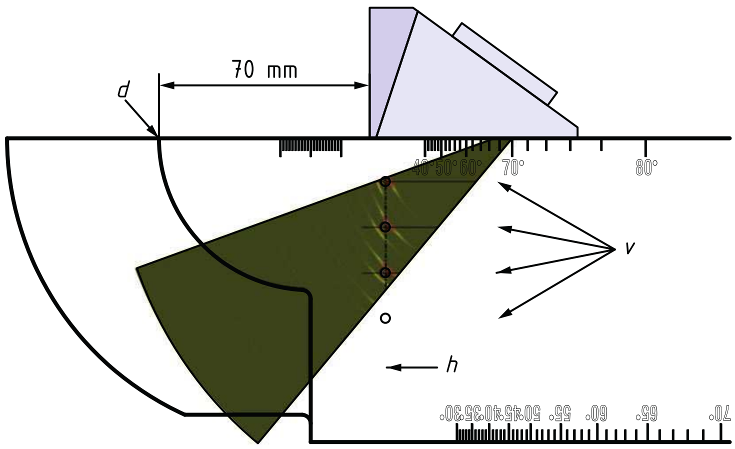
Functions	Recommended practice
Active element assessment	Active elements ring when struck by a voltage impulse. A single element −1-step E-scan over each element in a probe producing a B-scan on a wedge is adequate to identify elements that do not ring. For 0° probes, the B-scan on the 25 mm thickness is adequate.  **Key** 1 wedge interface signal
Element assignment (in accordance with ISO 18563-3)	For linear array probes with a wedge, the same setup as for active element assessment can be used and the arrival times from each element should display a monotonic increase in arrival time. For 0° linear arrays without a wedge, the probe can be placed on a surface with a sloped back wall and achieve a similar response to that with a wedge in place.  

Table B.4 *(continued)*

Functions	Recommended practice
Plotting check	Aligned position of 3 mm SDH on an S-scan can provide an indication of position plotting accuracy and delay law generation. Software will usually provide coordinates in the X direction to indicate stand-off distance from some probe reference point. To confirm plotting is suitable, all peaked signals should be within 1 mm of the actual position of the SDH relative to the probe/software reference coordinate.  **Key** *d* convenient stand-off reference *v* vertical positions within 1 mm of true value with allowance for hole radius *h* horizontal offset within 1 mm of true value with allowance for hole radius When equalising sensitivity using a TCG for delay laws, special caution is required for S-scans. In E-scans, where the process effectively duplicates the manual raster scan, the TCG simply corrects amplitude for losses due to increasing sound path to the same target for greater sound paths. Any uniform target can be used. For S-scans, the process not only corrects for increasing sound path, it also corrects for angle losses (echo-transmittance). Therefore, any differences in target reflectivity with angle are also equalised. This renders notches (and FBHs) unsuitable for TCG construction for S-scans. Only SDHs at increasing depths and concave radii of increasing diameters should be used for TCG constructions for S-scans.
Anisotropy assessment	In order to assess anisotropy, measurements the arrival times of longitudinal and transverse modes are obtained using separate straight beam longitudinal wave and transverse wave probes as described in Annex A.

Bibliography

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

[2] ISO 13588, *Non-destructive testing of welds — Ultrasonic testing — Use of automated phased array technology*

[3] ISO 18563-3, *Non-destructive testing — Characterization and verification of ultrasonic phased array equipment — Part 3: Combined systems*

[4] *Non-destructive testing, Recommendations for the use and validation of non-destructive testing simulation*, IIW Best Practice Document IIW-2363-13, Villepinte: International Institute of Welding (IIW)

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