Suitability Verification of a Roughness Measurement Process Using the MSA and the *Cdl** Capability Coefficient

J E F Oliveira[1], **F R A Neto**[1] **and S T Oliveira**[2]

[1] Dimensional Metrology Laboratory, Federal Institute of Pernambuco, Recife, 50740-545, Brazil
[2] Dimensional Metrology Laboratory, Federal Center for Technological Education Celso Suckow da Fonseca, Rio de Janeiro, 20271-204, Brazil

joseferreira@recife.ifpe.edu.br; fran@discente.ifpe.edu.br; sidney.oliveira@cefet-rj.br

Abstract. The objective of this work is to apply the Measurement System Analysis (MSA) as well as the capability coefficient *Cdl**, which consider both variability and central tendency in its calculation to evaluate the roughness measurement process of surfaces obtained by planning operations. Through this study, it was possible to carry out a comparison between the two methods with the purpose of verifying the variations presented between them with the intention of adopting only the capability coefficient as a parameter for verifying the capability of the measurement process. In this work, a systematic approach was proposed for the use of the *Cdl** coefficient for evaluation of measurement processes. This capability coefficient was recently developed by our research group entitled Tolerancing and Metrology.

1. Introduction

The guarantee of a reliable measurement involves a series of interconnected steps which go far beyond just having an instrument or a measurement system suitable for a given measurement. It involves several parameters such as the monitoring and control of environmental conditions, the use of validated measuring methods, suitable accessories, qualified personnel and other things. There are two types of measurements to verify the quality and quantify performance in the industry: measurement of its products and measurement of its processes [1]. When the data quality is low, the benefit of measurement system is also low. When the data quality is high, this benefit becomes higher [2]. In this context, the Measurement System Analysis (MSA) aims to verify the suitability of a measurement system for a given application [3].

According to the IQA [3], the MSA study divides the variability into two categories: Location (where the tendency, linearity and stability of the measurement system are studied) and Dispersion (where the repeatability, reproducibility and analysis of the R&R parameter is often considered as the total variability of the measuring, excluding the part variation and the process tendency) [4].

Another way to verify the suitability of a measurement process concerns the use of specific capability coefficients for measurement systems such as the capability coefficient *Cdl** [5, 6] developed by our research group and as presented in Equation (1).

$$C^*_{dl} = \frac{U}{3 \cdot \sqrt{\left(\frac{s}{\sqrt{n}}\right)^2 + \left(\frac{U_{cal}}{k_{cal}}\right)^2}} \cdot l \qquad (1)$$

Where: U = maximum allowed measurement uncertainty; s = sample standard deviation; n = sample size; U_{cal} = uncertainty inherited from the measuring instrument or measuring system, obtained directly from its calibration certificate; k_{cal} = coverage factor associated with the uncertainty U_{cal} and l = variable that expresses the relationship between the indication average ($\bar{X}$) and the nominal value (VN), being assigned the value l_1 given by Equation (2) or l_2 according to Equation (3). The maximum value of l is 1.

$$l_1 = \frac{\bar{X}}{VN}, \; se \; \bar{X} < VN \qquad (2)$$

$$l_2 = \frac{VN}{\bar{X}}, \; se \; \bar{X} \geq VN \qquad (3)$$

The total analysis of measurement systems constitutes on of the basic foundations for quality assurance, since unreliable measurement results can generate two types of basic problems: the approval of defective parts or the disapproval of good parts, impacting in the competitiveness of organizations [7].
This work aims to verify the suitability of the roughness measurement process for surfaces obtained by planning process, as well as to verify the convergence between the MSA and the *Cdl** coefficient in order to be able to use it for this purpose, minimizing costs and time spent on measurements and processing measured data.

2. Methodology

Initially, ten parts of carbon steel (specification ABNT 1020) were taken, and the surfaces of the parts have been planed using a horizontal shaper and a carbide tool according to figure 1. The cutting depth was 0.5 mm and the cutting speed was 60 strokes/min. The roughness parameter used was *Ra* [8]. The rugosimeter used in the measures has the following characteristics: model DR 130, nominal range = 10 µm; resolution = 0.01 µm; *Cut-off* = 0.25 mm/ 0.8 mm/ 2.5 mm and uncertainty in measurement (U_{cal}) = 0.08 µm for a coverage factor (k_{cal}) = 2.0. The pieces were measured taking the reference temperature = (20±1)ºC and relative humidity = (50±10)% [9, 10]. The uncertainty in measurement maximum allowable (U) = 0.025 µm and the nominal value (VN) = 3.5 µm.

Regarding the MSA, the study of repeatability and reproducibility [11, 12] was carried out by two metrologists in ten samples which each one of them measured five times. The procedure used is showed in Figure 2, where: σ_{repe} = estimate of the standard deviation for repeatability; σ_{repro} = estimate of the standard deviation for reproducibility; *R&R* = absolute parameter of repeatability and reproducibility and *%R&R* = relative parameter of repeatability and reproducibility.

To apply the *Cdl** capability coefficient, the study was divided in three parts: Considering all points measured by the two metrologists; Considering only the points measured by the metrologist number one and considering only the points measured by the metrologist number two to compare the results and verify the possible implications. The value of the maximum allowable uncertainty in measurement (U) is equal 0,1 µm, corresponding to approximately 33% of the maximum allowable tolerance.

To the statistical treatment of the measured data, the normality of the samples was initially verified, applying the Shapiro-Wilk test, Kolmogorov Smirnov test and Cramer von Mises test [13, 14, 15, 16, 17]. If the samples were approved in at least one of the tests, they are considered to come from a population with normal distribution. Then, the verification of possible outliers in the samples was carried out, applying the Dixon test (Q-test); Grubbs test and Chauvenet test [18, 19, 20].

Figure 1. Planing operation

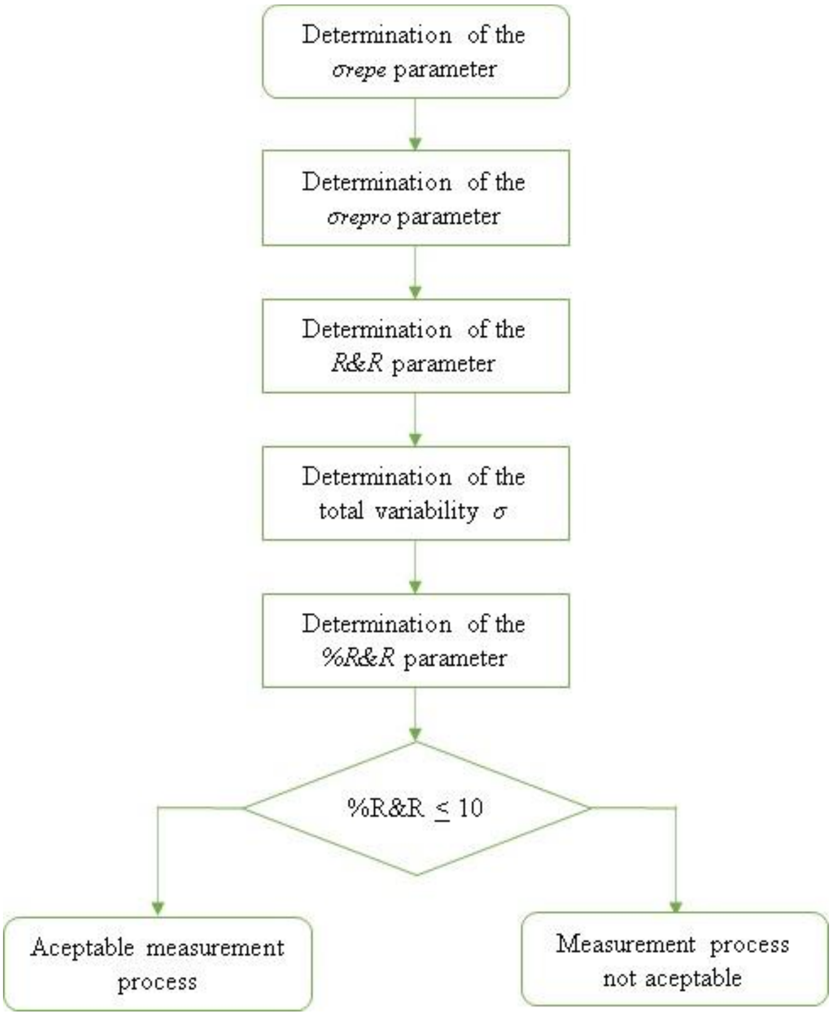

Figure 2. Stages of the repeatability and reproducibility study

3. Results and Discussions

The Table 1 presents the measurements taken and the Table 2 shows the values of the variables used in the calculation of the %R&R with a value approximately equal to 86%. According to the Table 3, the measurement process is considered unacceptable.

The Figure 3 shows the interaction between the two metrologists and the Figures 4 and 5 present the mean and range charts per metrologist, respectively. It is verified that all points are found within the control limits. The Figures 3, 4 and 5 were generated using Minitab Software, version 19.

The roughness suitability verification through the *Cdl** capability coefficient was divided into three parts: using all measured points (n = 100) with *Cdl** = 0.67; using only the data of metrologist number one (n = 50) with *Cdl** = 0.61 and using only the data of metrologist number two (n = 50) with *Cdl** = 0,57. The values of the capability coefficient were approximately equal for the three situations and presented a result of inadequacy of the measurement process, since its value was less than 1.33, corroborating the results obtained through the R&R study. The *Cdl** coefficient can be calculated per sample as shown in Figure 6. This chart was obtained with data generated by metrologist number one, using the 3C Control Chart and Capability Software [21]. The *Cdl** did not remain constant for each peace.

Table1. Measurement data

Part	Metrologist number one (µm)					Metrologist number two (µm)				
	x_1	x_2	x_3	x_4	x_5	x_1	x_2	x_3	x_4	x_5
1	3.23	3.69	3.68	3.39	3.31	3.41	3.33	3.44	3.16	3.04
2	3.36	3.24	3.61	3.52	3.08	3.07	3.06	3.77	3.82	3.09
3	3.02	3.85	3.23	3.03	3.38	3.64	3.57	3.92	3.05	3.19
4	3.35	3.40	3.19	3.13	3.30	3.40	3.12	3.44	3.16	3.63
5	3.31	3.35	3.67	3.20	3.40	3.57	3.04	3.12	3.17	3.49
6	3.29	3.61	3.37	3.02	3.16	3.30	3.54	3.89	3.52	3.18
7	3.09	3.15	3.07	3.31	3.33	3.13	3.16	3.26	3.17	3.26
8	3.93	3.39	3.96	3.77	3.08	3.85	3.79	3.17	3.92	3.41
9	3.32	3.52	3.73	3.33	3.60	3.01	3.95	3.04	3.56	3.47
10	3.23	3.10	3.02	3.45	3.42	3.38	3.36	3.06	3.20	3.50

Table 2. *R&R* study parameters

Parameter	Value
σ_{repe}	0.240 µm
σ_{repro}	0
R&R	1.441 µm
σ	0.261 µm
%R&R	86.2%

Table 3. Classification of the measurement process

%R&R	Decision
If *%R&R* ≤ 10%	Acceptable
If 10% < *%R&R* ≤ 30%	Partially acceptable
If *%R&R* > 30%	Not acceptable

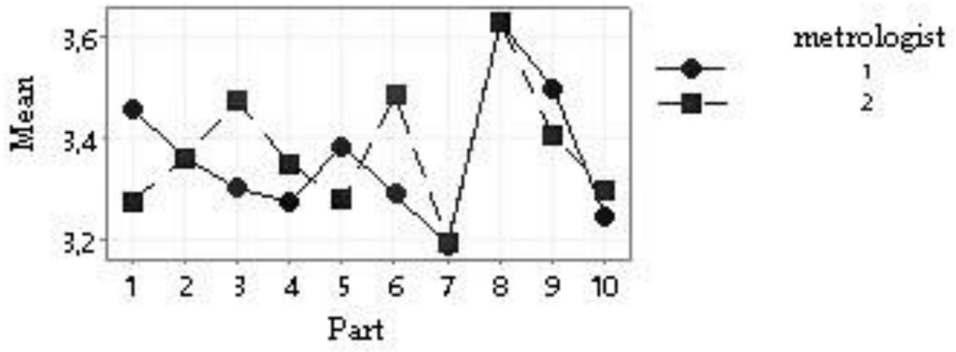

Figure 3. Interaction between metrologists

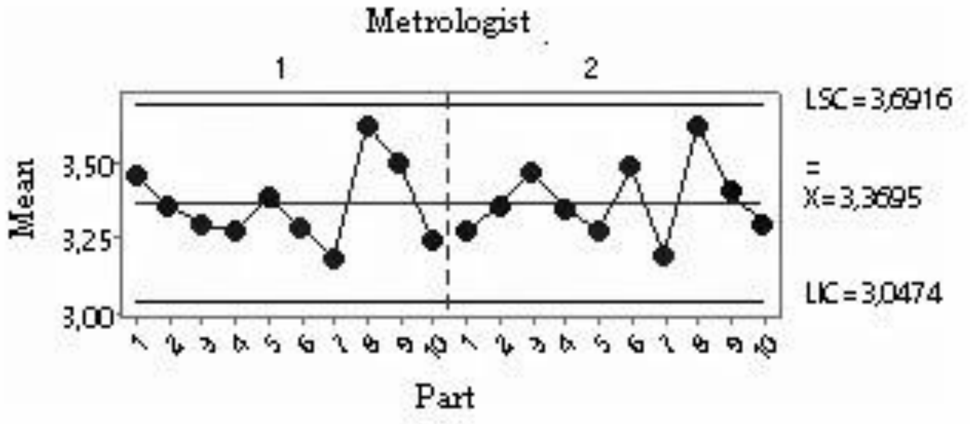

Figure 4. Mean control chart for both metrologists

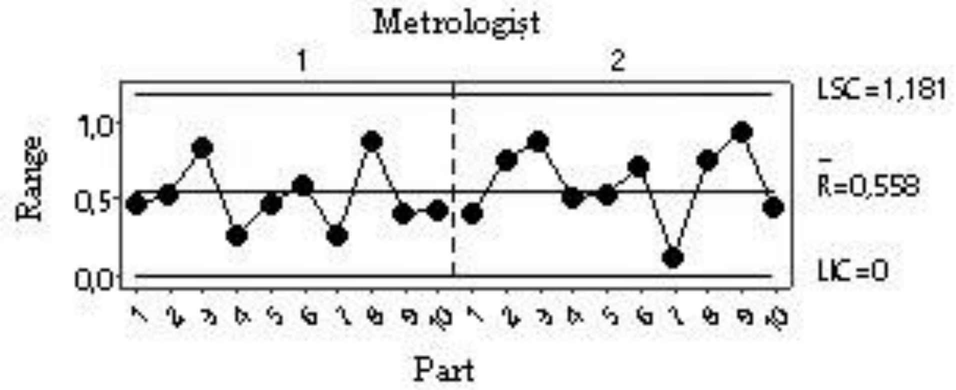

Figure 5. Range control chart for both metrologists

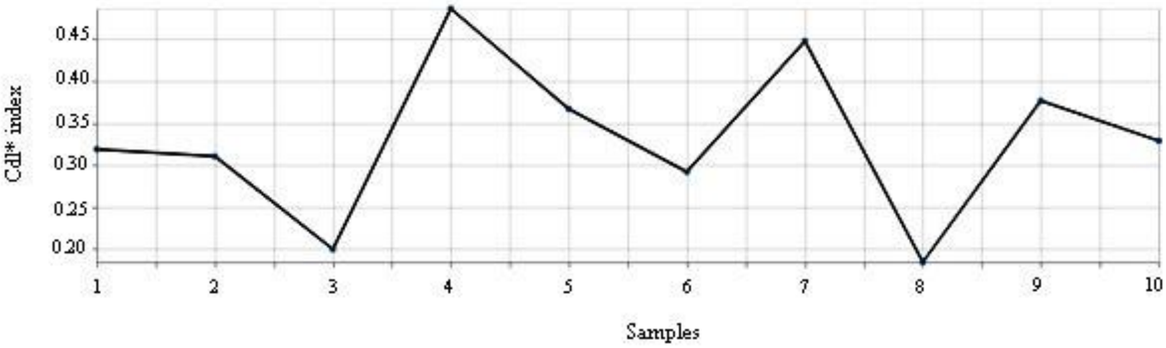

Figure 6. Variation of the capability coefficient *Cdl** for parts measured by metrologist number one

In order to verify if the manufacturing process was in statistical control, the 3C Control Chart and Capability Software [21] was used to generate the mean and range control charts, according to Figure 7 and Figure 8. Regarding the range chart, the process is in statistical control. However, regarding the mean control chart, there is a point above the upper control limit, and it is also verified by six consecutive points going up and down, characterizing that the process is out of statistical control, according to ISO 7870-2 [22].

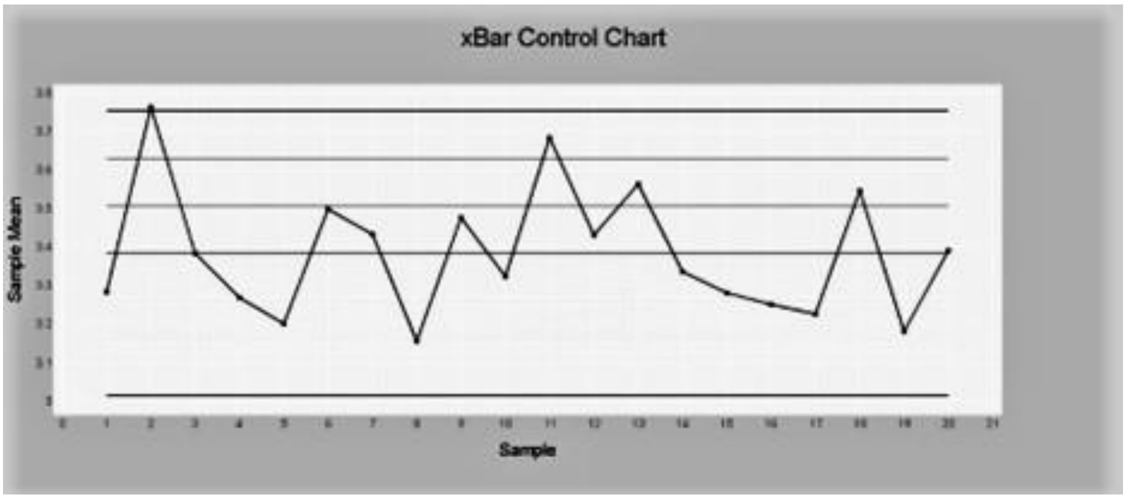

Figure 7. Statistical process control chart mean

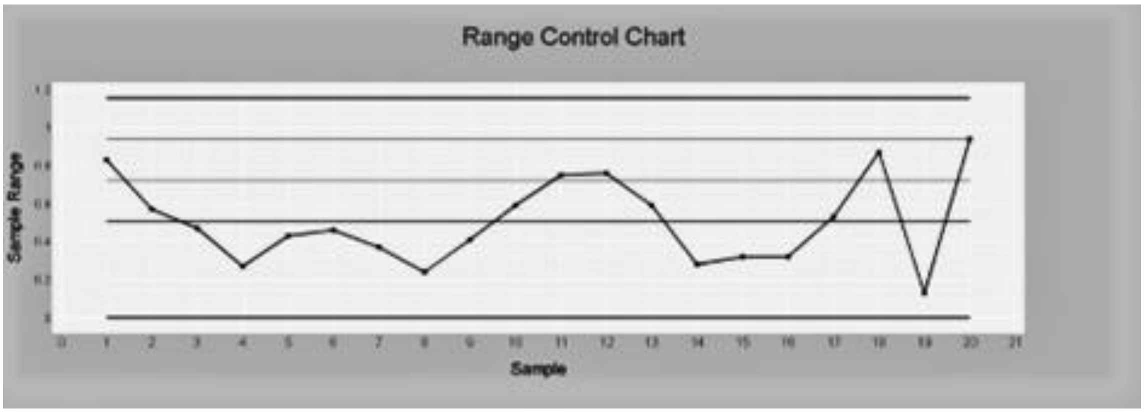

Figure 8. Statistical process control chart for range

4. Conclusions

Analyzing the data related to the R&R study, the standard deviation for reproducibility was equal to zero, as both metrologists were trained for measurement, and they followed the same measurement procedure. On the other hand, the standard deviation referring to repeatability presents a high value, which may indicate a problem in the rugosimeter. However, this problem may be due to the planing, which generated surfaces with variations in surface finish, even maintaining the repeatability conditions in the manufacturing process (the same operator, the same cutting conditions, the same machine tool, the same manufacturing procedure, the same cutting tool and the same environmental conditions). A possible explanation is that it is a very old horizontal shaper.

In order to verify the stability of the process, mean and range control charts were generated. Analyzing these charts, it was verified that the process was not in statistical control, corroborating the idea that the problem is not with the rugosimeter, but with the manufacturing process. Thus, before applying a R&R study or a capability study, it should be verified whether the manufacturing process is in statistical control.

When analyzing the variation chart of the *Cdl** coefficient for the data of the metrologist number one, a variation is verified for each part ($n = 5$). However, it is reasonable to calculate the capability coefficient for all points measured by each metrologist. The *Cdl** value was equal to 0.61 for all data of the metrologist number one. If the arithmetic mean of the ten *Cdl** values presented in Figure 2 were used, the result of *Cdl** would be equal to 0.33. This value represents a difference of approximately 51% for the *Cdl** value equal to 0.61.

References

[1] Smith R R; McCrary S W and Callahan R N. Gauge repeatability and reproducibility studies and measurement system analysis: a multimethod exploration of the state of practice. Journal of industrial technology, vol. 23, nº 1, march 2007.

[2] AIAG. (2002). Measurement Systems Analysis, Reference Manual, Third Edition. Southfield, Michigan Automotive Industry Action Group.

[3] IQA. Análise de sistemas de medição – MSA, Manual de referência Instituto da Qualidade Automotiva, 2. ed., São Paulo, 2004.

[4] Albertazzi A and Sousa A R. Fundamentos de metrologia científica e industrial. Editora Manole, Barueri, 2008.

[5] Oliveira J E F, Oliveira C A N, Oliveira S T, Soares A M F, Oliveira E J A, Silva N G and Araujo R P. Aplicação da Análise de Pareto através de um experimento fatorial para o coeficiente de capabilidade (Cdl*) – um estudo de caso relacionado à grandeza torque. Brazilian Journal of Development, Curitiba, , v. 7, n.1, jan 2021.

[6] Oliveira J E F, Oliveira C A N, Araujo R P, Oliveira E J A, Silva N G and Soares A M F. Development of the capability coefficient (Cdl*) for quality control of measuring instruments and systems. Brazilian Journal of Development, Curitiba, v.7, n.2, p. 13459-13480 feb. 2021.

[7] Oliveira J E F. A Metrologia Aplicada aos Setores Industrial e de Serviços: Principais aspectos a serem compreendidos e praticados no ambiente organizacional, Brasília, 2008.

[8] ABNT NBR ISO 4287:2002. Especificações geométricas do produto (GPS) - Rugosidade: Método do perfil - Termos, definições e parâmetros da rugosidade.

[9] Brunelli A. Calibration Handbook of Measuring Instruments. 1^{th} ed. ISA, 2017.

[10] NASA. Measurement Uncertainty Analysis Principles and Methods - NASA Measurement Quality Assurance Handbook – ANNEX 3. National Aeronautics and Space Administration, Washington DC 20546, 2010.

[11] Pan J N. Evaluating the Gauge Repeatability and Reproducibility for Different Industries. Quality & Quantity 40:499–518, Springer, 2006.

[12] Mikulová P, Plura J and Knop K. Repeatability and Reproducibility Studies for Non-Replicable Tests. Sciendo, vol. 2, pp. 275-284, 2020.

[13] Shapiro S S and WILK, M. B. An analysis of variance test for normality (complete samples). Biometrika, vol. 52, No. 3/4, (Dec., 1965), 591 – 611.

[14] Sheskin D J. Handbook of parametric and nonparametric statistical procedures. 3rd Edition. CRC Press LLC. Florida, 2003.

[15] Kapur K C. Reability Engineering. Hoboke, New Jersey: John Wiley & Sons,Inc., 2014.

[16] Kececioglu D. Reliability and Life Testing Handbook. Vol. 1 and 2. Englewood Cliffs, New Jersey: Prentice Hall, Inc., 1993 and 1994.

[17] Kececioglu D. Reliability and Life testing Handbook. Vol. 1, Destech Publications Inc. USA, 2002.

[18] Rorabacher R D B. Statistical treatment for rejection of deviant values: critical values of Dixon's "Q" parameter and related subrange ratios at the 95% level. Anal. Chem., 63 (2), 1991, 139 – 146.

[19] Grubbs F E. Procedures for Detecting Outlying Observations in Samples. American Society for Quality, Technometrics, Vol. 11, No. 1, 1969, p. 1-21.

[20] Vuolo J H. Fundamentos da teoria de erros. 2. ed., São Paulo: Blucher, 1996.

[21] Neto F R A, Oliveira J E F, Oliveira C A N, Oliveira S T, Soares A M F, Oliveira E J A and Silva N G. Desenvolvimento de um Software Open Source para Monitoração de Estabilidade de Instrumentos e Sistemas de Medição. XV Congresso Iberoamericano de Ingeniería Mecànica, Madrid, 2022.

[22] ISO 7870-2: 2013. Control Charts - Part 2: Shewart Control Charts. ISO/TC 69 Applications of statistical methods.