Ultrasonic transverse velocity calibration of standard blocks for use in non-destructive testing

C E R Silva, D S Braz, L E Maggi and R P B Costa Felix
Laboratory of Ultrasound (Labus), Directory of Scientific and Industrial Metrology (Dimci), National Institute of Metrology, Quality, and Technology (Inmetro), Av. Nossa Sra. das Graças, 50 (Building 1), Duque de Caxias, RJ, Brazil, ZIP 25250-020
E-mail: cesilva@inmetro.gov.br

Abstract. Standard blocks are employed in the verification of the equipment used in Ultrasound Non-Destructive Testing. To assure the metrology reliability of all the measurement process, it is necessary to calibrate or certify these Standard blocks. In this work, the transverse wave velocity and main dimensions were assessed according to the specifications ISO Standards. For transverse wave velocity measurement, a 5 MHz transverse wave transducer, a waveform generator, an oscilloscope and a computer with a program developed in LabVIEW™ were used. Concerning the transverse wave velocity calibration, only two Standard blocks of the 4 tested is in accordance with the standard.

1. Introduction
Standard blocks named V1 and V2 are employed in the calibration and verification of equipment used in Ultrasonic Non-Destructive testing (US NDT). To assure the metrology reliability of all the measurement process, it is necessary that standard blocks are used, preferentially if they were certified such as a CRM (Certified Reference Material) [1]. These follow the principle of CRM and the technical requisites of ISO 2400 [2] and ISO 7963 [3] standards. The transverse velocity is the main characteristic to be evaluated.

The aim this work was to calibrate 4 reference blocks, evaluating its main dimensions and acoustic properties. Therefore, four reference blocks, being two V1 blocks and two V2 blocks were used. The main dimensions and the transverse velocity were assessed.

2. Theoretical Approach
In V1 blocks, to dimensional calibration, the specified maximum admissible error is of ± 0.10 mm, in accordance with ISO 2400 standard. In V2 blocks, maximum permissible measurement error is of ± 0.10 mm, in accordance ISO 7963 standard.

The measurement transverse wave velocity shall be 3255 m/s ± 15m/s. The velocity shall be measured within a maximum permissible measurement error of ± 0.2%, i.e. with uncertainty of ± 6 m/s for transverse waves.

3. Methods
The dimensional calibrations of two V1 blocks (Nº 121 e Nº176) and two V2 blocks (Nº 255 and Nº182) were carried out in the Laboratory of Dimensional Metrology (Lamed)/INMETRO. A system
composed by laser interferometer (reference value), a table with a system of horizontal micrometric
displacement (maximum range: 300 mm), moved by c.c. motor and a microscope with camera CCD
coupled to a computer were used. Specific software to determine the measurements was used. The
scale is aligned to the laser and to the microscope in this system.

For transverse wave velocity assessment, the ultrasonic measurement system consisted of 5 MHz
transverse wave transducer with diameter of 12.7 mm (Olympus, V155), a waveform generator
(Agilent Technologies, USA, 33250A), an oscilloscope (Agilent Technologies, USA, DSO-X 3012A),
and a computer with a program (BCNDT_rev00.vi) developed in LabVIEW™ 11, (National
Instruments, Austin, TX, USA).

The waveform generator was used to excite the transducer using a 3-cycle sine wave burst with
20 Vpp of amplitude. The signal from echo was acquired and digitalized using the oscilloscope. All
signals and acquired data were recorded analysed using the software developed in LabVIEW™.
This system is used to measure the time of flight difference between the first and second back wall
echoes.Velocities were then calculated (i.e. path/time/2). The time of flight was measured in different
directions, i.e. at two well separated positions through the 25 mm thickness and one position through
the 100 mm thickness for V1 standard blocks. For V2 standard blocks, three different positions
through the 12.5 mm thickness were carried out. In each position, five measurements, under
repeatability conditions, were realized. Because shear waves are polarized, in each location of the
probe was made two measurements with the plane of polarization in the second measurement
perpendicular to the first measurement and parallel to one side of the block.

Each measurement series was carried out in three consecutive days.

3.1. Method validation
To BCNDT_rev00.vi software validation, at hand measurement (HM) using the cursors oscilloscope
to determine the time of flight difference between the first and second back wall echoes was carried
out.

Therefore, the results were statistically compared using the normalized error, in order to know the
measurement performance according equation (1) [4][5]:

\[ E_n = \frac{x - X}{\sqrt{U_{HM}^2 + U_S^2}} \]  

Where:
\( x \) - At Hand measurement data.
\( X \) - Software measurement data;
\( U_{HM} \) - Expanded uncertainty from Hand measurement data;
\( U_S \) - Expanded uncertainty from software measurement data

For \( E_n \) numbers:
- \(|E_n| \leq 1.0\) - indicates “satisfactory” performance;
- \(|E_n| > 1.0\) – indicates “unsatisfactory” performance.

4. Determination of standard uncertainty of Type A and Type B.
All uncertainties were assessed according to GUM [4]. The time base resolution of the oscilloscope is
assumed to present a rectangular distribution; hence the Type B uncertainty is estimated by dividing
the resolution by \( 2\sqrt{3} \). The distance is obtained from calibration certified and thus its Type B
uncertainty is defined as expanded uncertainty divided by \( K \).

The Type A uncertainties were estimated as the standard deviation from 5 repeated measurements,
divided by \( \sqrt{5} \). Type B uncertainties were estimated, as following in Table 1:
Table 1. Uncertainty components of Type B.

| Uncertainty components                      | Probability Distribution | Sensitivity coefficients |
|---------------------------------------------|--------------------------|--------------------------|
| Time base resolution of the oscilloscope    | Rectangular              | -d . t -2a               |
| Distance from calibration certified         | Rectangular              | 1 .d-1a                  |

Where: \( d \)  distance of sound propagation (m); \( t \)  time (s).

Finally, the expanded uncertainty was calculated considering a coverage factor \( k = 2 \) (95.45% confidence level).

The combination between all calculated uncertainties to determine the transverse velocity uncertainty was obtained using the equation (2):

\[
U = \sqrt{\left(\frac{s}{\sqrt{n}}\right)^2 + \max\left(\frac{U_i}{k_i}\right)}
\]  

(2)

Where:
- \( s \) - Standard deviation between the average the found values.
- \( n \) - Number of independent repeated observations
- \( \max\left(\frac{U_i}{k_i}\right) \) - Maximum found uncertainty divided by respective coverage factor.

5. Results and Discussion

The main dimensions to calculate V1 and V2 blocks transverse velocity are given in Table 2. In V2 and V1 blocks it could be observed that the systematic measurement error of the main dimensions were lower than the maximum permissible measurement error established by ISO 7963 and 2400 standards, which is ± 0.10 mm.

The transverse velocity measurements results and its respective uncertainty realized for different modes (HM and S) are shown in Table 3. The software developed in LabVIEW™ was validated. Consequently, the software can be used to calibrate the standard blocks.

The transverse velocity values of V1 and V2 standard blocks and its respective uncertainties are in Table 4.

The nominal transverse wave velocity values (according the ISO Standards) were compared with the average obtained values from 03 (three) days of measurements. The systematic measurements errors were compared with of maximum permissible measurement error as specified ISO 2400 and 7963 standards (15 m/s). As it can be seen in all measurements only V1 0176/09 and V2 182/09 Standard blocks showed transverse wave velocity average values below the maximum error admissible and measurement uncertainty (0.2% or ± 6 m / s).
Table 2. Nominal value and systematic measurement error of V1 and V2 standard blocks main dimensions.

| Block | Serial number | quota | Nominal value | Measured quantity value [mm] | Measurement uncertainty [mm] | k | Systematic error [6]. |
|-------|---------------|-------|---------------|-------------------------------|-------------------------------|---|-----------------------|
| V1    | 121/06        | a     | 100           | 100.0020                      | 0.0030                        | 2.0 | 0.005                 |
|       |               | b     | 25            | 25.0360                       | 0.0030                        | 2.0 | 0.039                 |
|       | 0176/09       | a     | 100           | 99.9950                       | 0.0020                        | 2.0 | 0.007                 |
|       |               | b     | 25            | 25.0000                       | 0.0020                        | 2.0 | 0.002                 |
| V2    | 0182/09       | c     | 12.5          | 12.5190                       | 0.0030                        | 2.0 | 0.022                 |
|       | 225           | c     | 12.5          | 12.5030                       | 0.0020                        | 2.0 | 0.005                 |

Table 3. Software validation results.

| Mode | Velocity [m/s] | Expanded Uncertainty [m/s] | EN number | Performance |
|------|----------------|-----------------------------|-----------|-------------|
| V1   |                |                             |           |             |
| 121/06 | HM 3242.4       | 1.3                         | 0.09      | Satisfactory |
|       | S 3242.8       | 4.3                         |           |             |
| 0176/09 | HM 3244          | 31                          | 0.13      | Satisfactory |
|       | S 3254          | 69                          |           |             |
| V2   |                |                             |           |             |
| 0182/09 | HM 3240.40      | 0.90                        | 0.98      | Satisfactory |
|       | S 3242.8       | 2.3                         |           |             |
| 225  | HM 3251         | 15                          | 0.04      | Satisfactory |

Table 4. Transverse wave velocity and measurement uncertainty of V1 and V2 Standard blocks.

| Standard Block/Serical number | Nominal value/maximum permissible measurement error [m/s] | Average transverse wave velocity [m/s] | Expanded uncertainty [m/s] | k | % | Systematic error [6]. |
|-------------------------------|----------------------------------------------------------|----------------------------------------|-----------------------------|---|---|-----------------------|
| V1 121/06 3255 ± 15          | 3254                                                     | 69                                     | 1.96                        | 2.09 | 1                      |
| V1 0176/09 3255 ± 15         | 3242.8                                                   | 4.3                                    | 1.96                        | 0.13 | 12.2                    |
| V2 0182/09 3255 ± 15         | 3242.8                                                   | 2.3                                    | 1.96                        | 0.07 | 12.2                    |
| V2 225 3255 ± 15             | 3252                                                     | 22                                     | 1.96                        | 0.67 | 2                      |

6. Conclusion
This work concludes that V1 and V2 blocks in calibrated main dimensions are in agreement with the technical specifications of ISO 7963 and ISO 2004 standards. Concerning the transverse wave velocity calibration only V1 0176/09 and V2 182/09 Standard blocks are in accordance with these standards.
Acknowledgements

The authors would like to acknowledge the financial support from the CNPq and Faperj. Especial thanks to Lamed/Dimec/Inmetro.

References

[1] Instituto Nacional de Metrologia, Normalização e Qualidade Industrial – (Inmetro). URL: http://www.inmetro.gov.br/ [accessed on 16/May/2013].
[2] ISO 2400, Non-destructive testing. Ultrasonic testing. Specification for calibration block No. 1. 2012.
[3] ISO 7963, Non-destructive testing. Ultrasonic testing. Specification for calibration block No. 2. 2010.
[4] Evaluation of measurement data – Guide to the expression of uncertainty in measurement (GUM) – JCGM 100:2008, First Edition, Sep – 2008.
[5] ISO/IEC17043, Conformity assessment - General requirements for proficiency testing, 2010.
[6] International vocabulary of metrology - Basic and general concepts and associated terms (VIM) – JCGM 200:2012.