MEASUREMENT UNCERTAINTY DETERMINATION OF THE THICKNESS GAUGING BY ULTRASOUND AS A NON-DESTRUCTIVE TESTING

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Abstract: This paper intends to report the measurement uncertainties associated to ultrasonic thickness gauging. The way the measurement system is composed and the associate quantity were assessed. The measurement uncertainty was estimated according to Guide to the Expression of Uncertainty in Measurement, GUM.

Key words: thickness measurement, ultrasound, uncertainty measurement.

1. INTRODUCTION

Ultrasonic thickness gauging are frequently employed in situations where an inspector has access to only one side of a part whose thickness must be determined, such as the case of a pipe or tube, or where simple mechanical measurement is impossible or impractical for other reasons such as the size of a part or access limitations. The fact that thickness gauging can quickly and easily be made from one side, with no need to cut parts, is one of the major advantages of this technology [1].

The transducer contains a piezoelectric element which is excited by a short electrical impulse to generate a burst of ultrasonic waves. The sound waves are coupled into the test material and travels through it until they encounter a back wall or another boundary. The reflections then travel back to the transducer, which converts the sound energy back into electrical energy. The gauge is programmed with the speed of the sound in the test material, from which it can calculate the thickness using the simple mathematical relationship e = (V) x (t/2), where e = the thickness of the part, V = the velocity of sound in the test material, t = the measured round-trip transit time.

Accordingly to ABNT NBR 15824:2010 standard [2] the measurement value should be obtained from at least two consecutive readings, where the deviation is equal or less than 0.2 mm. If the thickness is not acceptable in the first two measurements, it may be repeated until this specification is satisfied.

Therefore, the importance to determine the quantitative indication concerning the quality of these results was observed in such a way that the users can assess its reliability. Thus, there must be an understood procedure and general acceptance to assess and express the uncertainty. In this sense, the Guide to the Expression of Uncertainty in Measurement, GUM [3] describes a method to evaluate the uncertainty of a measurement based on the uncertainty propagation.

The methodology, firstly, defines the mensurand that in the present study is the thickness, which depends on the ultrasonic propagation velocity in the tested material and acoustic time-of-flight.

From this definition, this study aims at reporting the measurement uncertainties associated with the testing of ultrasonic thickness gauging and show the importance of the measurement system calibration, as part of the measurement uncertainty contribution comes from the calibration certificate of both devices and instruments.

2. METHODS

To implement this work the following instruments were used: an arbitrary function generator, a digital oscilloscope, two V1 standard blocks, a nominal central frequency transducer at 5 MHz (Φ12.7 mm). Temperature and tested thickness were from 22 to 26 ° C and 25 to 100 mm, respectively. First, to qualify the procedure, five measurements in 03 different thicknesses of V1 standard block (25, 90 and 100 mm) were performed.. The deviation in this range of thickness cannot be larger than 0.2 mm. After qualifying the procedure, the actual measurement of the thickness were carried out at 25 mm thickness of the two blocks, which is within the range of qualification. In the following procedure, the measurement instrument has no internal system of "V – Path” compensation. This type of instrument cannot be used with the procedure conducted to assess the measurement uncertainty in this study. All procedures were performed according to ABNT NBR 15824:2010 standard. A program (Tick.ed1) to acquire and analyze the signals was developed in Labview 2009. V1 blocks (No. 121 and No. 176) were dimensionally calibrated in Dimensional Metrology Laboratory (Lamed) Inmetro.

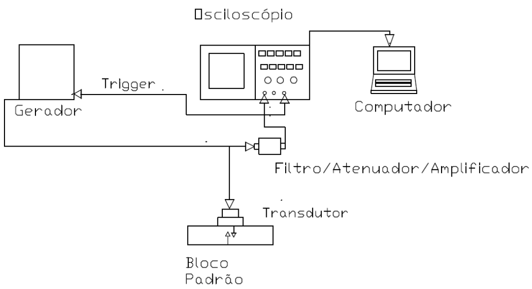

Figure 1. Experimental setup to determine the thickness measurement.

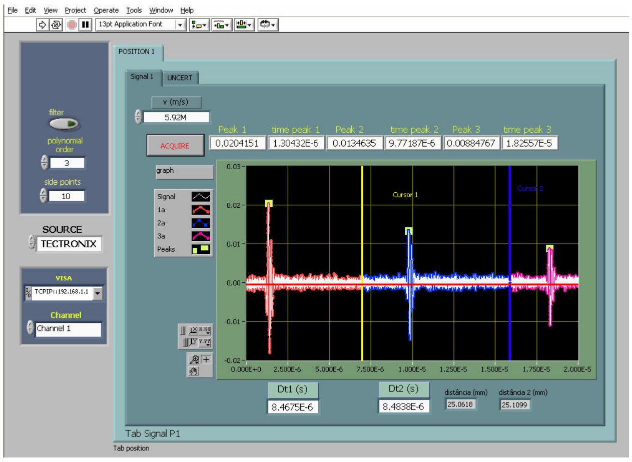

Figure 1. Thick.ed1 program.

The dimensional calibration of two V1 blocks (Nº 121 e Nº176) (Figure 3) was carried out in the Dimensional Metrology Laboratory (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 CCD camera 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.

The performance of the implemented system was evaluated by the determination thickness values, as well as the respective measurement uncertainty from ultrasound thickness gauging. The results were compared with the dimensional calibration certificate (Lamed) by calculating the normalized error [4] taking into account the specified *ABNT NBR 15824:2010* criterion.

$$Error_{normalized} = \frac{|x_A - x_B|}{\sqrt{U_{x_A}^2 + U_{x_B}^2}} \quad (10)$$

Where x_A represents the value of one measured thickness (by ultrasound), x_B represents the value of the same parameter declared dimensional calibration certificate, U_{xA} and U_{xB} are the measurement uncertainties.

2.1. Determination of thickness measurement uncertainty.

The determination of the thickness measurement uncertainty is the contribution of the difference between two measurements that should not have a greater deviation than 0.2 mm and the uncertainty of the method qualification in the range of the tested thickness can be seen in the equation that follows (1):

$$(u_e^2 = u_{ae\,TypeA}^2 + u_{ed\,TypeB}^2) \quad (1)$$

Thus, the measurement uncertainty of method qualification was estimated based on the measurement uncertainty of the time base oscilloscope $(u_{t(TypeB)})$, of the ultrasonic velocity deriving from the block calibration certificate $(u_{v(TypeB)})$ and number of measurements for their determination in each distribution $(u_{rd(typeA)})$.This way, the uncertainty *ed* is given in equation 2:

$$u^2(ed) = u_t^{\,2}(TypeB) + u_v^{\,2}(TypeB) + u_{rd\,(typeA)}^2 \quad (2)$$

The Type B uncertainty of velocity $(u_{v(TypeB)})$ was estimated by dividing the expanded uncertainty by k (coverage factor) from the standard block calibration certificate. The standard uncertainty of Type B of time $(u_{t(TypeB)})$, is calculated according to the equation (3) of the accuracy of the horizontal axis, considering a rectangular distribution [3, 5]:

$$\mathrm{u}_{t\,(\mathrm{Type\,B})} = \frac{1}{\sqrt{3}}(20x1\,ppm \times \Delta l_t), \quad (3)$$

and Δl_t the reading time from oscilloscope. The Type A uncertainty $(u_{rd\,(typeA)})$ was estimated as the standard deviation of five measurements divided by $\sqrt{5}$.

The uncertainty of Type B $(u_{rd\,TypeB})$ was estimated dividing the expanded uncertainty by k (coverage factor), from the calibration certificate of the process qualification method. The uncertainty of Type A $(u_{ae\,TypeA})$ was estimated as the difference between two first measurements, where the deviation must not be greater than 0.2 mm divided by $\sqrt{3}$.

3. RESULTS AND DISCUSSION

Table 1 shows the nominal and measured values and the measurement uncertainty of the two calibrated blocks. The nominal value (specified standard) was compared with the obtained average values of 03 measurements cycles. The difference between the values (Systematic error [6]) and the measurement uncertainty were compared with the specified tolerance found in the standard; they were lower than the established standard boundary.

The measured values and their respective uncertainties are in accordance with ISO 2400 [7] and EN 12223 [8] specifications. These values are used in the next step of this work, in which the thickness gauges were carried out by ultrasound.

Table 1. Nominal value and systematic measurement error + measurement uncertainty of V1 standard blocks main dimensions.

Block	Serial number	quota	Nominal value	Measured quantity value (mm)	Measurement uncertainty (mm)	*k*	Systematic error+ measurement uncertainty
V1	121/06	a	100	100.002	0.003	2.0	0.005
		b	25	25.036	0.003	2.0	0.039
	0176/09	a	100	99.995	0.002	2.0	0.007
		b	25	25.000	0.002	2.0	0.002

3.1 Standard Blocks thickness gauging by ultrasound

According to ABNT NBR 15824:2010 standard, before starting the measurements, it is necessary to qualify the measurement method. In Table 2 the proceeding qualification data and the uncertainties of each distribution are presented.

Table 2 Qualification Method of V1 Standard Block thickness gauging.

Standard Block	Dimensional calibration and expanded uncertainty V1 Standard block (mm)	Average thickness measured by ultrasound (mm)	Expanded uncertainty (mm)	*k*	%	Error Normalized
V1 NS. 121_T1*	25.000 ± 0.0020	24.988	0.027	2.14	0.11	0.71
V1 NS. 121_T2*	91.023 ± 0.0020	91.012	0.060	1.96	0.07	0.42
V1 NS. 121_T3*	99.995 ± 0.0020	99.945	0.070	1.96	0.07	1.54

*thickness 1, 2 and 3

T1 and T2 measured thickness values can be accepted considering the ABNT NBR 15824:2010 criterion (> 0.2mm deviation), as all normalized errors were lower than 1, except T3. Thereby, T3 measured thickness values cannot be in accordance with the previous criterion standard, despite the deviation is within the criterion standard.

After the method qualification, the thickness gauging in the 02 V1 standard blocks were carried out only in T1 or 25,000 mm in the dimensionally calibrated block. Table 3 presents the dimensional calibration values + uncertainty, the average measured thickness by ultrasound and their expanded measurement uncertainties of V1 standard blocks. The calibrated value of the block thickness was compared to two measurements average. The measured values of thickness coupled with the uncertainty lies within calibrated values for this block and they are lower than specified deviation from ABNT NBR 15824:2010 standard. The measurement uncertainty represents 0.10% of measured thickness value. Uncertainty contribution evidences that the greater influence was from the measurement process, as seen in Table 4. In this paper, the used instruments and fixtures uncertainties contribution were low, this not being the highest impact factor on the final uncertainty result. Therefore, the measurement process added the highest contribution (1,27E-02) to the final uncertainty result. On the other hand, if the instruments and fixtures were not duly calibrated, they should contribute for the outcome, causing the uncertainty outcome to be over ABNT NBR 15824:2010 criterion.

Table 3. Ultrasonic Thickness measurement and expanded measurement uncertainty of V1 standard blocks.

Standard Block	Calibrated value and Expanded UncertaintyV1 Standard Block (mm)	Average Measured Thickness (mm)	ExpandedMeasureament Uncertainty (mm)	*k*	%	Normalized Error
V1 NS. 121	25.04 ± 0.0030	25.04	0.026	1.96	0.10	0.11
V1 NS. 0176_09	25.00 ± 0.0020	25.00	0.026	1.96	0.10	0.19

By determining the measurement uncertainty it is possible to compare the results obtained by different methods of thickness gauging if, of course, such methods derive from calibrated instruments, with guaranteed traceability. This is only possible if they had their calibration certification issued by calibration laboratories accredited according to ISO / IEC 17025 [9] or when there is not laboratory accredited for the quantity to be calibrated, with standards traceable by laboratories belonging to Brazilian Calibration Network (RBC) or a laboratory with national or international measurement system recognition.

Table 5. Uncertainty contribution of V1 standard block by ultrasound thickness gauging

Quantity	Standard Uncertainty	Prob. Dist.	Sensi. Coef.	Uncert. Contrib.	Comb. Uncer.
u_t [s]/Type B	9.75E-11	Rectangular	2.96E+06	2.89E-04	
u_v [mm]/Type B	2.09E+03	Rectangular	4.22E-06	8.83E-03	
u_{rd} [mm] /Type A	9.15E-03	Normal	1	9.15E-03	
u_{ed} [mm]/ Type B	1.27E-02	Rectangular	1	1.27E-02	
u_{ae} [mm] /Type A	3.52E-03	Rectangular	1	3.52E-03	
u_e [mm]					1.32E-02

The use of calibrated instruments and guaranteed traceability, as used in this study, allowed us to estimate the measurement uncertainty for the process thickness gauging by ultrasound; this would be impossible if they did not have a calibration certificate.

4. CONCLUSION

The results presented by ultrasound thickness gauging are within the dimensional calibration values for V1 standard blocks and are lower than ABNT NBR´s 15824:2010 specified deviation. Estimating the measurement uncertainty, it was possible to assess that the measurement process had a higher contribution to the uncertainty combined value.

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