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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 multi-éléments automatisés

Partie #: Titre de la partie

ICS 19.100

Member bodies are requested to consult relevant national interests in ISO/TC 44/SC ## before returning their ballot to the ISO Central Secretariat.

This draft International Standard is submitted to all ISO member bodies for voting, as a standard prepared by an international standardizing body in accordance with Council Resolution 42/1999. The proposer, the International Institute of Welding (IIW), has been recognized by the ISO Council as an international standardizing body for the purpose of Council Resolution 42/1999.

To expedite distribution, this document is circulated as received from the committee secretariat. ISO Central Secretariat work of editing and text composition will be undertaken at publication stage.

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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

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

ISO 19675 was prepared by IIW, *International Institute of Welding*.

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

1 Scope

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

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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 inspection — Vocabulary*

ISO 18563-3, *Characterization and verification of ultrasonic phased array equipment – Part 3: Combined system*

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

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

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5577, EN 1330-4 and EN 16018 apply.

4 Symbols and abbreviated terms

See Table 1

Abbreviated term	Definition
ACG	Automated Gain Calibration
FSH	Full Screen Height
RF	Radio Frequency
SDH	Side Drilled Hole
SNR	Signal to Noise Ratio
TCG	Time Corrected Gain

Table 1 — Abbreviated terms

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 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.

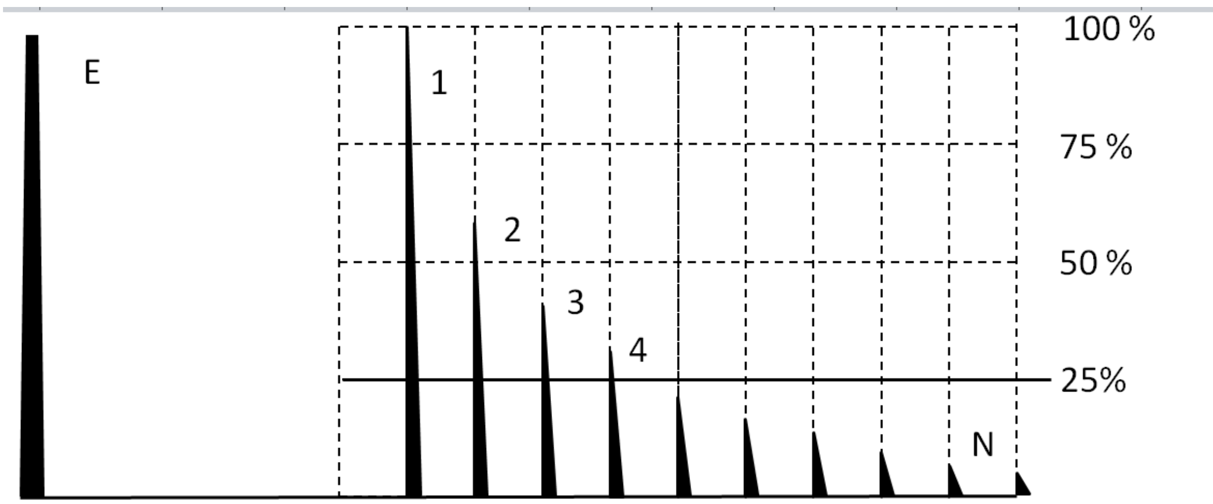
The pre-machined block shall be:

a) free from internal discontinuities. For this purpose, an ultrasonic examination shall be carried out after heat treatment, with a 0 ° 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 equipment gain shall be set to achieve a grain scatter noise of 10 % of the screen height. No echo shall have an amplitude greater than that of the grain scatter noise;

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

c) to present a low attenuation.

NOTE Absolute measurements of attenuation may be difficult to obtain because the echo amplitude depends on factors in addition to amplitude. The attenuation significance may be estimated by simple qualitative tests. Relative attenuation measurements can be made by examining the exponential decay of multiple backwall reflections (a satisfactory attenuation corresponds generally to the observation of at least 4 echoes above 25% FSH when the probe recommended in 5.2.3 a) is used).



Key
FSH – Full Screen height
E – emission signal
1, 2, 3, 4…. N – multiple backwall reflection

Figure 1 — Acceptable attenuation

5.3 Final machining

5.3.1 Dimensions and surfaces finish

The dimensions and tolerances of the phased array calibration block 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 2.

Reference marks shall be regular and not too deep (approx. 0,1mm 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 in accordance with Annex A.

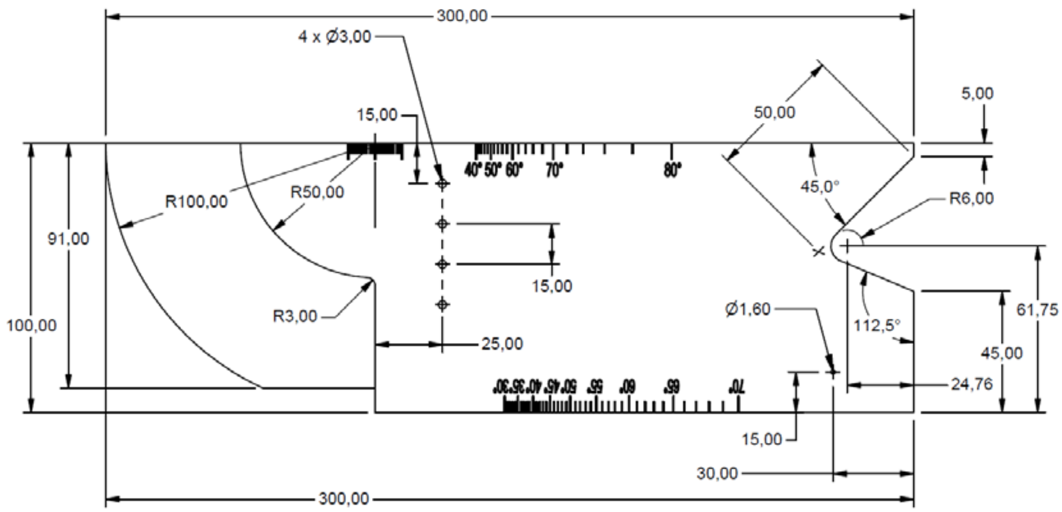
6 Marking

The block shall be permanently marked, in the area shown in Figure 3, with:

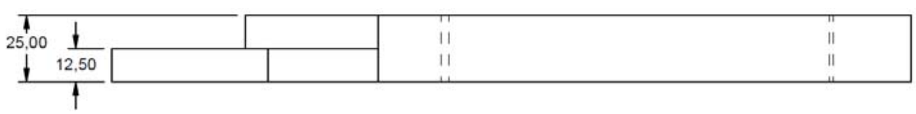
a) the number of this International Standard;

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

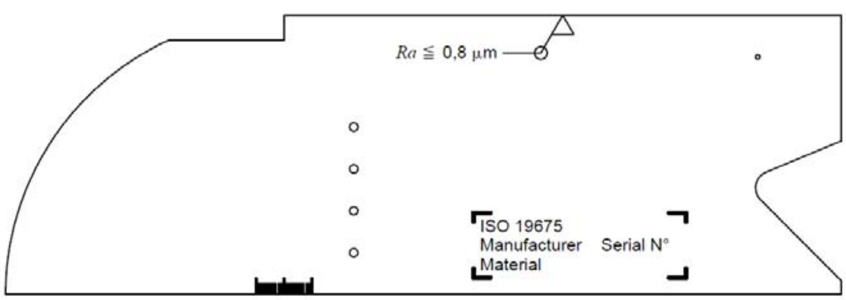
c) the steel grade used to make the block.



a) Front view



b) Bottom view



c) Back view

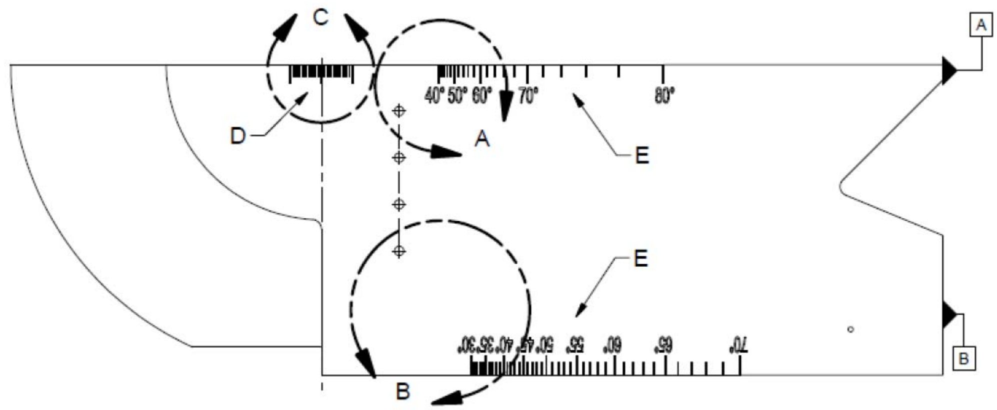
Tolerances:

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 $R_a \leq 0,8$ μm

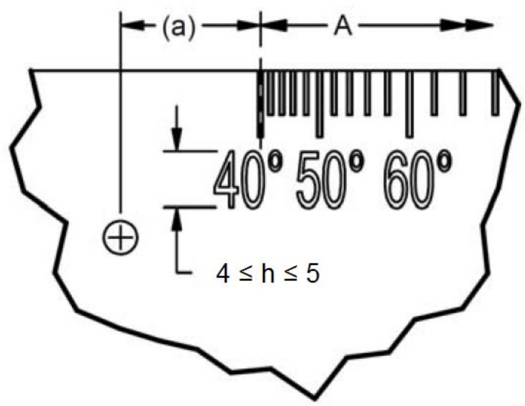
Machining Tolerances for reflectors

a) hole diameters, ± 0.2 mm
b) all pertinent angles, ± 1°
c) central position of reference reflectors, ± 0.1 mm
d) angle identification and index mark lengths, ± 0.4 mm

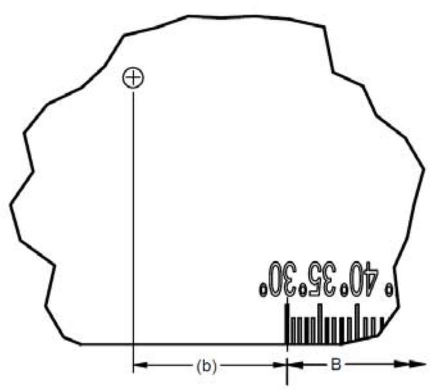
Figure 2 — Block dimensions with tolerances



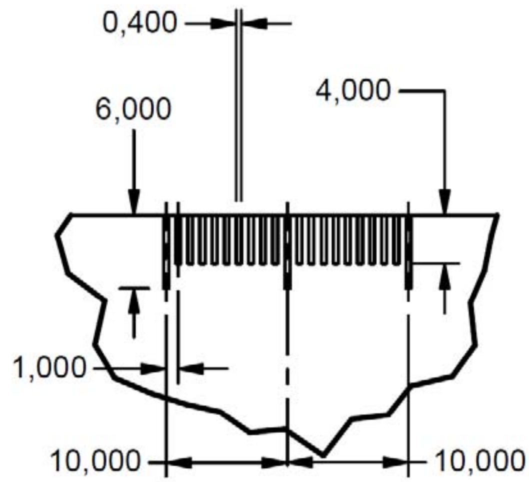
a) Side view



b) Detail A



c) Detail B



d) Detail C

NOTE see Table 2 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 international standard, ISO 19675;

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

c) attenuation results measured in accordance with 5.2.3;

d) all velocity measurements in accordance with Annex A.

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 2 — Indent distance

Distance (a) mm	Distance from Datum "A" mm	Indent with label	Indent without label	Distance (b) mm	Distance from Datum " B" mm	Indent with label	Indent without label
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 dimensions and velocities (for checking material anisotropy)

A.1 General

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

In general three types of waves can be transmitted in an unbounded 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 velocities 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 measured 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. The accuracy of the dimensional checks shall be provided as part of the block documentation.

A.3 Velocities measurement

A.3.1 General

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

The following equation is used:

$$V = 2\ d/t$$

The time of flight is measured in the 3 directions (X,Y,Z) at three positions In accordance with Figure A.2.

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

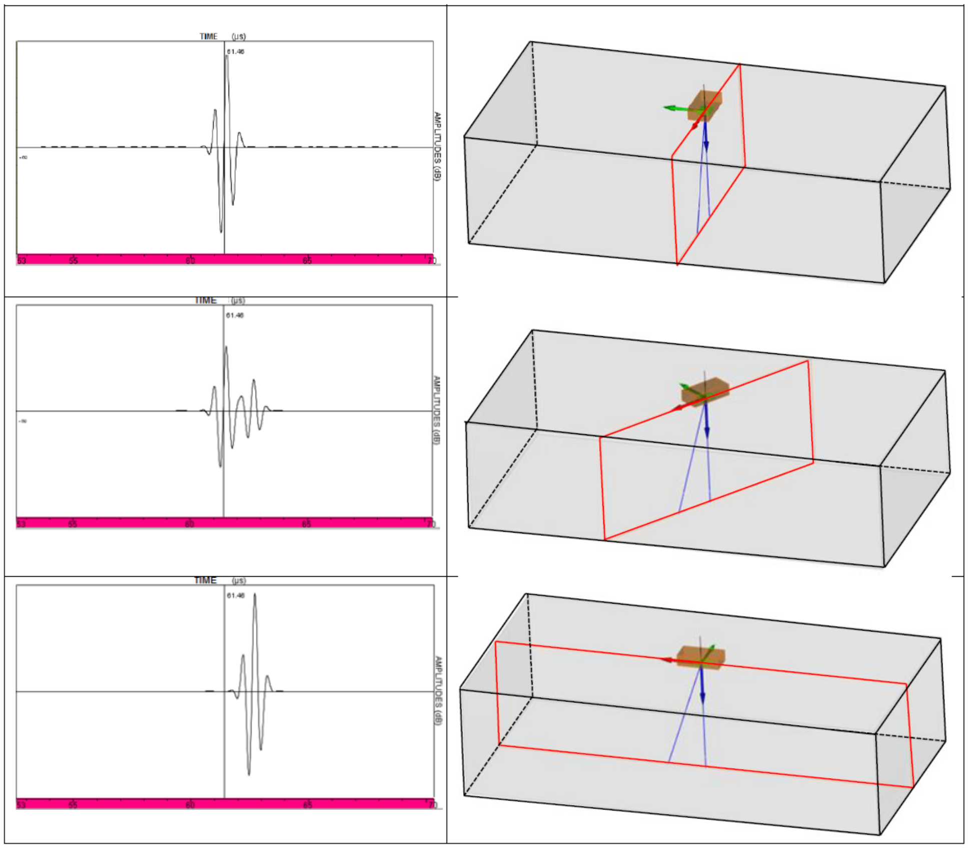
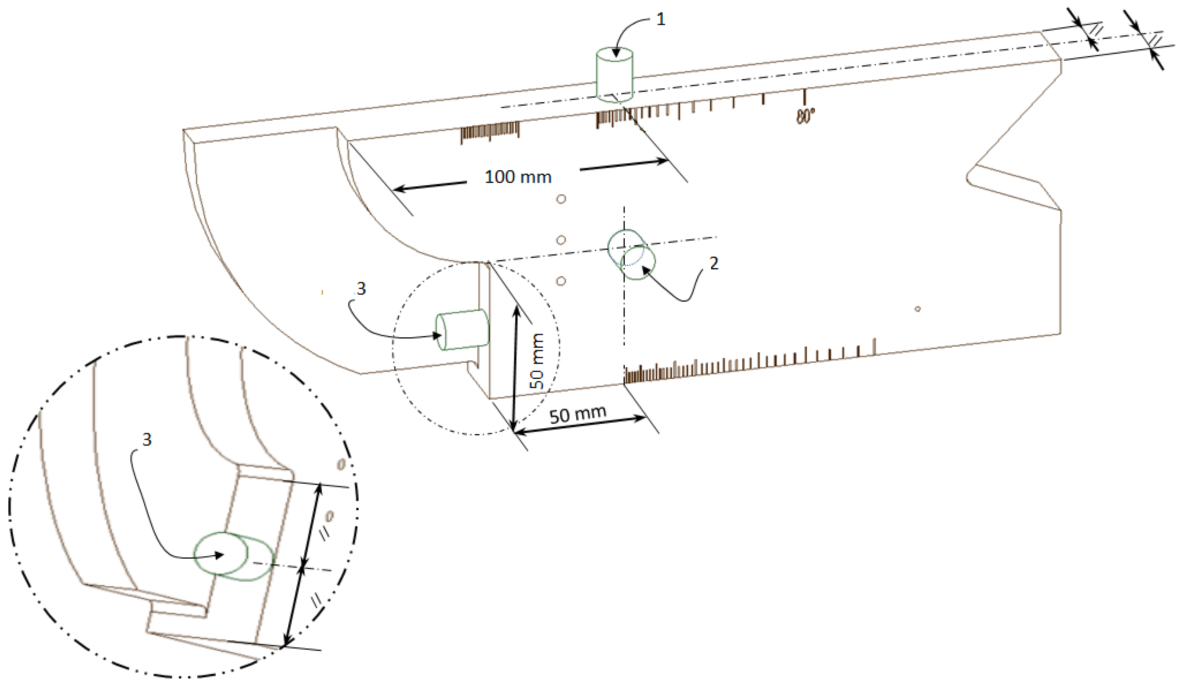


Figure A.1 — Illustration of the birefringence effect observed in an anisotropic medium with transverse waves, when rotating the probe in one position



Key
1, 2, 3 probe positions

Figure A.2 — Probe positions for velocity measurements

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 second (#) backwall echo at 3 positions in accordance with Figure A.3.1.

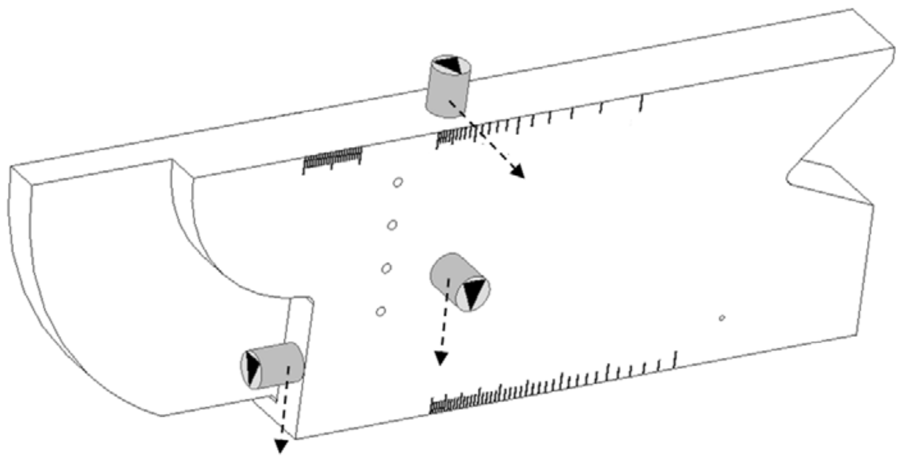
A.3.3 Transverse waves

To couple transverse waves, suitable coupling media of high viscosity are required. For the 3 positions defined in Figure A.2, use a 0° 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 second (#) backwall echo.

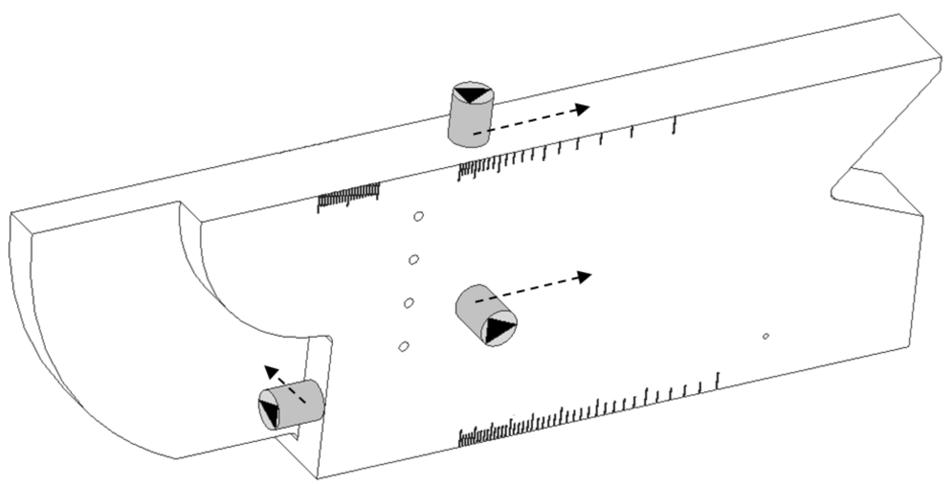
Because transverse waves are polarized, make two measurements in each location of the probe with the plane of polarization in the second measurement perpendicular to the first measurement and parallel to one side of the block in accordance with Figures A.2 and A.3.

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

NOTE (#) Multiple backwall echoes may be used, (*) 1 mm/µs ≡ 1000 m/s



a) First polarisation plane to determine V_{T1}



b) Second polarisation plane to determine V_{T2}

Figure A.3 — Probes position and orientation for transverse waves velocities measurement

A.3.4 Report of velocities measurement 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 references velocities [1] are:

— V_{L0} : 5920 m/s;

— V_{T0} : 3255 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;

Velocities measurement shall be recorded in accordance with Table A.1.

Table A.1 — Template to report measurement results

Position	L - Longitudinal		T – Transverse			
	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 sound velocities of longitudinal waves shall stay within the interval (5890; 5950) m/s.

All calculated sound velocities of transverse waves shall stay within the interval (3240; 3270) m/s.

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

Annex B
(informative)

Description of how to use the phased array ultrasonic testing (PAUT) calibration block

Tables B.1 to B.4 provide examples of phased-array ultrasonic test system functions that can be checked by the calibration block. A comparison is provided with similar functions checked using a calibration block in accordance with ISO 2400.

NOTE A comprehensive guideline is available from IIW [3].

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

Function	Existing Mono-element	Recommended PAUT
Probe Index (transverse wave)	Centre of 100mm radius	Same process
Beam Angle (transverse wave)	Index aligns with engraving with beam directed at 50mm or 1.5mm diameter holes.	Same process using 3mm SDHs
Beam Squint	Probe casing angle with respect to block wedge when corner reflection peaked	Same process possible using protractor and straight edge
Linearity of Timebase	Graticule spacing interval for 25mm multiples	Same process
Calibration of Timebase	Range-delay adjustments with extra option to calibrate with 91mm step from longitudinal mode to equal 50mm transverse	Same process but the plastic insert is not available for compression mode to 50mm equivalent (note: the setup using the 91mm step and plastic insert are anachronistic for mono-elements)
Linearity of attenuator	Adjust 1.5mm diameter SDH to 80% and then add 2dB and subtract, 2, 6, 18 & 24dB	Same process
Linearity of screen height	Ratio of 2 signals maintained with increasing dB to put larger signal at 10% steps of FSH	Same process
Pulse duration	RF pulse duration at 10% peak amplitude from backwall	Same process
Measurement of dominant Frequency	Count number of cycles in 1µs (the 6mm step was 2µs in pulse-echo Longitudinal mode)	Convert timebase to time and use signal from radius or thickness
Signal to noise ratio (SNR)	Set 1.5 mm SDH peaked to 10% FSH. Remove and dry probe and add gain until noise reaches 10% FSH	Same process with side drilled hole now 1.6 mm

Table B.2 — Additional Functions for PAUT

Function	Existing Mono-element	Recommended PAUT
Wedge Delay	–	Wedge delay can be determined with PAUT instrument software using a SDH at a fixed depth or to a fixed distance such as the 100mm radius.
Sensitivity equalisation for E-scans	–	Uniform sensitivity for E-scans– set using SDH.
Sensitivity equalisation for S-scans (ACG)	–	Uniform sensitivity for S-scans– set using 50mm or 100mm radius.
Assess for grating lobes	–	Assessment of potential grating lobes is 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 1 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.
Delay law calculator/plotting accuracy assessment	–	Delay law accuracy compares plotted position relative to probe reference point (e.g. nose of wedge) for well-defined parameters - wedge and steel velocity, wedge angle).
Element assignment	–	1 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 backwall.
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 — Guideline for recommended usage of the PAUT calibration block

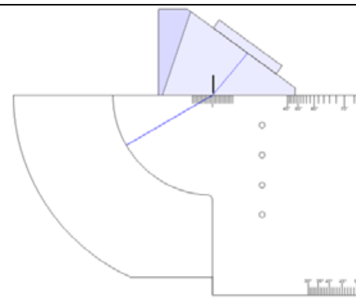
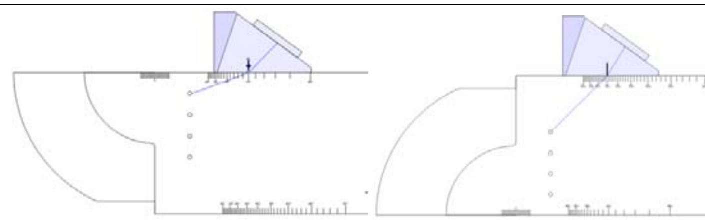
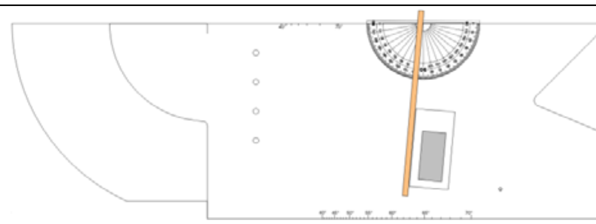
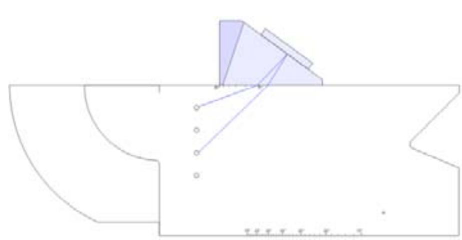
Function	Recommended practice
Probe Index (transverse wave)	
Beam Angle (transverse wave)	 70° and 45° positions
Beam Squint	 Maximise corner-use protractor to assess skew angle
Linearity of Timebase	Interval to peaks using multiples of 25mm (or thinner) thickness
Calibration of Timebase	Longitudinal mode-25mm & 100mm intervals (maybe more) Transverse mode – 50mm and 100mm radii
Linearity of attenuator	Fixed signal from 3mm 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 backwall signal from any surface including 100mm radius and measure either the time from 10% levels or the equivalent soundpath for either longitudinal or transverse mode.
Measurement of dominant Frequency	Count cycles in a known 1μs time interval (use same signal as pulse-duration assessment signal)
SNR	Set 1.6mm SDH peaked to 10% FSH. Remove and dry probe and add gain until noise reaches 10% FSH

Table B.4 — Additional Functions for PAUT

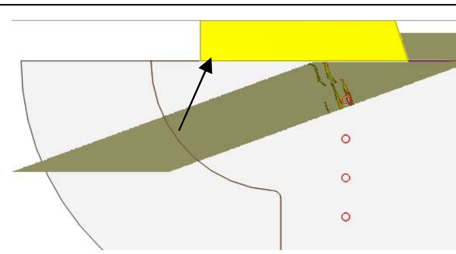
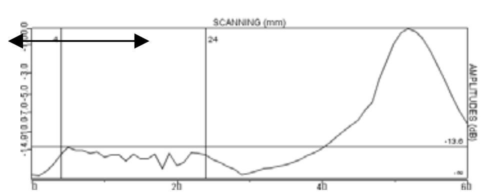
Additional Functions for PAUT	Recommended practice
Wedge Delay	Any SDH or even the radius can be used to check a constant distance or depth to a known target for the delay law software to confirm wedge distances for a specific angle or range of angles.
Sensitivity equalisation for E-scans	Any SDH can be used to monitor for attenuation effects of the changes in wedge path. These attenuation effects are to be added to the delay laws over the range of elements multiplexed.
Sensitivity equalisation for S-scans (ACG)	A constant soundpath 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 a SDH will have increasing soundpath to the target and this introduces another variable to the process that is only supposed to be correcting for wedge and angle losses. Proximity of the 3mm SDHs is now 25mm from the radius centre. This will need to be assessed for interference with setting ACG for delay laws with long wedge path distances where the exit point migrates over several millimetres.
Assess for grating lobes	 Collect B-scan  Assess lobe amplitude Specify dB level to which a grating lobe must be below peak signal on intended refracted axis to be acceptable (e.g. -20dB)

Table B.4 — *continued*

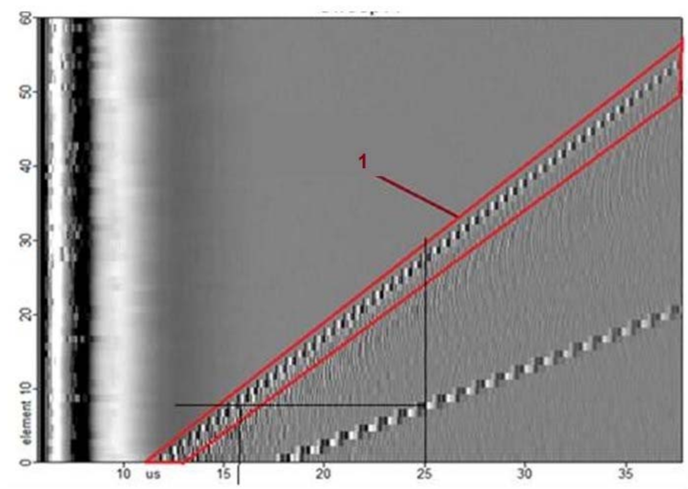
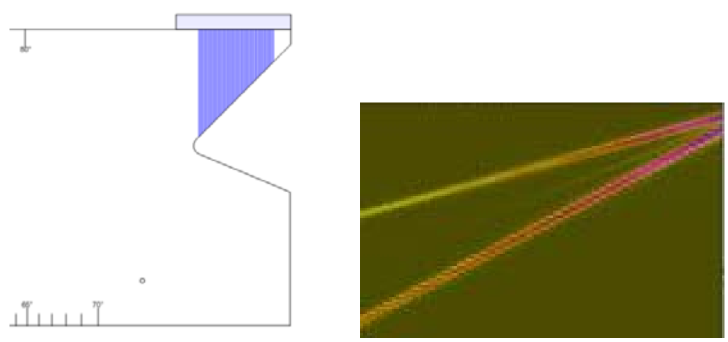
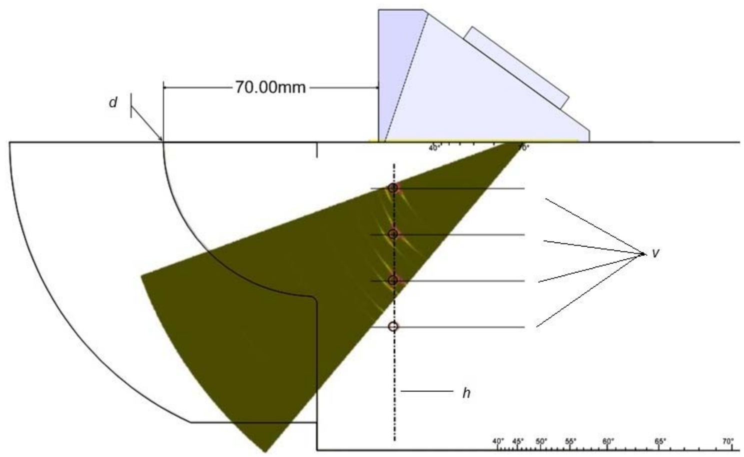
Additional Functions for PAUT	**Recommended practice**
Active element assessment	Active elements ring when struck by a voltage impulse. A 1-element-1-step E-scan over each element in a probe producing a B-scan on a wedge is adequate to identify elements that do not ring. For 0° probes the B-scan on the 25mm thickness is adequate.  1 wedge interface signal
Element assignment (in accordance with ISO 16392-3)	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 must 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 backwall and achieve a similar response to that with a wedge in place. 

Table B.4 — *continued*

<table>
<tr><th>Additional Functions for PAUT</th><th>Recommended practice</th></tr>
<tr><td>Delay law calculator/plotting accuracy assessment</td><td>
Aligned position of 3mm SDHs can provide an indication of position plotting accuracy and delay law generation.
Software will usually provide coordinates in the X direction to indicate standoff distance from some probe reference point. To confirm plotting is suitable all peaked signals should be within 1mm of the actual position of the SDH relative to the probe/software reference coordinate).


Key
d convenient standoff 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
NOTE 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.
</td></tr>
<tr><td>Anisotropy assessment</td><td>In order to assess anisotropy, measurements the arrival times of longitudinal and transverse modes are obtained using separate longitudinal wave and 0° transverse wave probes as described in Appendix A.</td></tr>
</table>

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] *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)