New ISO Calibration Block for Phased Array Ultrasonic Testing

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Abstract. With the introduction of Phased Array Ultrasonic Testing and its subsequent widespread adoption in industry, there has been a significant change in the way that ultrasonic inspection is performed. There are international standards that describe how to perform PAUT, but no such standards describing what blocks should be used for calibrating PAUT systems. As such, people in different parts of the world deal with PAUT calibration in a variety of ways.

The original question was: is the existing ISO 2400 block well suited for PAUT calibration or is another block required?

The answer to this question turned out to be that the ISO 2400 block did not satisfy all PAUT calibration requirements. So a project started within Sub-commission VC of the International Institute of Welding (IIW) to design a calibration block specifically for phased array inspection. This calibration block is being voted on at ISO, which should result in a new international standard ISO 19675. (ISO 2400 will remain in force). We will describe the main steps of the IIW project to design this block, along with the suggested usage of the block and its main features.

1. Introduction

For many years the IIW[1] block, often known as the V1 block, now often referred to as the ISO 2400 block, has been used for conventional ultrasonic calibrations. This block meets basic code requirements for calibration of ultrasonic systems when performing standard inspections, such as material velocity and wedge delay calibration over a range of material thicknesses. This block also has other features such as probe index measurement, probe

[1] The IIW (International Institute of Welding) is an international organization that focuses on welding based topics, and has a series of technical commissions dealing with all aspects of welding. Commission V focuses on NDT and quality assurance of welded products, with Sub-commission VC dealing with ultrasonic based weld inspection techniques. IIW is a recognized ISO International Standardization Body. IIW can manage standardisation projects.

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angle verification and the ability to set sensitivity in accordance with AWS D1.1 requirements.

2. Historical background of the authentic IIW block

The history of the IIW block was that it was originally designed in Commission V of the International Institute of Welding. Two proposals for reference blocks were received during 1955-1956, one from the Dutch delegation (Fig. 1A), the other from the British delegation (Fig. 1B). Sub Commission VC made a comparative study of the possibilities offered by the use of each of these blocks. After several series of tests undertaken by experts of the sub commission, the results obtained [1], [2], [3] favoured the block proposed by the Netherlands delegation, which appeared to offer possibilities of wider application than the British block as it was included in the BS 2704 issued in 1956.

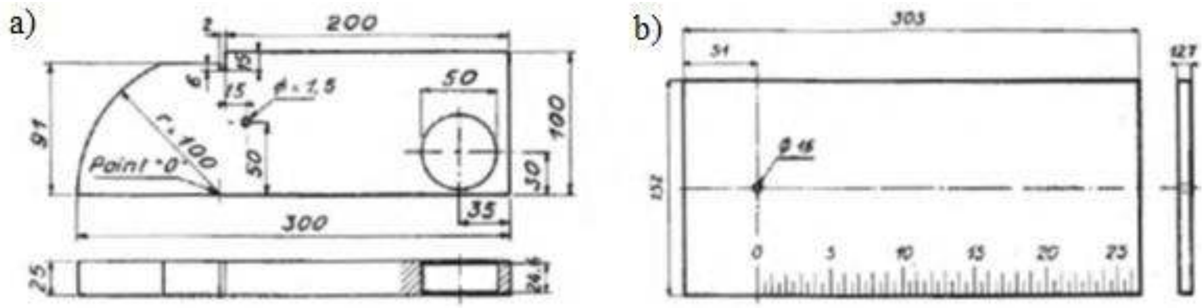


Fig.1: First designs of the authentic IIW block

Many derivative designs from the authentic IIW block were further used and introduced in national standards (NF A09-310, BS 2704, DIN 54120, NEN 2510, JIS Z 2345, AWS D1.1 …).
F.H.C Hotchkiss [4] made an extensive review of the various designs and pointed out the differences and possible advantages. Problems caused by material anisotropy were also discussed. It is apparent from the results of these studies that variations in calibration settings of angle beam search units are not due solely to differences in geometry among the population of blocks currently used; ultrasonic properties like material attenuation and anisotropy also play an important role.
T.P. Lerch et al [5] gave results on measurements made on 18 blocks made from different steels; they found variations in velocities and attenuation but they noticed that the influence was limited. However, they welcomed the decision of the CEN committee to:
- specifying the type of steel the blocks shall be machined from,
- detailing the processing steps for the steel prior to machining,
- identifying the ultrasonic measurements to be made to determine the ultrasonic quality of the steel,
- setting acceptance criteria for the ultrasonic measurements.

These recommendations are now included in ISO 2400 [6] first issued in 1972 (last revision in 2012) and kept in ISO 19675. This standard requires: austenising heat treatment in at 920 °C for 30 min; rapid cooling (quenching) in water; tempering by heating to 650 °C for 3 h and cooling in still air. If these requirements are properly followed, the block should show an isotropic behavior and discrepancies as pointed out by T.P. Lerch should be eliminated. Unfortunately some blocks that claimed to be in accordance with this standard were found to be non isotropic. That is why a little bit more is now required in the PAUT standard.

3. Origin of the PAUT IIW block project

Discussion within IIW Commission V started in roughly 2009 about phased array ultrasonic testing (PAUT) and the PAUT IIW block. With the introduction of PAUT and its subsequent widespread adoption in industry, there has been a significant change in the way that ultrasonic testing is performed. There are international standards that describe how to perform PAUT, but no such standards describing what blocks should be used for calibrating PAUT systems. As such, people in different parts of the world deal with PAUT calibration in a variety of ways.

The original question that was asked in Commission V was: is the existing IIW block well suited for PAUT calibration or is another block required? The answer to this question turned out to be that the IIW block did not satisfy all PAUT calibration requirements, so Commission V started a project to design a calibration block especially for PAUT. A working group was formed with representation from many countries. This working group was active over a period of roughly five years, and performed the majority of the work electronically via Web based meetings. Reports were presented to IIW Commission V annually at the Annual Assembly where approval for the on-going work was received. A progress report [7] was presented outside IIW at the last NDT conference in Canada.

4. PAUT block project development

4.1 Project Background and objectives

Initial work focused on defining the project scope and goals. The statement of purpose for this project was: design a practical and affordable phased array calibration block that can handle the basic calibration functions required by existing standards, which is widely applicable to many industries and countries. The basic PAUT calibrations are: material velocity calibration, wedge delay and angle corrected gain calibration.

Other requirements for the block were as follows. The block must:

- be portable and cost effective,
- satisfy code requirements,
- be designed to allow to check phased array probes as specified in other ISO standards [8],
- be designed to allow the buyer to check by quick and simple means that the ultrasonic properties of the block are in accordance with the requirements.

It was clear that the manufacture of the PAUT calibration block must be governed by an ISO standard in order for the block to be widely accepted in the world. IIW has a relationship with ISO, in that the IIW can write technical standards and submit them to ISO through what it is called Route II.

It was also clear that the calibration block must fulfill all necessary code and standards requirements. The main codes and standards that were considered are ISO, EN and ASME. They deal with PAUT slightly differently and have different requirements. In general, ASME doesn’t specify calibration blocks but rather guidelines on what calibration must accomplish. The ASME working group decided to defer to the IIW working group for calibration block design. EN standards are more prescriptive and detailed with regards to calibration block requirements. CEN has drafted three phased array standards. These are the three parts of ISO 18563. Part 3 [8] is the most relevant for this work, and it requires several additional checks compared to ASME:

- Channel assignment and relative sensitivity variations,
- Some beam characterization measurements, including squint angle and grating lobes,
- Simultaneous measurement of the index point and the angle of refraction,
- Check of imaging and imaging algorithms, which is mainly required for S-scans.

4.2 Other Considerations

There were discussions about other capabilities that could be built into the block. With phased array, there are many application specific measurements that are outside code requirements but that can be required for specific applications. Examples of some of these possible measurements are: determining angular resolution, determining angular sensitivity, setting inspection sensitivity, setting notch sensitivity, maximum steering angles, etc.

When discussing these capabilities, it quickly became unclear how to handle these requirements. For each such capability that could be built into the block, there were many possibilities that could be required by a specific application. For example, when considering angular resolution, any measurement is a function of incidence angle, sound path, the size and spacing of the reflectors being used. If side drilled holes (SDH) of a specific diameter and spacing were used at a given sound path and angular direction, this only provides information about angular resolution in this narrow slice of phase space making it a limited measurement of angular resolution. This issue is similar for all of these measurements, meaning that no comprehensive solution is possible in a single block. For this reason, it was decided to not include these capabilities into the calibration block. These requirements are job specific, and must be addressed as such.

The exception to this is inspection sensitivity. The vertically oriented SDH's have been added into the block for other reasons (beam angle determination, linearity of screen height, plotting check ….), but they provide a limited capability to set sensitivity. The diameter of these holes is 3 mm, which allows sensitivity to be set as per European codes and a limited sensitivity range for ASME code.

5. Block design

5.1 Main design steps

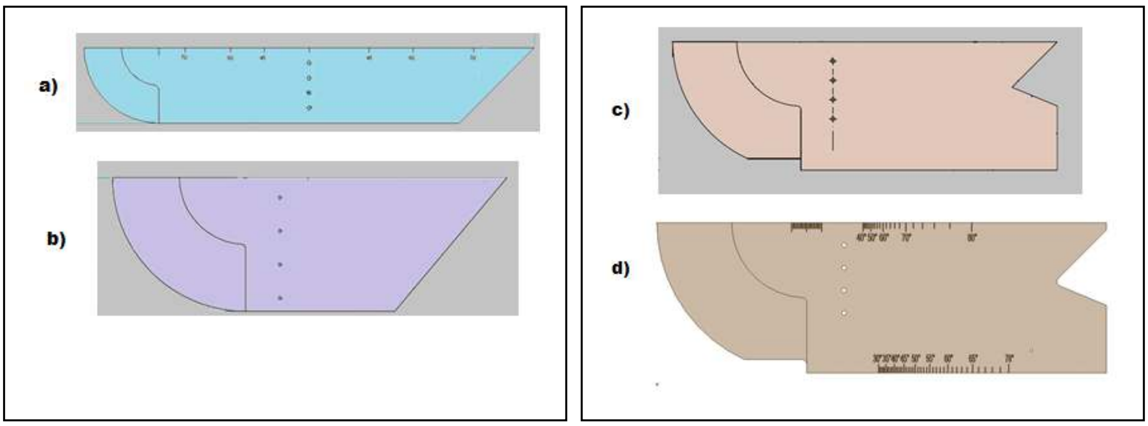


Fig. 2: main design steps of the PAUT block

The early proposal (a) was made to Sub-commission VC by Colin Bird. It was rapidly decided to increase the block height (b) from 50 mm to 100 mm. Then the slope designed to make possible element assignment was broken in two parts and the 100 mm quarter was adapted to allow performing velocity measurements in the 3 main directions of the block (c). Then the final design was refined and the marks defined (d).

The standard ISO 19675 is now in the final voting stage (FDIS) and it will hopefully be a full ISO standard later in 2016.

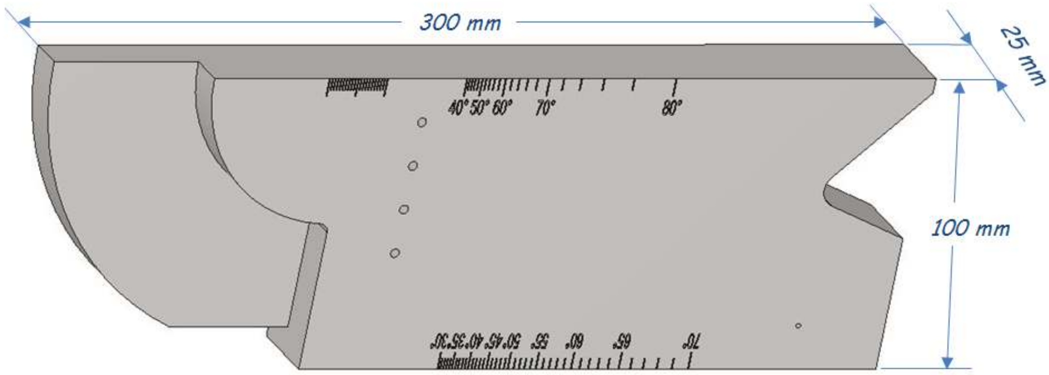


Fig. 3: PAUT calibration block design as considered in ISO/FDIS 19675

At the first glance, the PAUT IIW block looks very similar to the former IIW conventional UT block, but it allows carrying out far more checking and calibration functions. Thank's to modelling for the great help to speed up the design validation.

5.2 Modelling

To the best of the working group's knowledge, this is the first ultrasonic calibration block designed primarily using ultrasonic beam modelling software. CIVA™ was used for this work, which is a software developed by CEA in France. CIVA™ is a sophisticated full beam propagation model that uses a semi-analytical method based on the synthesis of the impulse response function, allowing modelling of defect interaction as well as 3D anisotropy modelling. This was done in two stages as per a matrix agreed upon by working group members. The first stage was to model the overall positioning of reflectors for high level block design. The goal of this stage was to set an overall block design that incorporates all of the required functions in a way that allows both ease of use and avoiding artefacts. An example of the type of modelling done in this stage was to model the response from the vertically oriented SDH to ensure that a quick calibration check can be done for S-scans without interfering echoes, as shown in Fig. 4. Part of this stage was also to choose the outside dimensions of the block.

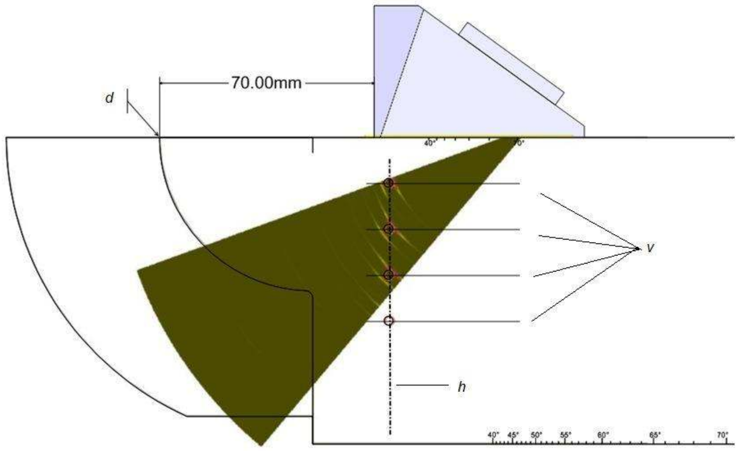


Fig. 4. Modelling of S-scan response from the vertically oriented SDH

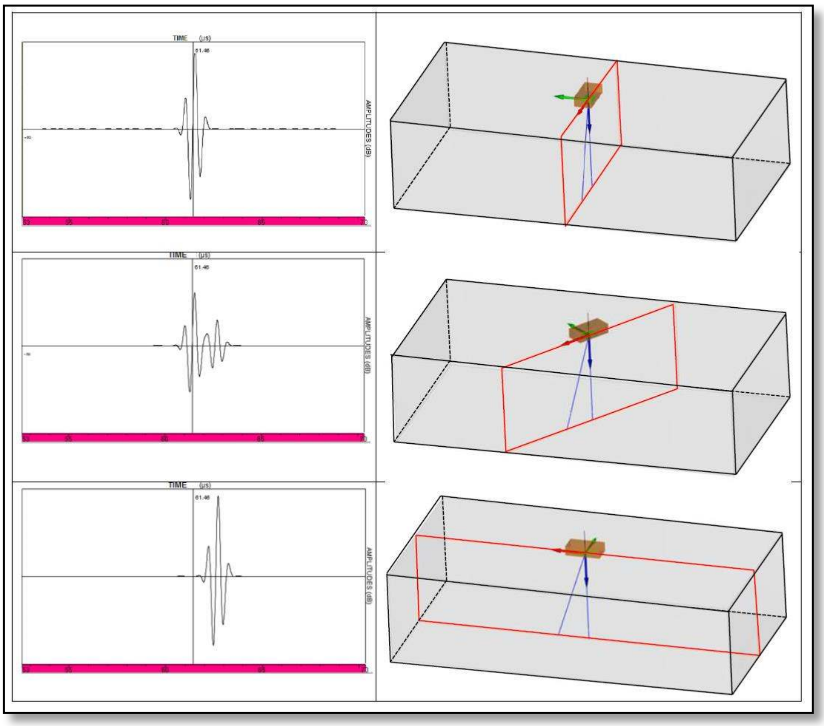


Fig. 5. Illustration by modelling of the birefringent effect observed in an anisotropic medium with transverse waves when rotating the probe in one position

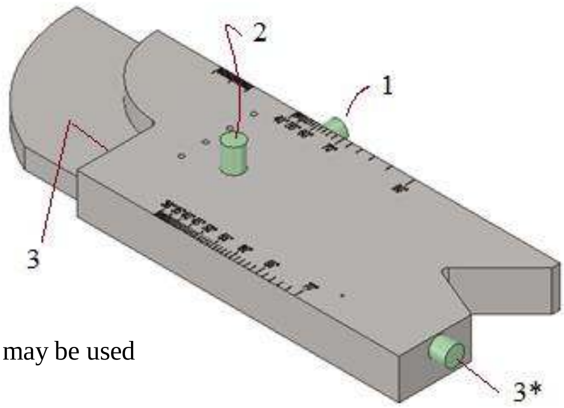
6. Block usages

IIW had explained [9] how the first conventional UT block may be used to check in a general way some functions of conventional pulse echo equipment. So Commission V decided to keep the same philosophy introducing two annexes in ISO 19675 in order to give to the block user's quick information concerning possible usage of the new block as shown on Fig. 6.

Fig. 6: The new PAUT block machined in accordance with ISO 19675

Annex A is normative and describes how to check material anisotropy and gives instructions to the block manufacturer how to determine ultrasonic velocities (these values are required as part of the documents that shall be supplied with the block).

Annex B is informative. The goals are to compare the usage of the PAUT calibration block with that of the ISO 2400 block, and to briefly illustrate some of the other possible usages such as: wedge delay, grating lobes assessment, active element assessment, sensitivity equalisation, plotting check, element assignment, etc.



Position 3 or 3* may be used

Fig. 7: probes positions for anisotropy checking

Anisotropy checking (annex A)

Provided the requirements made in ISO 19675 concerning the material, heat treatment and surface finish of the PAUT calibration block are met, anisotropy shouldn't be relevant and the velocities determined should be in the range mentioned in the standard (VL0= 5920 m/s ± 30 m/s and VT0 = 3255 ± 15 m/s) . The great advantage of the design of the PAUT block is that allows the buyer of the block to perform a simple test to verify the compliance with the standard requirements. As a matter of fact, determination of the velocity in the block is possible in three orthogonal directions.

Assessment requires the use of a longitudinal wave straight beam probe and a transverse probe. Probes selected shall be broadband and not more than 12.5mm diameter. Appropriate coupling medium shall be used. Placing the probes in the 3 positions indicated in Fig. 7, time readings shall be made for the interval between the backwall and first multiple. When making the readings with transverse wave straight beam probe, the probe will be rotated through 90° and the arrival times compared for the fast and slow wave-modes. The arrival times for the three modes are then recorded and the velocities deduced by calculation. If anisotropy is present the effect may first be noted in a slight acoustic birefringence. This is the splitting of the fast and slow shear waves. In a block having low anisotropy, the difference between the fast and slow shear wave arrivals may not be possible to discern.

<u>Illustration of possible usages (annex B)</u>

- Beam angle (angle beam probe)

First the delay law for the angle beam being assessed shall be configured. Then the probe index shall be determined, by positioning the probe to maximise the echo response from the 100mm radius. Using a fine-tip marker, a line is drawn on the wedge where the centre point of the 100mm radius meets the wedge. Then the probe is moved to maximise the response from either the uppermost or lowermost 3mm diameter side drilled hole as in Fig. 8.
Read the value of the angle indicated on the scribed markings to the nearest 0.5° to determine the actual refracted angle can now be read.

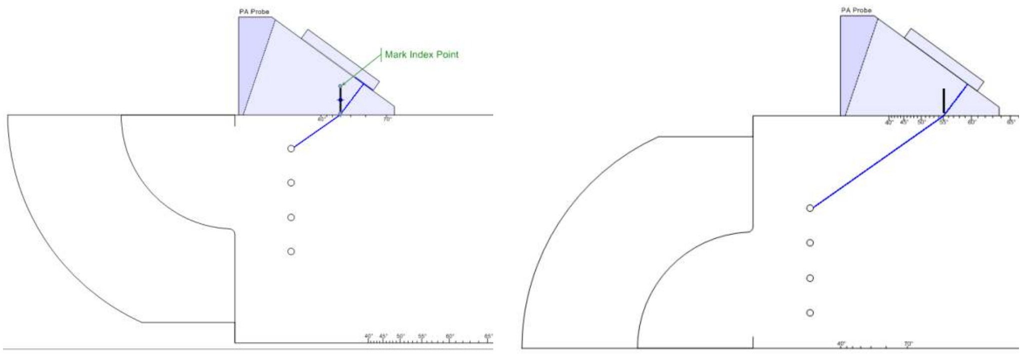


Fig. 8: Determining Probe Actual Refracted Angle

- Element assignment

A B-scan of the delay law acquisitions is displayed and the amplitude and time of the backwall signal for each element in the array is observed. If the element #1 is nearest the end of the PAUT calibration block it will have the shortest arrival time in pulse-echo and all subsequent elements should display a monotonic increase in arrival time. Fig. 9 illustrates a B-scan from a 64 element probe with the response seen from the V surface of the block. The response from each element is slightly greater in time than its next adjacent element indicating correct assignment of elements.

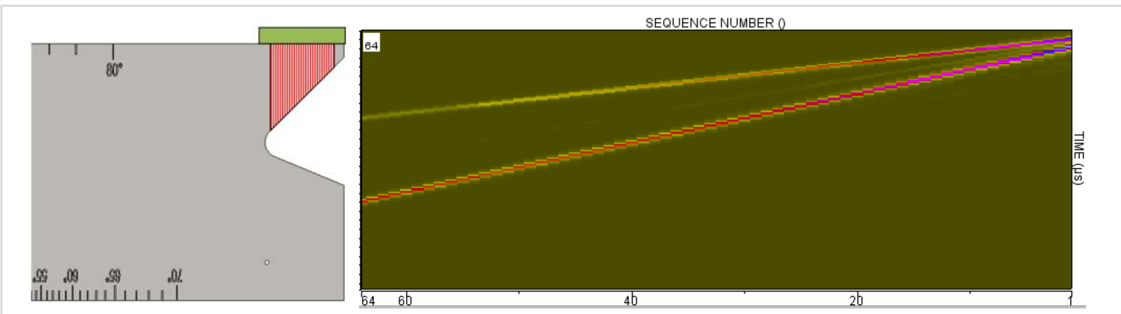


Fig. 9: Probe placement and corresponding B-Scan for element assignment

7. Conclusions

This project for design of a PAUT calibration block is now almost complete, with the ISO standard being issued later in 2016. It is the hope of the working group that this calibration block becomes a useful tool that is used in industry for calibration of PAUT inspections.

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