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STUDY THE CONTRIBUTION OF THE UNCERTAINTY GENERATED BY THICKNESS VARIATION OF COUPLANT IN THICKNESS MEASUREMENT BY ULTRASONIC

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Abstract. *The ultrasonic technology has been practiced for several decades. The thickness measurement by ultrasonic method has been widely used and has played an important role in quality control of steel construction. In the measurement procedure, steps that involve checking thickness of a piece though the ultrasonic testing and analyzing results require extreme care because they can generate a measurement imprecision. This work focus on the design of parts requiring increasingly tighter tolerances and rigorous metrological control. This experiment consisted of analyzing the uncertainties of the measurement results obtained in block scaled by ultrasonic method and with the thickness of coupling parameter used.*

Keywords: *Ultrasonic, Thickness gauge, Coupling layer, Measurement uncertainty.*

1. INTRODUCTION

Ultrasonic testing is a nondestructive test method which is based on ultrasound waves to detect internal defects in materials or for measuring wall thickness and corrosion detection and has been practiced for several decades. An example of application of the technique is the measurement of the thickness of industrial parts where instruments have been perfected to improve the interpretation of data (NDT RESOURCE CENTER). The main purpose of ultrasonic testing is the detection of internal discontinuities in materials ferrous and non-ferrous and metal and non-metal through the introduction of a sound beam which is reflected by this discontinuity. The techniques derived from the use of ultrasonic are used in many areas, particularly in healthcare applications and nondestructive testing (OLIVEIRA, 2008).

Therefore, ultrasonic, as well as all non-destructive examination, aims to reduce the degree of uncertainty in the use of materials or pieces of responsibilities and the more controlled and well known is the process of measuring higher the quality of the result. Therefore, it is necessary to measure the action is carried out in accordance with specific rules aimed at obtainment of reliable results. And one of the advantages of this method relative to other assays is that ultrasonic has a high sensitivity in the detectability of small internal discontinuities, for example, cracks and fissures.

In this article will be discussed analysis of the effect of the coupling layer measurement using ultrasonic technique.

2. METHODOLOGY

The more controlled and known measurement process is better the quality of the result. It is therefore necessary that the action of measuring conforms to with certain rules that search to obtain reliable results. This set of rules and procedures for ensuring the reliability of the measurements is that makes of metrology a science. In order to analyze the effect of the couplant thickness measurement by ultrasonic was performed assembly as shown, in which the transducer was coupled to a gauge height gage, in order to vary the thickness of the couplant through scale tracer. Measurements in order to analyze the effect of thickness measurement by ultrasonic coupling layer, as shown in “Fig. 1”, the transducer was coupled to a gauge height gage, varying the thickness of layer of couplant through the scale of the tracer. Measurements were performed on a block-ted to climb four steps, and the data of its calibration presented in “Tab. 1”.

Lay emphasis on that the height gage is analog type with nominal range of 0 to 300mm, and its smallest division is 0,01mm. The calibration block was performed with the aid of coordinate measuring machine (MMC) belonging to the dimensional metrology laboratory CEFET/RJ that was calibrated by Hexagon Metrology belonging to RBC as DEA certificate N° 186-10 of 09/06/2010. The laboratory meets the requisites of the NBR ISO /IEC 17025. The experiment was conducted at an average temperature of 24°C.

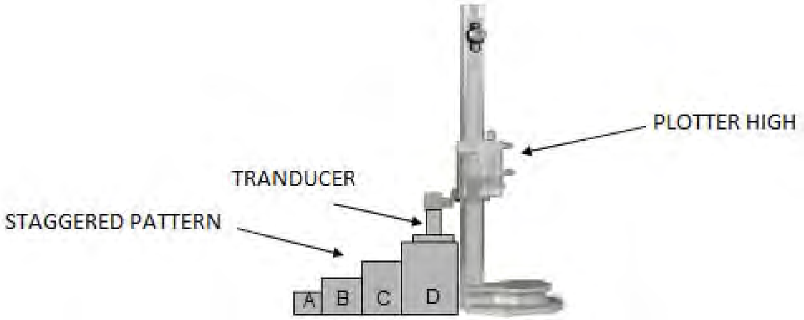

Figure 1. Schematic drawing of the assembly for verification

Table 1. Calibration data block.

THICKNESS	A	B	C	D
	3.590	5.788	7.731	10.717
	3.524	5.813	7.742	10.717
	3.505	5.825	7.740	10.734
	3.530	5.798	7.734	10.696
	3.456	5.840	7.740	10.728
SOMA	17.605	29.064	38.687	53.592
AVERAGE	3.521	5.813	7.737	10.718

The following discussion will be divided by scaling of steel with the measurement data, varying the thickness of layer of couplant from 0 to 1.0 mm.

3. RESULTS

Thickness Block "A"

"Table 2" shows the value of the average thickness of the block, depending on the thickness of layer of couplant. Importantly, each thickness was measured six times; however, some results were considered outliers and excluded from the sample set.

Table 2. Mean values of the thickness of the block "A" according to the coupling layer

THICKNESS OF COUPLANT (mm)	AVERAGE (mm)
0	3,51
0,1	3,67
0,2	4,04
0,3	4,53
0,4	5,05
0,5	5,6
0,6	5,79
0,7	6,07
0,8	6,49
0,9	6,91
1,0	7,35

Initially, a linear regression was performed and the data obtained are presented below. "Fig. 2" shows the resulting graph.

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Linear Regression for Data1_B:
Y = A + B * X

Parameter       Value           Error
------------------------------------------------------------
A               3,395           0,06615
B               3,93909         0,11182
------------------------------------------------------------

R               SD              N               P
------------------------------------------------------------
0,99639         0,11728         11              <0.0001
------------------------------------------------------------
```

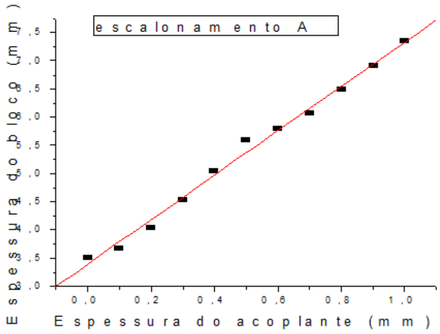

Figure 2. Graph relating the average value of block "A" according to the thickness of layer of couplant.

By polynomial regression data were obtained according to the following fig.3 below:

```
Polynomial Regression for Data1_B:
Y = A + B1*X + B2*X^2

Parameter       Value           Error
------------------------------------------------------------
A               3,3721          0,094
B1              4,09177         0,43735
B2              -0,15268        0,42123
------------------------------------------------------------

R-Square(COD)   SD              N               P
------------------------------------------------------------
0,99292         0,12339         11              <0.0001
------------------------------------------------------------
```

Figure 3. Polynomial Regression.

Analyzing the value of R ^ 2 for the two situations, it is concluded that the best option is a straight line, as presented higher value and equal to 0.99639. Therefore, the relationship between the thickness of layer of couplant and the average thickness of the block "A" is shown in Eq. (1).

$$y = 3{,}395 + 3{,}93909x \qquad (1)$$

Where:
x = value of the thickness of layer of couplant.
y = thickness value of the scaled block.

Thickness Block "B"

“Table 3” shows the relationship between the thickness of layer of couplant and the average thickness B of scaling block.

Table 3. Measuring the variation of the average thickness of scaling block B with increasing coupling layer.

THICKNESS OF COUPLANT (mm)	AVERAGE (mm)
0,0	5,8
0,1	5,87
0,2	5,93
0,3	6,0
0,4	6,3
0,5	6,66
0,6	6,99
0,7	7,36
0,8	7,78
0,9	8,14
1,0	8,45

Applying polynomial regression of degree 2, was obtained the following values. “Figure 3” shows the graph for this variation.

Polynomial Regression for Data1_B:
Y = A + B1*X + B2*X^2

Parameter	Value	Error
A	5,73133	0,07212
B1	0,77811	0,33555
B2	2,06643	0,32318

R-Square(COD)	SD	N	P
0,99232	0,09467	11	<0.0001

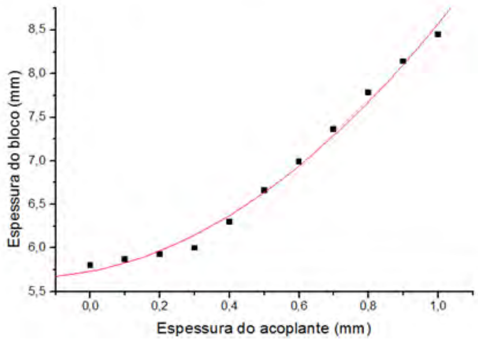

Figure 3. Graph of the variation of average thickness of the block with the variation of the couplant.

Applying the linear regression, obtained the following values. “Figure 4” shows the points of the straight line obtained, while the red line represents the set.

Linear Regression for Data1_B:
Y = A + B * X

Parameter	Value	Error
A	5,42136	0,12445
B	2,84455	0,21036

R	SD	N	P
0,97626	0,22062	11	<0.0001

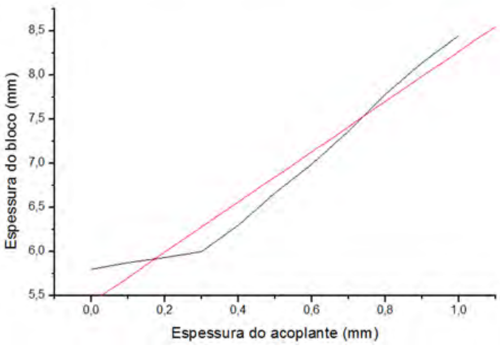

Figure 4. Graph showing the real line (in black) and the fitted straight line (in red).

Again, analyzing the R-squared of both regressions, observed that the equation of degree 2 is best fit to the points (R 0.99232). “Equation (2)” represents the relationship between these two quantities.

$$y = 2{,}06643x^2 + 0{,}77811x + 5{,}73133 \tag{2}$$

Thickness Block "C"

“Table 4” shows the relationship between the thickness of layer of couplant and the average thickness C of the scaling block.

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Table 4. Measuring the variation of the average thickness C of the scaling block with increasing thickness of the couplant.

THICKNESS OF COUPLANT (mm)	AVERAGE (mm)
0,0	7,75
0,1	7,87
0,2	8,11
0,3	8,47
0,4	8,84
0,5	9,23
0,6	9,42
0,7	9,66
0,8	10,01
0,9	10,42
1,0	10,55

The data relating to linear regression are presented below. The characteristic line is shown in "Fig. 5".

Linear Regression for Data1_B:
Y = A + B * X

Parameter	Value	Error	
A	7,62727	0,04791	
B	2,98727	0,08097	
R	SD	N	P
0,99671	0,08493	11	<0.0001

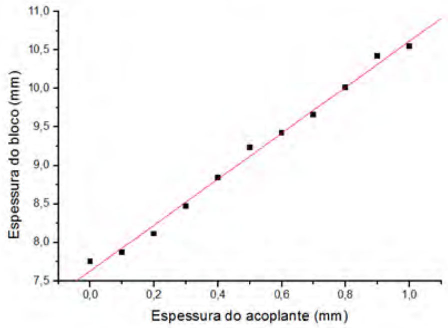

Figure 5 - Variation of measuring the thickness of the block C as a function of the thickness of assuming a linear regression couplant.

The data considering the linear regression grade 2 are shown below. Figure 6 shows the characteristic curve.

Polynomial Regression for Data1_B:
Y = A + B1*X + B2*X^2

Parameter	Value	Error	
A	7,63951	0,06832	
B1	2,90569	0,31788	
B2	0,08159	0,30617	
R-Square(COD)	SD	N	P
0,99349	0,08968	11	<0.0001

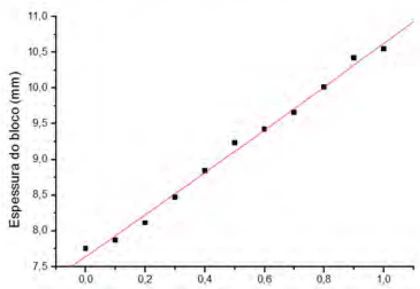

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Figure 6 - Variation of measuring the thickness of the block C as a function of the thickness of layer of couplant considering a polynomial regression of degree 2

Figure 7 shows the characteristic curve for the third degree polynomial regression.
For a polynomial regression of degree 3, as shown below:

```
Polynomial Regression for Data1_B:
Y = A + B1*X + B2*X^2 + B3*X^3

Parameter       Value           Error
------------------------------------------------------------
A               7,69958         0,07295
B1              1,95124         0,6643
B2              2,5845          1,59102
B3              -1,66861        1,0441
------------------------------------------------------------

R-Square(COD)   SD              N               P
------------------------------------------------------------
0,99523         0,08206         11              <0.0001
------------------------------------------------------------
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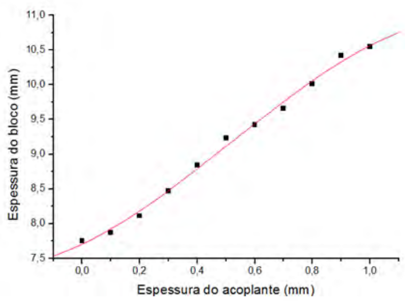

Figure 7 - Variation of measuring the thickness of the block C as a function of the thickness of layer of couplant considering a polynomial regression of degree 3

Analyzing the three situations, it appears that the line best fits the measured points for this situation. Equation (2) represents the line in question.

$$y = 2{,}98727x + 7{,}62727 \qquad (3)$$

Thickness Block "D”
“Table 5” shows the relationship between the thickness and the average thickness of layer of couplant D scaling block.

Table 5: Variation of the measurement scaling average thickness D of the block with increasing coupling layer

THICKNESS OF COUPLANT (mm)	AVERAGE (mm)
0,0	10,74
0,1	10,79
0,2	10,86
0,3	11,01
0,4	12,0
0,5	12,22
0,6	12,41
0,7	12,79
0,8	13,2
0,9	13,53
1,0	13,93

The data relating to the second degree polynomial regression are presented below.
“Figure 8” shows the graph of the characteristic polynomial regression of the second degree.

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Polynomial Regression for Data1_B:
Y = A + B1*X + B2*X^2

Parameter	Value	Error
A	10,53804	0,16153
B1	2,60396	0,75155
B2	0,84149	0,72385

R-Square(COD)	SD	N	P
0,97332	0,21203	11	<0.0001

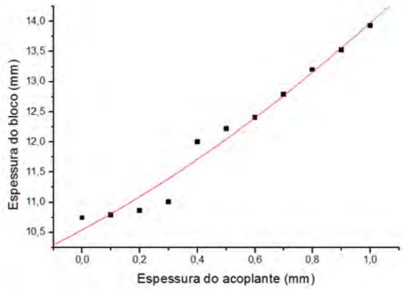

Figure 8 - Change in measurement of the thickness D of the block depending on the coupling layer considering a polynomial regression of degree 2

Considering the linear regression:

Linear Regression for Data1_B:
Y = A + B * X

Parameter	Value	Error
A	10,41182	0,12191
B	3,44545	0,20607

R	SD	N	P
0,98428	0,21613	11	<0.0001

Figure 3. Linear Regression.

According to the R ^ 2, the line represents the best accumulated points, being the same as that presented in Equation (4).

$$y = 3{,}44545x + 10{,}41182 \tag{4}$$

Through analysis of the dimensions is possible to verify that there is a systematic error component according to the coupling layer, which behaves in a manner virtually linear as proven by this study. However, it is not practical or functional during operation with ultrasonic to perform such removal, since it does not know for sure, using conventional measuring techniques, and the thickness of the couplant which immediately capture the measured value. Because of this, it becomes practical and settles such variation as a type B component of measurement uncertainty, as discussed below.

An important contribution to the study of ultrasonic measurement uncertainty, relates to determine the influence of the coupling layer this measurement. To the present, there was no evidence record that takes into account this source of error. However, this study evidenced by his presence. Within this context, the aim of this work is to present a reasonable variation for this source of error by adopting a source of uncertainty type B, as a component of expanded uncertainty of measurement, since it does not make a sense for the industry to rise this spring as a chick the uncertainty in daily measurements.

Initially, it is important to consider that during probing, no one knows for sure what the coupling layer when making the measurement. However, it can reasonable be considered that such variation may occur between 0 and 0,2 mm. As no data more likely in this case, it is assumed that in this range, the probability will be the same, therefore, the probability distribution used will be a rectangular, and the uncertainty type B[1] is given as equation (5).

$$i_e = \frac{\Delta e}{\sqrt{3}} \tag{5}$$

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Where:

i_e = uncertainty related to the variation of the thickness of layer of couplant between 0 e 0,2mm.

Δe = the difference between the measured value considering the thickness of layer of couplant 0,2mm to 0mm

The table 6 show this source of uncertainty for each of the measurements

Table 6: Determination of type B uncertainty for each dimension of the block

Stagger	Block thickness to the thickness of 0mm couplant (mm)	Block thickness to the thickness of couplant 0,2mm (mm)	Δe (mm)	ie (mm)
A	3,51	4,04	0,53	0,305996
B	5,80	5,93	0,13	0,075056
C	7,75	8,11	0,36	0,207846
D	10,74	10,86	0,12	0,069282

Analyzing the Δe values for each of the blocks, it is obvious that these values do not follow a tendency. Even so, it was evaluated if any of these could represent an outlier. Tests were, therefore, four values of criteria for Δe Dixon, Chauvenet and Grubbs [2, 3, 4, 5], but no point was deleted. For this specific situation can be taken, for example, an average value for Δe which is equal to 0.29 mm.

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