Avaliação metrológica de um detector de falha utilizado em ensaios não destrutivos por ultrassom.

Metrological evaluation of a flaw detector used in non-destructive testing by ultrasound.

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Abstract: Nondestructive tests are widely used in various sectors of industry, and its main techniques are based on the use of ultrasound. The flaw detector is a device used in ultrasonic testing. In this article, it is studied the influence of the flaw detection settings on the measurement result. It was observed that when the speed of sound and the thickness of the standard block are known, the equipment gives the best results, with a maximum error of 0.08%. The results show the importance of having a standard block calibrated in order to minimize errors.

Keywords: Metrology; Flaw detector; non-destructive testing and ultrasound.

1. INTRODUCTION

Nondestructive testing (NDT) are widely used in industry, particularly in the evaluation of mechanical parts. Among the NDT techniques, the most widely used are based on the use of ultrasound, for example, for measuring the thickness or location of flaws and discontinuities [1]. Many of these measurements are performed using specific equipment, as a flaw detector. This equipment is used to detect defects in materials, can be used in external or internal environments, and plays an important role in the reliability of nondestructive tests carried out [2].

The purpose of this paper is to obtain a metrological evaluation of measurements carried out by a flaw detector in order to show the importance of knowing the different features present in an ultrasound test.

2. CASE STUDY

In order to evaluate the results given by the flaw detector and to show the importance of understanding the fundamentals involved in the test, different measurements were performed. Three transducers with different nominal frequencies were used, and tests were conducted using different equipment settings. Tests were performed using a standard block type 1, with speed of sound and dimensions previously calibrated. The development and implementation of this research were performed at Inmetro's Laboratory of Ultrasound (Labus), which has the entire infrastructure to carry out the proposed work.

3. MATERIALS AND METHODS

3.1. Flaw detector

The flaw detector used in this work was the model portable analyzer EPOCH 600 (Olympus NDT, USA) – see figure 1. That allows changing various settings of the tests [2].

Figure 1: Flaw detector model Epoch 600 (Olympus NDT, USA)

It is noteworthy that the equipment measures the time of flight [s] of the pulse, however, presents the results in length [m]. Therefore, the speed of sound in material under test is an input on the equipment, which is used for converting the time of flight measured by the equipment, in length.

3.2. Test body

A standard block type 1 was used for the tests [3]. The block has a thickness of 25.036 mm with expanded uncertainty of 0.003 mm (k = 2.0 p = 0.95) and a height of 100.002 mm and expanded uncertainty of 0.003 mm (k = 2.0, p = 0.95). Those dimensions were calibrated in the Dimensional Metrology Laboratory of Inmetro (Lamed). The block has an ultrasonic propagation speed of 5910.6 m·s-1 with expanded uncertainty of 6.3 m·s-1 (k = 2.36, p = 0.95), as calibrated at Labus.

3.3. Experimental procedure

Tests were performed in different ways, all using transducers with different nominal frequencies and changing the configuration for calculating the time of flight considering the first peak or the maximum peak. The transducers used in the tests were the following: V306 2.25 MHz, V309 5 MHz, and A320s 7.5 MHz, all with a diameter of 0.5" (Panametrics NDT, USA). For the first, second and third tests, the calibrated speed of sound of the block (5.910 m·s-1) was used as input on the Epoch 600.

In the first, the block height measurements were carried out using as reference the time of flight between the start signal and the first reflection (first echo).

In a second moment, the height of the block was measured, with reference to the time of flight between the first reflection (first echo) and second reflection (second echo).

In the third test the equipment was set before the measurements. The adjustment was performed by measuring the block height and fixing it by means of the "zero setting" in the signal received by the equipment, in order to presented the same value calibrated by Lamed. Then, the third reflection of the block thickness was measured, equivalent to a size of approximately 75 mm (three times the block thickness). We chose to measure the third reflection, because according to the ABNT NBR 15824 - Nondestructive testing - Ultrasound - Thickness measurement, the measuring instrument shall be deemed fit to measure thickness in a range of ± 25% of the thickness of the block used in the default setting. In other words, the size of 75 mm is the limit for the measurement set in a block of 100 mm [4].

Finally, we used a feature of the Epoch 600, called "auto-calibration". By means of this tool, it is possible to estimate the value of the propagation velocity for the material tested by a known dimension value. Thus, the transducer was positioned on top of the block and it was informed to the equipment their height (100 mm). By doing that, the speed of sound of the block was estimated. Thereafter, it was measured the third reflection block thickness using the speed of sound estimated by the equipment.

3.4. Measurement Uncertainty

In order to assess the reliability of measurement results, showing a quantitative indication of the quality of results, the measurement uncertainty was estimated. For a general relation $h = f(x_i)$, the general formula for the model uncertainty is obtained by the equation 1:

$$u_c^2 = \sum_{j=1}^{N} \left(\frac{\partial h}{\partial x_j} \right)^2 \cdot u_j^2 \qquad (1)$$

Where u_c is the combined standard uncertainty associated with the outcome of the measurement (or calculation) h, and u_j the standard uncertainty, evaluated as Type A or Type B, associated with each variable parameter x_j used to express the value of h. [5].

Therefore, the initial step is to identify the sources of uncertainty. The following sources of uncertainty were identified: repetition (Type A), the speed of sound in block 1 (Type B) and the equipment resolution (Type B).

The uncertainty of repetition comes from ten measurements; the uncertainty of the speed of sound in block 1 comes from of the calibration certificate emitted by Labus (c =5910.3 m/s; U = 6.3 m/s; k = 2.36); and, finally, the resolution of the equipment (0.01 mm).

4. RESULTS AND DISCUSSION

Table 1 presents the mean values and their respective uncertainties, for the test conducted using the time of flight between the excitation signal and the first echo as reference. Table 2 depicts the results for the test conducted using time of flight between the first and second echo as reference. In Table 3, one can see the results for the test using the "zero setting", while Table 4 shows the results achieved using the auto-calibration procedure.

Assessing Table 1, it is noted that as the nominal frequency of the transducer increases, the values of the results tend to decrease. As the wavelength decreases when the frequency increases a higher resolution can be achieved. Moreover, transducers with higher nominal frequency have thinner coupling layer, than the total time of flight is shorter and, consequently, the thickness values are closer to the reference value. Besides, the values measured using as references the first peak are smaller to those measured in relation to the maximum peak. This is due to the maximum peak always appears after the first peak (bigger total time of flight). Here, it is important to mention that the previous analysis is valid only for results presented on Table 1. In the other result, the differences in time of flight are mathematically annulled (Table 2) or corrected using the NDT equipment settings (Tables 3 and 4).

Table 1: Test 1 - References: Excitation signal and first echo. (Reference value = 100.002 mm)

		Mean [mm]	Uncertainty [mm]	Error [mm]
V306 2.25 MHz	***First Peak***	102.005	0.090	2.005
	Maximum Peak	103.092	0.091	3.092
V309 5 MHz	***First Peak***	101.613	0.090	1.613
	Maximum Peak	102.073	0.090	2.073
A320S 7.5 MHz	***First Peak***	101.764	0.090	1.764
	Maximum Peak	101.765	0.090	1.765

The results achieved using the excitation signal and first echo as reference showed an error greater than the other tests, with the maximum error of 3.09% (Table 1). On the other hand, determining the time of flight between the first and second echo, the maximum error falls to 1.12%. A possible explanation for this difference is that the time of flight between the excitation signal and the first echo contains the time of flight taken in the coupling layer of the transducer. Hence, that time of flight is bigger than the one measured between the first and second echo, where the time of flight in the coupling layer is annulled.

Knowing the speed of sound in the material and its thickness, it is possible to perform the zero adjustment. This setting gave the best result, with a maximum error of 0.08% (Table 3). Here it is important to highlight that all errors were smaller than the estimated measurement uncertainty (Table 3). Finally, knowing only the thickness, it is possible to use the "auto calibration". This setting showed a maximum error of 1.03% (Table 4).

Table 2: Test 2 - References: first and second echo. (Reference value = 100.002 mm)

		Mean [mm]	Uncertainty [mm]	Error [mm]
V306 2.25 MHz	*First Peak*	101.000	0.090	1.00
	Maximum Peak	99.907	0.090	0.093
V309 5 MHz	*First Peak*	100.496	0.089	0.496
	Maximum Peak	101.122	0.091	1.122
A320S 7.5 MHz	*First Peak*	99.926	0.088	0.074
	Maximum Peak	100.972	0.089	0.972

Table 3: Test 3 - Test carried out with zero adjustment and excitation signal as reference. (Reference value = 75.108 mm)

		Mean [mm]	Uncertainty [mm]	Error [mm]
V306 2.25 MHz	*First Peak*	74.951	0.067	0.049
	Maximum Peak	74.940	0.066	0.060
V309 5 MHz	*First Peak*	74.955	0.066	0.045
	Maximum Peak	74.964	0.066	0.035
A320S 7.5 MHz	*First Peak*	74.964	0.066	0.036
	Maximum Peak	74.946	0.066	0.054

Table 4: Test 4 - Test performed using auto-calibration, and excitation signal as reference. (Reference value = 75.108 mm)

		Mean [mm]	Uncertainty [mm]	Error [mm]
V306 2.25 MHz	*First Peak*	75.516	0.071	0.516
	Maximum Peak	75.775	0.067	0.775
V309 5 MHz	*First Peak*	75.551	0.067	0.551
	Maximum Peak	75.526	0.067	0.526
A320S 7.5 MHz	*First Peak*	75.347	0.067	0.347
	Maximum Peak	75.155	0.067	0.155

5. CONCLUSION

In general, the flaw detectors allow having control of various setting parameter. However, despite the advantage of having greater control over the testing carried out, it is clear that the operator must hold theoretical knowledge and experience about the performed test. Just one configuration incompatible with the test can generate inconsistent results compromising the inspection. Besides, the transducer frequency, as well as the reference used for measuring the time of flight, are factors that may influence on the final outcome.

Considering the different possible settings in the NDT equipment, the operator training has major importance in order to mitigate errors by choosing the appropriate parameters settings. Moreover, it is evident the importance of having a standard block with the speed of sound, as well as their dimensions calibrated, in order to minimize errors.

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REFERENCES

[1] ABENDI: Associação Brasileira de Ensaios Não Destrutivos. Available in: <www.abende.org.br> Jul. 24, 2014.

[2] Epoch 600: User manual. DMTA-10006-01PT –. December 2013.

[3] ISO 2400:2012 - Non-destructive testing Ultrasonic testing Specification for calibration block No. 1

[4] ABNT NBR 15824 – Nondestructive testing - Ultrasound - Thickness measurement.

[5] JCGM 100:2008 - Evaluation of measurement data - Guide to the expression of uncertainty in measurement. 1st Ed.

[6] Maggi L E, Silva C E R, Alvarenga A V and Costa-Felix R P B 2011 Ultrasonic calibration and certification of V1 and V2 type reference standard blocks for use in Non-Destructive Testing, Journal of Physics: Conference Series.