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DEVELOPMENT OF AN ELECTRONIC SPREADSHEET FOR CALIBRATION OF MANOMETERS: A SIMPLIFIED WAY TO MEASURE MEASUREMENT UNCERTAINTY

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Abstract: When using an instrument, it is necessary to know the uncertainty of the measurement performed, which is an important variable for the quality and safety of a process. In this sense, this work develops a tool that aims to measure the measurement uncertainty of an instrument, as well as to facilitate a possible calibration process. However, since there are differences according to the instrument to be evaluated, it was necessary to make a cut, and the worksheet developed in this work is specific for analog manometers. The methodology of this work is based on the ISO GUM method, and the spreadsheet was developed using Microsoft Excel software. The developed spreadsheet met the proposed requirements, being a simplified way to calculate the uncertainty of a manometer. It was also noticed that the spreadsheet has didactic potential, being not only a way to check the results, but also to carry out instrument calibration practices in a faster and more assertive way.
Keywords: calibration, uncertainty of measurement, manometers, electronic worksheet, quality.

INTRODUCTION

Like all equipment and instruments, the tools used to perform measurements also have a certain useful life. Thus, instrument calibration is essential to ensure measurement reliability, as well as the quality of products and processes associated with it[1-2].

Given this scenario, it is necessary to determine the uncertainties involved in the procedure. This need involves avoiding obtaining data that do not express the truth, which can generate a series of consequences such as: economic losses by incorrectly disposing of newly manufactured parts, judicial, changing medical verdicts, leading to misdiagnoses and, consequently, erroneous treatments, among other examples. The definition of uncertainty raises doubts, that is, in a measurement, the degree of dispersion of the obtained values, which has the potential to belong to the measured value[3].

According to the International Vocabulary of Metrology (VIM), there is a recommendation that the elements that are part of the measurement uncertainty must be segregated into two groups, Type A and Type B. These groups are determined from evaluations, based on combined statistical methodologies or in other ways, with the objective of obtaining the variance marked by probabilistic mathematics[4].

The Uncertainty approach is described in the Guide to the Expression of Uncertainty in Measurement (GUM), where the uncertainty applied to the measurement is detailed mathematically. In GUM it is also possible to obtain data about uncertainty applied to a single measurement, something trivial in the industrial sector[5]. It is noteworthy that it involves complex mathematical concepts and numerous formulas.

In this sense, this work aims to facilitate the determination of uncertainties present in pressure measurements, as well as calculate them, through the development of an electronic spreadsheet. Due to the existence of differences in the mathematical descriptions of uncertainties, from one device to another, the instrument chosen for this work was the analog manometer, pointed out arbitrarily.

MATERIALS AND METHODS

The present methodology seeks to describe the calculations applied to determine the measurement uncertainty according to the ISO GUM method for analog manometers[5]. The software used in this work for the development of electronic spreadsheets was Microsoft Excel. However, the resources used to prepare this spreadsheet are found in most software available on the market.

The first step is to identify the manometer to be calibrated, recording its resolution and indication range, that is, its nominal range. In sequence, the parameters of the standard manometer must be identified, namely its resolution, expanded uncertainty and nominal range. Subsequently, the manometer to be calibrated must be fixed to the bench, with the standard, then the advance and return measurements of pressures in various adjusted ranges must be recorded. It is calculated by means of Equation 1 and 2, respectively, correction and hysteresis.

$$C = \overline{M} - V_p \quad (1)$$

$$H = |\overline{A} - \overline{R}| \quad (2)$$

In which:
C: Correction;
M: Average value of the range;
V_p: Standard value;
H: Hysteresis;
$\overline{A}$: Average Advance Value;
$\overline{R}$: Average Indentation Value.

To calculate the uncertainty of an instrument, it is necessary to obtain the effective degrees of freedom value, and then, with the help of the t-Student table, determine the value of the coverage coefficient that will be used to calculate the measurement uncertainty. Therefore, the sources of present uncertainties and their respective mathematical representations, which are used in the spreadsheet, will be described. These sources are: repeatability, hysteresis, pressure gauge resolution, standard gauge resolution and inherited from the standard, which are calculated respectively by Equation 1, 2, 3, 4 and 5. By combining them using Equation 6 it is possible to find the combined uncertainty that must be multiplied by the coverage coefficient as per Equation 7 to find the measurement uncertainty of an analog manometer.

$$U_R = \frac{s}{\sqrt{n}} \quad (1)$$

$$U_H = \frac{H}{2\sqrt{3}} \quad (2)$$

$$U_{RM} = \frac{R_M}{2\sqrt{3}} \quad (3)$$

$$U_{RP} = \frac{R_P}{2\sqrt{3}} \quad (4)$$

$$U_{HP} = \frac{0{,}1\% \cdot F_E}{2} \quad (5)$$

$$U_C = \sqrt{(U_R)^2 + (U_{RM})^2 + (U_{RP})^2 + (U_{HP})^2 + (U_H)^2} \quad (6)$$

$$U = k \times U_C \quad (7)$$

In which:
U_R: Uncertainty of repeatability;
S: Standard deviation;
n: Number of calibration points;
U_h: Hysteresis uncertainty;
H; Hysteresis;
U_{RM}: Uncertainty of the resolution of the pressure gauge to be calibrated;
R_M Manometer resolution to be calibrated;
U_{RP}: Uncertainty of standard gauge resolution;
R_p: Standard gauge resolution;
U_{RP}: Uncertainty inherited from standard gauge;
F_E: Standard Manometer Scale Background;
U_C: Combined uncertainty;
U: Expanded uncertainty;
k: Scope Coefficient.

The coverage coefficient value depends on the effective number of degrees of freedom and for a given coverage probability. Thus, it is assumed that the sample distribution as t-student and the effective number of degrees of freedom is determined through Equation 8. Finally, after calculating this value, the coverage coefficient value can be obtained through of tables. The worksheet developed in this work aims to obtain a probability of 95.45%, with the K values obtained from Table 1.

$$v_{eff} = \frac{U_C^4(y)}{\sum_{i=1}^{N} \frac{U_R^4(y)}{v_i}} \quad (8)$$

Where:
v_{eff}: Effective number of degrees of freedom;
U_C: Combined uncertainty;
U_R: Uncertainty of repeatability;
v_i: Number of degrees of freedom.

v_{eff}	$k_{95,45\%}$	v_{eff}	$k_{95,45\%}$	v_{eff}	$k_{95,45\%}$	v_{eff}	$k_{95,45\%}$
1	13,97	**8**	2,37	**15**	2,18	**30**	2,09
2	4,53	**9**	2,32	**16**	2,17	**35**	2,07
3	3,31	**10**	2,28	**17**	2,16	**40**	2,06
4	2,87	**11**	2,25	**18**	2,15	**45**	2,06
5	2,65	**12**	2,23	**19**	2,14	**50**	2,05
6	2,52	**13**	2,21	**20**	2,13	**100**	2,025
7	2,43	**14**	2,20	**25**	2,11	> **100**	2

Table 1. Coverage coefficient values for a probability of 95.45%.

RESULTS AND DISCUSSION

The worksheet developed in this work can be seen in Figure 1, with the values that must be provided by the user being highlighted in green. Thus, this tool makes it possible to calculate the uncertainties of an instrument by providing the data from the manometers and the readings carried out, without the need for the user to know its methodology or consult tables.

The use of the spreadsheet minimizes the chances of errors in calculations, especially when associated with text editing control resources, as well as enabling the procedure to be carried out more productively. Thus, one can observe a potential for using it for professional use. It is also added that if programming is used, it is possible that a report is automatically generated through a button, which would imply a greater increase in the productivity of this tool.

Given the simplicity of the spreadsheet, it was observed that there is also an academic potential for applying this type of resource, especially for professional and technical courses where the approach to the subject is more superficial. It must be noted that currently there are several applications and software that allow the use of electronic spreadsheets on different types of devices, including smartphones. Thus, this resource is accessible and can be used by most students with their own devices.

CONCLUSIONS

It was observed that the developed spreadsheet has the potential to be used both for professional and academic applications, enabling a simple way to calibrate and measure the measurement uncertainty of analog manometers, which can be used in several devices. Thus, the spreadsheet met the proposed objectives, and it can be adapted to be used to work with other types of instruments such as: thermometers, scales, dial gauges, etc.

Initial Information	
Standard Instrument Resolution:	0,10
Resolution Instrument to be calibrated:	1,00
Standard Instrument Scale Background:	200

Standard	Load 1	Unload 1	Load 2	Unload 2	Load 3	Unload 3	Average Load	Average Unload	Average	Correction	Standard Deviation	Hysteresis
15	14,9	14,9	14,8	14,9	14,9	14,9	14,8667	14,9000	14,8833	-0,1167	0,0408	0,0333
30	29,8	29,6	29,7	29,7	29,8	29,7	29,7667	29,6667	29,7167	-0,2833	0,0753	0,1000
45	45,0	44,6	45,1	44,7	45,1	44,7	45,0667	44,6667	44,8667	-0,1333	0,2251	0,4000
60	60,1	59,7	60,0	59,8	60,1	59,8	60,0667	59,7667	59,9167	-0,0833	0,1722	0,3000
75	75,0	74,6	75,0	74,6	75,0	74,6	75,0000	74,6000	74,8000	-0,2000	0,2191	0,4000
90	89,9	89,5	89,9	89,6	89,8	89,6	89,8667	89,5667	89,7167	-0,2833	0,1722	0,3000
105	104,9	104,5	105,0	104,6	105,0	104,6	104,9667	104,5667	104,7667	-0,2333	0,2251	0,4000
120	119,9	119,7	119,8	119,8	119,9	119,7	119,8667	119,7333	119,8000	-0,2000	0,0894	0,1333
135	135,2	135,0	135,1	135,2	135,2	135,0	135,1667	135,0667	135,1167	0,1167	0,0983	0,1000
150	150,3	150,1	150,2	150,2	150,2	150,2	150,2333	150,1667	150,2000	0,2000	0,0632	0,0667

<table>
<tr><th>Value</th><th>U_R</th><th>U_H</th><th>U_RM</th><th>U_RMP</th><th>U_HMP</th><th>U_C</th><th>v_eff</th><th>K_95,45%</th><th>U</th></tr>
<tr><td>15</td><td>0,0167</td><td>0,0096</td><td rowspan="10">0,0289</td><td rowspan="10">0,2887</td><td rowspan="10">0,1000</td><td>0,3075</td><td>579134</td><td>2</td><td>0,61494</td></tr>
<tr><td>30</td><td>0,0307</td><td>0,0289</td><td>0,3097</td><td>51601</td><td>2</td><td>0,61950</td></tr>
<tr><td>45</td><td>0,0919</td><td>0,1155</td><td>0,3405</td><td>943</td><td>2</td><td>0,68101</td></tr>
<tr><td>60</td><td>0,0703</td><td>0,0866</td><td>0,3265</td><td>2325</td><td>2</td><td>0,65303</td></tr>
<tr><td>75</td><td>0,0894</td><td>0,1155</td><td>0,3399</td><td>1042</td><td>2</td><td>0,67971</td></tr>
<tr><td>90</td><td>0,0703</td><td>0,0866</td><td>0,3265</td><td>2325</td><td>2</td><td>0,65303</td></tr>
<tr><td>105</td><td>0,0919</td><td>0,1155</td><td>0,3405</td><td>943</td><td>2</td><td>0,68101</td></tr>
<tr><td>120</td><td>0,0365</td><td>0,0385</td><td>0,3114</td><td>26453</td><td>2</td><td>0,62284</td></tr>
<tr><td>135</td><td>0,0401</td><td>0,0289</td><td>0,3108</td><td>17979</td><td>2</td><td>0,62165</td></tr>
<tr><td>150</td><td>0,0258</td><td>0,0192</td><td>0,3086</td><td>101967</td><td>2</td><td>0,61710</td></tr>
</table>

Results
14,8833 ± 0,6149 psi
29,7167 ± 0,6195 psi
44,8667 ± 0,681 psi
59,9167 ± 0,653 psi
74,8 ± 0,6797 psi
89,7167 ± 0,653 psi
104,7667 ± 0,681 psi
119,8 ± 0,6228 psi
135,1167 ± 0,6216 psi
150,2 ± 0,6171 psi

Figure 1. Worksheet developed in this work.

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