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MEASUREMENT PROCESSES ANALYSIS WITH GRR OR EXPANDED UNCERTAINTY? APPLICATION OF CONFIDENCE LEVEL OF 99,73% OR 95,45%?

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Abstract: This paper demonstrates the application of the ISO GUM for analysis of the measurement processes used in the product control. It describes the attention in the method application and the need to establish the acceptability criterion for the measurement process. But also their advantages, such as, the identification of the existent uncertainty sources, the simplification through the sample selection and the application of a confidence level of 95,45%.

Keywords: MSA, ISO GUM, measurement uncertainty

1. INTRODUCTION

Many companies which need to attend established requirements in the ISO 9001:2000 Standard [1] had concerned themselves with the measuring instruments control, and especially with the calibration to be carried out. However, if we verify the clause 7.6 of this Standard carefully, we will observe that it describes that “the organization must establish processes to ensure that monitoring and measurement can be carried out and in a manner that it is consistent with monitoring and measurement requirements”. It means, it is not enough that the instruments are calibrated and in agreement with their limits of permissible error. It is necessary that they are appropriated for the requested measurement task. How have the companies been evaluating this adaptation? It is common to the companies to establish a relationship among the maximum permissible error of the instrument with the tolerance of the product to be controlled. But the calibration has as its purpose to evaluate the condition of the measuring device, and the measurement process adopted in the inspection of the product can have other uncertainty sources, such as the environmental conditions, the appraiser and the own measurement method. The technical specification ISO/TS 16949 [2] introduced an additional requirement, in which demands that the companies accomplish the analysis of the measurement processes related in their control plans and it guides that the statistical methods of the customers reference manuals should be used, standing out the measurement systems analysis manual - MSA, elaborated by the American Automotive Industry Action Group [3].

Would this method be the only available for the companies? The German Automotive Association made available the VDA 5 Manual [4] with other method for evaluation of the measurement processes, using as base the statistical concepts established in the Guide for the Expression of Uncertainty in Measurement - ISO GUM [5]. Which are the advantages of the application of each method? Which are the requirements to be observed in their application?

Looking for answers for these subjects, this paper intends to rescue the main advantages of the MSA method and to incorporate them in the ISO GUM method, making the application for different physical quantities. The objective of the paper is to demonstrate the applicability of the ISO GUM method in the measurement processes analysis, as being an alternative, which can improve the evaluations in the companies.

So that, the objective of this paper can be reached initially by the accomplishment of a critical analysis of the MSA and VDA 5 methods, increasing their application difficulties and making a comparison among the established bases for each method, rescuing their strong points.

In the sequence, the caution to be taken in measurement processes analysis is presented as well as an orientation for the application of the ISO GUM method is presented. It respected the premise which demands the existent measurement conditions in the productive process should be maintained.

The analysis as the adaptation to the use of measurement process is based on the practical rule of the metrology [6] and, when necessary, a complementary analysis as the probability of incorrect inspections is accomplished, following the model presented by Donoso [7] or Kühn and Linss [8].

Additionally, an application will be presented, contemplating the measurement process analysis in agreement with the established recommendations in this paper and also following the orientations of the MSA manual, exemplifying as the measurement process analysis can be accomplished in a practical way in the companies.

2. CRITICAL ANALYSIS OF THE MSA AND VDA 5 METHODS

This paper does not have as its purpose to describe the methods in full detail presented in the MSA and VDA 5 manuals, because the same ones can be consulted in the respective sources. The objective of this chapter is to evaluate which the relevant points of each method in the analysis of a measurement process and to evidence the difficulties of its application.

2.1 MSA Method

The MSA Manual represents one of the main reference guides used by the companies that need to assist the requirements of the TS 16949:2000 guideline, regarding the measurement processes analysis used in their productive process. Its wide application is due to the recommendation given by the three great American assemblers: Crysler, Ford e GM. In the third edition, it was reaffirmed that its objective is to present guidelines to evaluate the adaptation of the measurement processes for the requested task. Its primary focus is measurement processes where the readings can be replicated on each part. The manual emphasizes the need to analyze the statistical properties of the measurement processes, such as the systematic error, the linearity, the repeatability and reproducibility (Figure 1). But it highlights that should be appraised only the relevant properties for each measurement process.

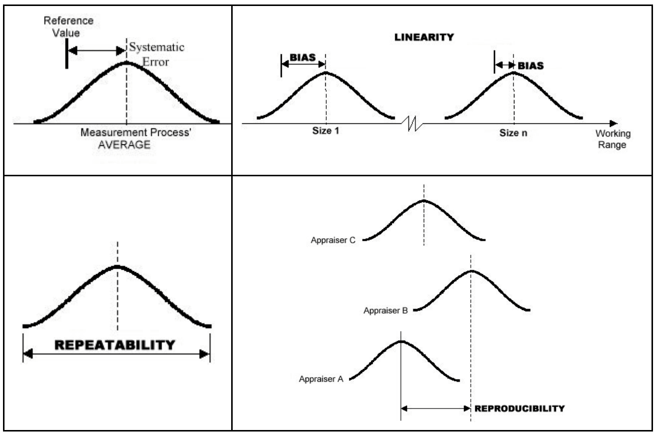


Figure 1 - Statistical properties in the MSA Method

In the evaluation of a measurement process, the manual points three fundamental aspects which should be considered:

a) the instrument should have an appropriate resolution and it recommends that it should not be superior to 10% of the tolerance (or of the productive process variation). It also detaches that the measurement process should have sensibility to detect changes in the product (or in the productive process), establishing that the number of categories (NDC) should be at least same to 5;
b) the measurement process must be stable;
c) the errors of measurement should be consistent over the expected range and adequate for the purpose of control. As criterion of acceptance of the measurement process, it is established that the systematic error or linearity is significantly equal to zero and that it does not exceed to the acceptable bias established for the measuring instrument. For the combined variation of the repeatability and of the reproducibility (GRR), the acceptance criterion defines the percentage that can be consumed of the tolerance (or of the productive process' variation). The %GRR is acceptable for inferior values to 10% and it could be expanded up to 30%, depending on the importance of its application.

Based on these aspects, some critical points should be outstanding:

a) being the resolution a source of variation of the measurement process, the recommendation of that it should not be superior to 10% of the tolerance (or of the variation of the productive process) is incompatible with the demand that %GRR should be inferior to 10%, because the error attributed to one of the uncertainty source would consume the acceptable limit;
b) for the calculation of the number of distinct categories (NDC), it is taken into account the values of GRR and the measure variation among the pieces used in the study (PV). Due to the difficulty in the selection of the pieces, the pieces used in the study cannot represent the real variation in the productive process, presenting as consequence a false value for NDC;
c) the demand of the systematic error and the linearity should be significantly equal to zero, it requests the occurrence of random errors, which cannot always be obtained. A case is the existent bias in the measuring instruments;
d) constantly, the MSA manual highlights that the preference of evaluation should be recommended in the productive process variation. In this sense, the method recommends that the pieces used in the study should be representative of the productive process, it allows a estimate of the variation of the productive process (TV). Among the main changes of the third edition quoted by Down et all [9], it should be outstanding that the 5,15 factor (for a confidence level of 99%) was suppressed in many calculations in the manual, due to the application of the TV value. However, this practice should be cautious, because an inappropriate selection of the parts can jeopardize the measurement process analysis completely;
e) for the calculations of %GRR that still demands the use of the multiplying factor, the manual does not present clarity as for the use of the 5,15 or 6 factor (this one for a confidence level of 99,73%). In the evaluation of %GRR, it is verified that in the Average and Range method the recommendation is for use of the factor 6. In the ANOVA method is used the traditional factor 5,15;
f) in spite of the manual declares that other variation sources can be considered in the GRR evaluation, the guidelines induce that it should be considered the appraiser and the equipment, as main components of the variability in the measurement process.

Clearly, the method MSA is practical, allowing that no specialized technicians in metrology can use it, due to its systematic application. But the method does not disguise the origin of the uncertainty sources and it limits to classify them coming of the appraiser and/or of the instruments. The demand for a rigorous selection of the pieces has also been harming the measurement processes analysis, because it intends to evaluate the variability of productive process at the same time. Everhart [10] states that the method is "time-consuming, costly and provides limited results". Another aspect to be outstanding is the application of a confidence level of 99 or 99,73% for the Gauge R&R percentile parameter. Dutschke [11] affirms that a larger confidence level can commit the meaning of the obtained results.

Due to the high confidence level applied in the GRR studies and a small number of replication in each part, the results of the measurement process variability are maximized. The Figure 2 exemplifies the data collected for a measurement process analysis.

PART	1	2	3	4	5	6	7	8	9	10
APPRAISER A										
TRIAL 1	82,1	89,8	81,5	88,7	85,1	94,8	98,9	89,2	89,7	91,7
TRIAL 2	83,2	90,2	82,7	88,7	84,5	95,4	98,6	89,2	89,5	90,2
TRIAL 3	82,6	89,9	81,4	88,7	84,5	95,2	98,5	89,4	89,6	91,4
RANGE	**1,1**	**0,4**	**1,3**	**0**	**0,6**	**0,6**	**0,4**	**0,2**	**0,2**	**1,5**
APPRAISER B										
TRIAL 1	84,5	92,2	82	90	84,4	92,7	99	88,7	90,7	89,1
TRIAL 2	84,2	92,3	83,6	90,7	85,7	93,6	100	89,2	90,8	89,9
TRIAL 3	84,9	92,1	83,9	91,5	86	93,5	99,2	89,9	90,5	89,8
RANGE	**0,7**	**0,2**	**1,9**	**1,5**	**1,6**	**0,9**	**1**	**1,2**	**0,3**	**0,8**
APPRAISER C										
TRIAL 1	82,7	91,4	81,5	89,9	85,1	95,2	99,4	89,4	90,6	89,6
TRIAL 2	82,9	91,3	82,7	90,2	85,8	94,8	99	89,7	89,8	89,4
TRIAL 3	82,7	91,4	82,3	90,2	85,4	94,2	98,8	89,9	89,2	89,5
RANGE	**0,2**	**0,1**	**1,2**	**0,3**	**0,7**	**1**	**0,6**	**0,5**	**1,4**	**0,2**
REPEATABILIY EV										
$\overline{\overline{RANGE}}$: **0,75**					EV: 2,7					
σ_{EV}: 0,45										
REPRODUCIBILITY AV										
x_{dif}: 0,66					AV: 2,0					
σ_{AV}: 0,33										
REPEATABILITY & REPRODUCIBILITY GRR										
σ_{GRR}: 0,56					**GRR: 3,4**					

Figure 2 – Example of data collected for a measurement process analysis

In this example it was obtained an average 0,75 for the ranges obtained by the appraisers. The largest range presented by the appraisers was 1,6. With the application of a confidence level of 99,73%, the study presented GRR = 3,3, very superior to the collected data. Considering that the measurement process is stable and the study was accomplished in 10 different pieces, the confidence level of 99,73% maximizes the results and can commit the analyses. For most of the industrial applications, the application of a confidence level of 95,45% would be acceptable and would be more representative of the reality of the measurement process. This confidence level has been used in several recent papers in the metrological literature associated with the measurement uncertainty [12].

The MSA manual does not include the measurement uncertainty as a method recommended for the measurement processes analysis. Ratifying Dietrich and Shulze's statement [13], it is possible to use the ISO GUM method [5] for this purpose, since considered the relevant variables. The own VDA 5 Manual [4] has an orientation for this application.

2.2 VDA 5 Method

One of the objectives of the VDA 5 Manual is to analyze the adaptation of the measurement processes used in the inspection of geometric quantities. In the evaluation of the measurement process, the method considers the following aspects:

a) adaptation of the measuring instrument:
- the resolution of the measuring instrument should be inferior to 5% of the product's tolerance;
- the tolerance controlled with the instrument should be superior to the T_{min} value (1):

$$T_{min} = \frac{6u_{PM}}{G_{PP}} \quad (1)$$

u_{PM} = standard uncertainty of the instrument;
G_{PP} = limit recommended for g_{PP}. The G_{PP} value can vary from 0,2 to 0,4, in agreement with the class of tolerance IT of the product;

b) adaptation of the measurement process:
- the main uncertainty components should be taken into account, among them: environmental conditions, appraisers, the measuring instrument and the object to be controlled;
- the value g_{PP}, obtained of the expression 2U/T, should be inferior to the G_{PP} value;

c) analysis of the measurement uncertainty: just the analysis of the parameter above is not enough, being necessary to evaluate its impact in the products inspection. If the measurement process is used in the control of a characteristic generated by a capable productive process, any reduction of tolerance needs to be accomplished. Equally, as it can be observed in the figure 3, if the value obtained for g_{PP} goes smaller than 50% of the established value for G_{PP}, it is not also necessary the reduction of tolerance.

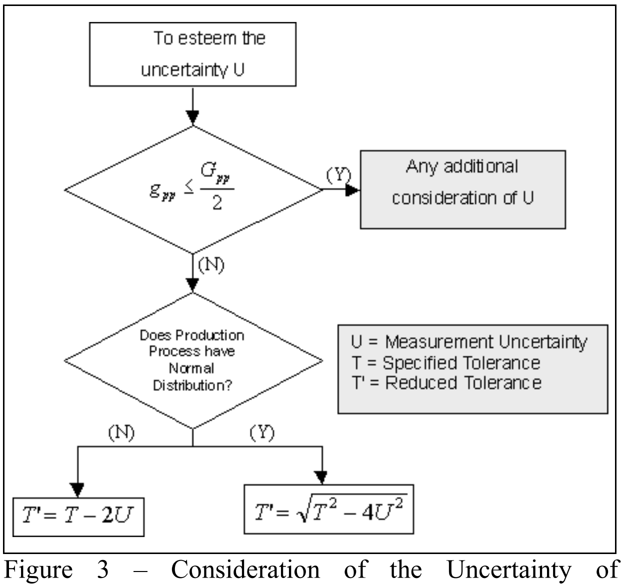


Figure 3 – Consideration of the Uncertainty of Measurement [4]

The document emphasizes that it should only be taken into account the measurement uncertainty in the control of the characteristic, if the g_{PP} value goes larger than 50% of G_{PP}. In these cases, the measurement uncertainty should be reduced lineally of the specified tolerance, if the distribution of the production process is not normal. Otherwise, the decrease can be quadratic.

Some important aspects also need to be outstanding for the VDA 5 method:

a) the recommendation of the method only for geometric quantities restricts the application of the measurement uncertainty for other physical quantities as an acceptable practice for measurement processes analysis;
b) the inclusion of non corrected systematic error as an uncertainty source can minimize to real deviation of the measurement process;
c) the reduction of the tolerance, as recommended by EN ISO 14253-1 [14], should be carefully accomplished. It is necessary to have clarity of the acceptable criterion for the measurement process. In case the customer works with the same uncertainty, the need to reduce the tolerance during the product inspection should not exist;
d) for the measurement situations, the application of a confidence level of approximately 95% is acceptable, being recommended in many papers related to the metrology.

In the sequence, a simplified method of evaluation of the measurement processes is proposed, extensive to the other physical quantities, based in ISO GUM, and that it takes into account the relevant aspects of the MSA method.

3. PROPOSAL OF THE EVALUATION METHOD

To make an appropriate analysis of the measurement process, it is necessary to have defined the measurement task to be executed, being necessary to know the characteristic to be controlled, its tolerance and the acceptable criterion for the measurement process. It is important to define the acceptable criterion priory, because it is a reference element in the selection of the measurement process. When any information is not available, it is used a admissible deviation of 20% of tolerance and it is acceptable up to 10% of tolerance to the systematic error of the process. This orientation is consequence of the practical rule of metrology, that it recommends a total uncertainty of the measurement process should not pass to 1/10, or at the most, 1/5 of the tolerance to be controlled. Considering that many production processes and several measurement methods are represented by normal distributions, it is possible to determine the occurrence probability for each event type that generates incorrect test decisions, starting from the double integration of the function density of probability, using the appropriate integration limits. Donoso [7] specifies that the different types of events can be acted for (2):

$$\text{Probability} = \int_{A-\mu_{rpp}}^{B-\mu_{rpp}} \int_{C}^{D} \frac{e^{\frac{-(y)^2}{[2.(\sigma_{rpp})^2}} . e^{\frac{-[x-\mu_{mpp}+y)]^2}{[2.(\sigma_{mp})^2]}}}{(2.\pi.\sigma_{rpp}\sigma_{mp})} dxdy \qquad (2)$$

μ_{rpp}: average of the real production process

σ_{rpp}: standard deviation of the real production process (not included σ_{pm})

μ_{mpp}: average of the measured production process

σ_{mp}: standard deviation of the measurement process

A, B: integration limits for the production process Y

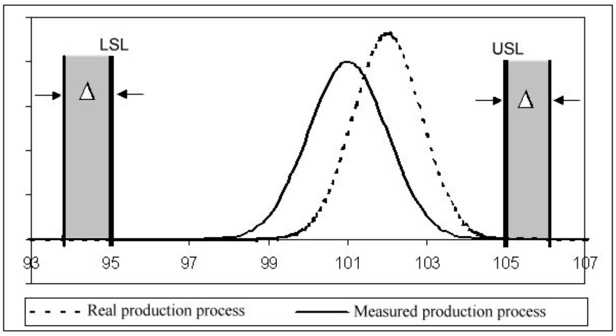
C, D integration limits for the measurement process X

To evaluate the impact of the acceptable criterion established for the measurement process, two cases were simulated to evaluate the customer's risk, in other words, the probability of accepting bad pieces. The calculation of probability was accomplished considering to be acceptable an enlargement of 10% of the tolerance in the limits of product's specification. The Figure 4 presents the data used to evaluate the impact of the measurement process in a capable production process (Cpk = 1,33), being the average moved in one standard deviation. In this case, a measurement process was considered with an error of 20% of the tolerance, being distributed 10% of the tolerance for the systematic error and 10% for the measurement process uncertainty. In these conditions, it was verified that the probability of acceptance of bad pieces was practically inexistent when the tolerance is enlarged in 10% in both specification limits.

Nominal value: 100

Tolerance of the product: 10

Enlargement of the tolerance (Δ): 10% T = 1



Characteristics of the measurement process:

- Systematic error = -1
- Measurement Uncertainty: 1

Characteristics of the production process:

- Measured average: 101
- Real average: 102
- Measured standard deviation: 1
- Real standard deviation: 0,866
- Measured Cpk: 1,33

Probability of acceptance of bad pieces: 0,0000007

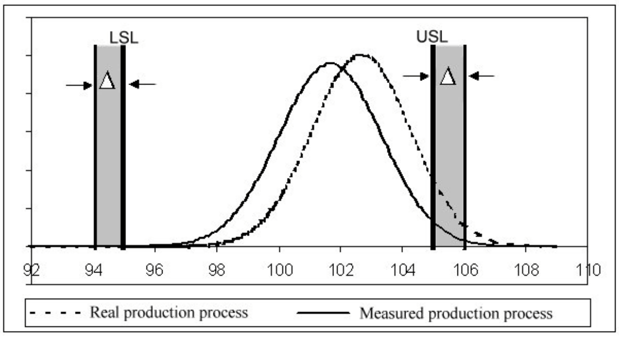
Figure 4 – Probability of acceptance of bad pieces in capable production process

The other simulation considered a process of non-capable production (Cpk =0,67). For this case it was verified that the probability of acceptance of bad pieces is 0,004, very small, when compared with the quality lack of the production process (Figure 5).

For a measurement process that presents deviations up to 20% of the tolerance, the probability of acceptance of bad pieces is low, being an acceptable criterion for many industrial applications.

Defined the acceptable criterion for the measurement process, the selection of the measuring device should be based on its resolution and in its acceptance criterion. An initial recommendation given by the method VDA5 is that the resolution is not superior to 5% of the product's tolerance and that the limit of permissible error to the instrument does not pass to 13% of the tolerance. For practical subjects, it is acceptable a maximum permissible error for the measuring instrument up to 15% of the tolerance.

Nominal value: 100
Tolerance of the product: 10
Enlargement of the tolerance (Δ): 10% T = 1



Characteristics of the measurement process:

- Systematic error = -1 UM
- Measurement Uncertainty: 1

Characteristics of the production process:

- Measured average: 101,667
- Real average: 102,667
- Measured standard-deviation: 1,667
- Real standard-deviation: 1,590
- Measured Cpk: 0,67

Probability of acceptance of bad pieces: 0,004

Figure 5 – Probability of acceptance of bad pieces in no-capable production process

For the evaluation of the measurement process, two main aspects are considered: the systematic error and the measurement uncertainty. The proposed method is composed of the following stages:

a) to establish the mathematical model for the obtaining of the measure, based on the measurement process in evaluation;
b) when there is influence of the repeatability, to select from one to three master pieces, with known conventional true value and that represent the actual or expected production process variation. For the characteristics, where the measurement is non-replicable, the alternative is to use from one to three homogeneous samples, composed of 10 items each;
c) when one of the uncertainty components is the appraiser, to select two to three appraisers that usually accomplish the measurement. Each appraiser should accomplish, at least, ten measurements in each master piece. In the case of non-replicable measurements, a measurement should be accomplished in each item that composes the homogeneous sample;
d) to calculate the average ($\overline{x}_{ij}$) and the standard deviation (s_{ij}) of each piece obtained by appraiser. The index i is associated the appraiser's identification (A, B, C) and j corresponds the identification of the master piece (1, 2 and 3).

The systematic error of the measurement process is obtained with the application of the mathematical model, using the average of the measurements obtained by piece and correcting the relevant and known systematic errors.

The evaluation of the measurement uncertainty should take into account the relevant standard-uncertainties $u(x_i)$ relevant, such as:

a) the uncertainty type A is certain for the average of the standard deviation obtained in each master piece, divided by the root of the number of measurements usually accomplished in each inspection. In case the value of the uncertainty type A is smaller than to standard-uncertainty related to the resolution, this should be applied;
b) the standard-uncertainty associated to the variation among the appraisers, when applicable, is obtained by the maxim differentiates among the general averages obtained by the appraisers, divided for $\sqrt{12}$, due to the rectangular behavior of their results;
c) the standard-uncertainty related to the measuring instrument;
d) other standard-uncertainty components, in agreement with the mathematical model established for the measurement process.

The deviation of the measurement process is obtained by the sum of the systematic error and the expanded uncertainty, and it should be inferior to the acceptable criterion established for the measurement process. In the case of unacceptable values, two actions are recommended before reject the measurement process: to verify the possibilities of reduction of the uncertainty sources or to esteem of the probability of incorrect inspections for the specific application.

3.1 Example of Application

To illustrate the proposed method, this section presents an application in the geometric quantity. It intends to use a thickness gauge to control the thickness of a product, whose specification is 1,70 +0,05 mm. For this control is selected a measuring instrument initially with a resolution of 0,001 mm and a acceptable bias of ± 0,003 mm. With a resolution corresponding to 2% of the tolerance and an acceptable bias of 6% of the tolerance, the equipment presents the basic conditions for the application. The bias of the thickness can be obtained in the calibration certificate.

The mathematical model that relates the main variables of the measurement process in study is presented in (3):

$$y = \overline{x} - CTV - E_{inst} - E_{app} \qquad (3)$$

y = measurement process systematic error
$\overline{x}$ = measures' average
CVT = conventional true value
E_{inst} = bias of the instrument used in the measurement
E_{app} = error due to the operators

It is selected 3 master pieces, whose conventional true value (CTV) was obtained at laboratory. For this study, it was obtained CTV_1 = 1,7243 mm, CTV_2 = 1,7083 mm and

CTV_3 = 1,7420 mm, with expanded uncertainty U = 0,0002 mm and k = 2.

For the accomplishment of the study 3 appraiser are selected to accomplish 10 measurements in each piece. The obtained data are presented in the Figure 6.

APPRAISER A										
Piece 1	1,724	1,725	1,726	1,726	1,726	1,726	1,725	1,725	1,725	1,726
Piece 2	1,709	1,708	1,708	1,709	1,709	1,710	1,709	1,708	1,708	1,708
Piece 3	1,743	1,743	1,743	1,742	1,743	1,742	1,743	1,742	1,743	1,743
APPRAISER B										
Piece 1	1,726	1,725	1,726	1,726	1,726	1,725	1,726	1,725	1,728	1,726
Piece 2	1,709	1,710	1,709	1,708	1,709	1,709	1,709	1,709	1,709	1,709
Piece 3	1,744	1,743	1,742	1,743	1,743	1,743	1,744	1,744	1,743	1,743
APPRAISER C										
Piece 1	1,725	1,726	1,726	1,725	1,724	1,724	1,726	1,724	1,723	1,724
Piece 2	1,709	1,708	1,708	1,708	1,708	1,709	1,708	1,708	1,708	1,708
Piece 3	1,743	1,742	1,742	1,743	1,742	1,741	1,742	1,742	1,742	1,742

Figure 6 – Obtained data (in mm)

For the evaluation of the measurement process systematic error, the mathematical model is applied and calculated the average of the obtained data (Figure 7).

APPRAISER A						
	$\overline{x}_{ij}$	s_{ij}	CTV	E_{inst}	E_{app}	y_{ii}
Piece 1	1,7254	0,0007	1,7249	0,0006	0	-0,0001
Piece 2	1,7086	0,0007	1,7083			-0,0003
Piece 3	1,7427	0,0005	1,7420			+0,0001
APPRAISER B						
Piece 1	1,7259	0,0009	1,7249	0,0006	0	+0,0004
Piece 2	1,7090	0,0005	1,7083			+0,0001
Piece 3	1,7431	0,0007	1,7420			+0,0005
APPRAISER C						
Piece 1	1,7247	0,0011	1,7249	0,0006	0	-0,0008
Piece 2	1,7082	0,0004	1,7083			-0,0007
Piece 3	1,7421	0,0006	1,7420			-0,0005
Systematic error average						-0,0001
Maximum bias of the measuring instrument						±0,002
Maximum systematic error of the measurement process						-0,0021

Figure 7 – Calculated values (in mm)

To obtain the maximum systematic error that the measurement process can present, it is necessary to include the systematic errors that will not be corrected during the measurement. An example is the bias of the own measurement instrument, that is not usually corrected during the accomplishment of the measurement in the productive process. To esteem this bias, it should be subtracted the calibration uncertainty of the acceptance criterion. In this application, it is had that the uncertainty is 0,001 mm, and the maximum bias that the instrument can present is 0,002 mm. To obtain the maximum systematic error of the measurement process, the systematic error average obtained in the study and the maximum bias should be added. For this application, the maximum deviation is -0,0021 mm.

For the calculation of the measurement uncertainty, they are considered as variation sources: the uncertainty type A, the uncertainty of the master piece, the reproducibility between the appraisers and uncertainty of the measuring instrument (Figure 8). In this case, the measurement process uncertainty is 0,0019 mm, for a confidence level of approximately 95%.

Sources of Uncertainty	Value	Divisor	$u(x_i)$	Dist.	c_i	$u_i(y)$	v_i/ veff
Type A	0,0007	1	0,0007	Normal	1	0,0007	9
Reproducibility	0,001	$\sqrt{12}$	0,0003	Ret	1	0,0003	∝
Resolution	-----	-----	-----	-----	-----	-----	-----
Measuring Instrument Uncertainty	0,001	2	0,0005	Normal	1	0,0005	∝
VTC Uncertainty	0,0002	2	0,0001	-----	1	0,0001	∝
		Combined Standard Uncertainty u(y) =				0,0009	26
		Expanded Uncertainty U =				**0,0019**	k = 2,10

Figure 8 - Estimate of the measurement uncertainty (in mm)

With base in the collected data, the measurement process presents a total deviation of 0,0040 mm, being 0,0021 mm originating from the systematic error and 0,0019 mm of the measurement uncertainty. This value is acceptable for the measurement process, due to the total deviation to be inferior to the 20% of the tolerance.

3. CONCLUSION

With the objective of analyzing a measurement process, the presented method takes into account some requirements in the selection of the measurement device, besides the deviation and the uncertainty of the measurement process. The instrument resolution should not be considered the only variable of the measurement process, but certainty it has influence in every process, and the use of an instrument with a resolution inferior to 5% of the tolerance contributes to approve the measurement process. Another aspect observed in the selection of the instrument was a cautious analysis in their acceptance limits, avoiding that they are not superior to 15% of the tolerance.

In the evaluation of the location error, it was considered the maximum bias that the measuring instrument can present. The systematic errors should be corrected and when this does not happen, they should be added to the systematic error average. Unlike what it demands the MSA method, for which the systematic error of the measurement process should be significantly equal to zero, the proposed method allows him to present values up to 10% of the tolerance of the product.

For evaluation of the width errors, the ISO GUM method was used. In the evaluation of the uncertainty, the repeatability of the measurement process is considered, being accomplished at least 10 measurements by piece, what allows a better estimate of the standard-deviation and a larger number of degrees of freedom. When the appraiser is an uncertainty source, more appraisers participate in the study to verify their contribution in the measurement process variation. Additionally, the uncertainty of the measuring instrument and of the master piece is considered. The great advantage in ISO GUM application belongs to the introduction of the relevant uncertainty sources in the measurement process and the visualization of the impact of each one on the expanded uncertainty. This visualization contributed to detect the uncertainty sources that can or should be minimized.

With the use of stable measurement processes, the application of confidence levels of 99% or 99,7% maximizes the existent variability in the same ones, and they commit the accomplished analyses. Considering that the main uncertainty sources are considered in the evaluation of the measurement process, a confidence level of approximately 95% is acceptable.

The application of the proposed method allows agility in the evaluations of the measurement processes, it brings clarity of the existent variation sources, it considers the impacts of the deviation and uncertainty separately, being an effective tool to be adopted by the companies in the analysis of their measurement processes.

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