An Alternative Method to Achieve Metrological Confirmation in Measurement Processes

M. Villeta[(1)], E.M. Rubio[(2)], A. Sanz[(3)], L. Sevilla[(4)]

[(1)]Department of Statistics and Operational Research III, Complutense University of Madrid (UCM), Av. Puerta de Hierro, s/n, E28040-Madrid, Spain. email: mvilleta@estad.ucm.es
[(2)]Department of Manufacturing Engineering, National Distance University of Spain (UNED), C/ Juan del Rosal, 12, E28040-Madrid, Spain. email: erubio@ind.uned.es
[(3)]Department of Materials and Aerospace Production, Polytechnic University of Madrid (UPM), Pl. Cardenal Cisneros, s/n, E28040-Madrid, Spain. email: asl@aero.upm.es
[(4)]Department of Civil, Materials and Manufacturing Engineering, University of Malaga (UMA), C/ Doctor Ortiz Ramos, s/n, E29071-Málaga, Spain. email: lsevilla@uma.es

ABSTRACT

Metrological confirmation process must be designed and implemented to ensure that metrological characteristics of the measurement system meet metrological requirements of the measurement process. The aim of this paper is to present an alternative method to the traditional metrological requirements about the relationship between tolerance and measurement uncertainty, to develop such confirmation processes. The proposed way to metrological confirmation considers a given inspection task of the measurement process into the manufacturing system, and it is based on the Index of Contamination of the Capability, *ICC*. Metrological confirmation process is then developed taking into account the producer risks and economic considerations on this index. As a consequence, depending on the capability of the manufacturing process, the measurement system will be or will not be in adequate state of metrological confirmation for the measurement process.

Keywords: Metrological Confirmation, Measurement Process, Tolerance, Uncertainty, Process Capability

RESUMEN

El proceso de confirmación metrológica debe ser diseñado e implementado para asegurar que las características metrológicas del sistema de medición cumplan los requisitos metrológicos del proceso de medición. El objetivo de este artículo es presentar un método alternativo a los requisitos metrológicos tradicionales sobre la relación entre la tolerancia y la incertidumbre de medición, que permita desarrollar tal proceso de confirmación. La vía propuesta para la confirmación metrológica considera una tarea concreta de inspección del sistema productivo mediante el proceso de medición, y se basa en el Índice de Contaminación de la Capacidad. De ese modo, el proceso de confirmación metrológica se desarrolla teniendo en cuenta el riesgo del productor además de consideraciones económicas sobre dicho índice. Como consecuencia de todo ello, dependiendo de la capacidad del proceso de fabricación, el sistema de medición estará o no en adecuado estado de confirmación metrológica para el proceso de medición.

Palabras clave: Confirmación Metrológica, Proceso de Medición, Tolerancia, Incertidumbre, Capacidad del Proceso

1. Introduction

Metrological confirmation process represents a fundamental element in the assurance of the quality of the manufacturing systems. Confirmation process must be designed and implemented to ensure that metrological characteristics of the measurement system meet metrological requirements of the measurement process [1]. Metrological confirmation process includes the calibration process, the verification process and the measurement uncertainty [2, 3]. Direct comparison between the measurement uncertainty and the metrological requirements will determine whether the measurement system is confirmed or not for a particular measurement process. In this sense, whether or not the tolerance to uncertainty ratio falls within a predetermined range of values, such as the established in [4], has been a routinely procedure used at the time of carrying out the metrological verification processes. The aim of this paper is to present an alternative method to the traditional metrological requirements about the relationship between tolerance and measurement uncertainty, considered in confirmation processes of measurement systems applied to industrial manufacturing systems.

The proposed way to metrological confirmation takes into account a given inspection task of the measurement process into the manufacturing system. Furthermore it is based on the Index of Contamination of the Capability (*ICC* index) proposed by Villeta [5-7]. Metrological confirmation process is then developed taking into account the producer risk and economic considerations on this index.

In such way, more capable manufacturing processes will be more demanding with the tolerance to uncertainty ratio. Therefore, depending on the capability of the manufacturing process, the measurement system will be or will not be in adequate state of metrological confirmation for the measurement process that is used to evaluate and improve the manufacturing process.

2. Metrological confirmation process

Metrological confirmation process constitutes a critical link to achieve quality manufacturing systems. The evaluation and control of manufacturing processes are based on the measurement results. If such results do not reflect the real status of manufacturing processes, incorrect decisions could be adopted with its economical associated costs.

The international standards ISO 10012:2003 [1] and ISO 9000:2005 [8] define metrological confirmation as the set of operations required to ensure that measuring equipment conforms to the requirements for its intended use. Metrological confirmation process includes calibration process, verification process and the measurement uncertainty, any necessary adjustment or repair, and subsequent recalibration, as well as comparison with the metrological requirements for the intended use of the equipment. Figure 1 illustrates the principal elements of metrological confirmation process.

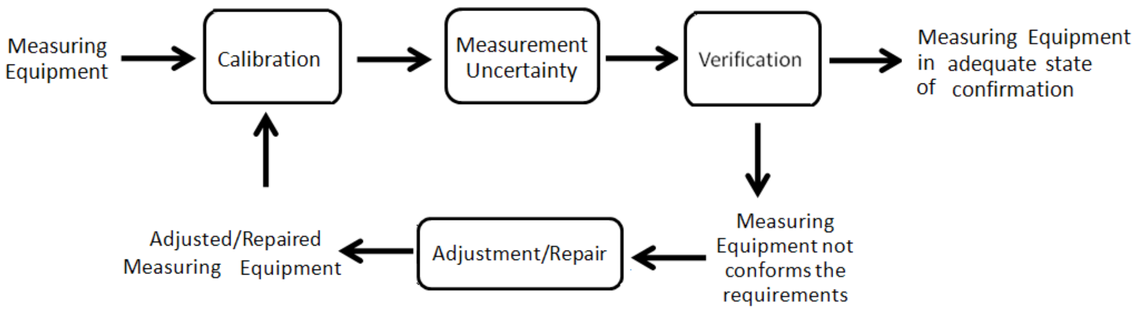

Figure 1. *Principal elements of metrological confirmation process*

The calibration process determinates the Measuring Equipment Metrological Characteristics (MEMC) in order to evaluate the uncertainty of measurement. Measurement uncertainty [3], non-negative parameter characterizing dispersion of the quantity values being attributed to a measurand based on the information used, is the mainstay of confirmation process. The verification process determines whether or not the identified metrological characteristics of measuring equipment (MEMC) meet the Customer Metrological Requirements (CMR) accordingly to the intended use of the measurement system.

Therefore, if the measuring equipment meets the metrological requirements specified for the measurement process, the measuring equipment is identified as conforms for such measurement process. Figure 2 summarize the basis of metrological confirmation process. That is, metrological confirmation process has two inputs: the customer metrological requirements (CMR) and measuring equipment metrological characteristics (MEMC); and only one output: the confirmation status of the measuring equipment.

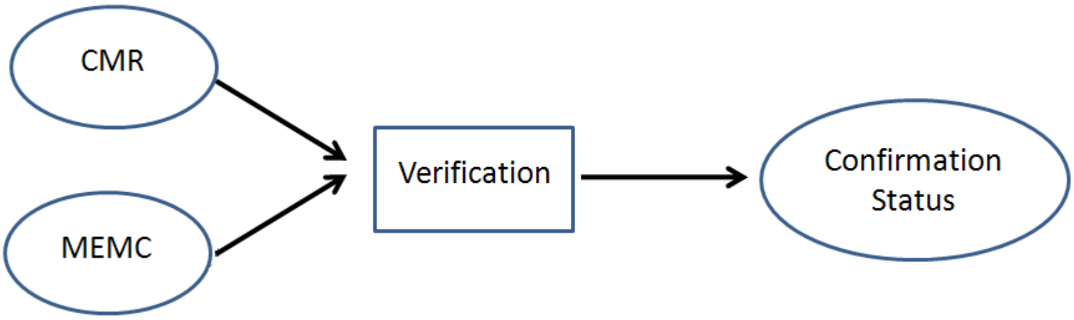

Figure 2. *Scheme of metrological confirmation process, where CMR represents the customer metrological requirements and MEMC are the measuring equipment metrological characteristics*

MEMC are factors that contribute to the uncertainty of measurement which lets direct comparison with the metrological requirements in order to establish the metrological confirmation [1]. With respect to CMR, this standard suggests that such requirements should take into account the risk of bad measurements, and the effects of these on the organization and the business; the CMR can be expressed in terms of permitted maximum error, operational limits, etc.

The relationship between tolerance and uncertainty has a great interest in metrological confirmation processes of measuring equipments from the area of dimensional metrology. Whether or not the tolerance to uncertainty ratio $T/2U$ falls within a predetermined range of values, such as the established in Equation (1) [4, 9], has been a routinely procedure used at the time of carrying out the metrological verification processes in this field:

$$3 \leq \frac{T}{2U} \leq 10 \tag{1}$$

where T represents the manufacturing tolerance and U is the expanded uncertainty of measurement [3]. Values of the tolerance to uncertainty ratio higher than 10, would lead to very expensive measurement systems. On the other hand, values lower than 3 would result in an unsuitable high number of rejected units, with the additional cost that it supposes. An illustration of this situation can be obtained from the Figure 3.

With these considerations in mind and taking into account the intended use of the measurement system, an alternative method to achieve metrological confirmation in measurement processes is developed in this work. The new method is based on the Index of Contamination of the Capability because manufacturing process capability determination is going to be considered as the final purpose of performed measurements. This index is described in next section.

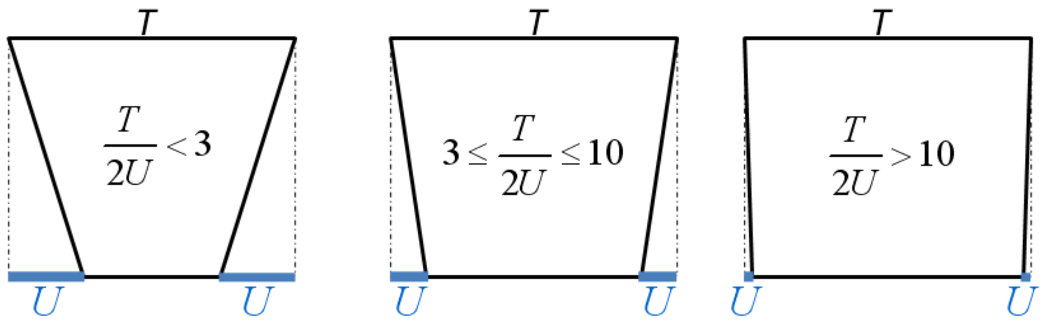

Figure 3. *Graphical sketch of relationship between the uncertainty and tolerance*

3. Index of Contamination of the Capability

In the industrial field, measurement systems are often used for evaluating and improving manufacturing processes. The variability of the measurement system affects on the data obtained from the measurement process, so these data can show a distorted image of the variation of the manufacturing process. These imperfections of measurement systems in industrial practice may result in erroneous decisions about the evaluation of manufacturing processes, which use to cause important costs to the companies.

In order to guarantee capable measurement systems for controlling manufacturing processes, Villeta [5] has proposed the *ICC* index. The model of Equation (2) has been considered for the attainment of this index.

$$Y=X+\varepsilon \tag{2}$$

where Y is the observed result after a measuring operation, X is the true value of the characteristic of a product and ε is the random error due to the measurement inaccuracy. It was assumed that X is normally distributed with average μ and variance σ_P^2 and ε is independent of X normally distributed with average zero and variance σ_M^2 .Thus in agreement with Equation (2) instead of observing the characteristic X, the empirical variable Y normally distributed with average μ and total variance σ^2 , given by Equation (3), is observed.

$$\sigma^2 = \sigma_P^2 + \sigma_M^2 \tag{3}$$

From this model and with the idea of evaluating the manufacturing process by mean of the capability index C_p (which is defined as $C_p=T/6\sigma_P$) throughout the measurement system, Equations (4) and (5) have been developed:

$$\hat{C}_{p,obs} = \frac{z_{\alpha/2}\hat{C}_{p,real}}{\sqrt{z_{\alpha/2}^2 + \left[6\gamma\hat{C}_{p,real}\right]^2}} \tag{4}$$

and

$$\hat{C}_{p,real} = \frac{z_{\alpha/2}\hat{C}_{p,obs}}{\sqrt{z_{\alpha/2}^2 - \left[6\gamma\hat{C}_{p,obs}\right]^2}} \quad (5)$$

where $z_{\alpha/2}$ represents the value of a standard normal distribution which leaves on its right a probability of $\alpha/2$ and $\gamma=U/T$. $\hat{C}_{p,obs}$ represents the observed process capability and $\hat{C}_{p,real}$ is an approach to the capability that the manufacturing process really has.

Due to the uncertainty of measurement, a capability lower than the manufacturing process really has is observed. This fact is a direct consequence from the expression in Equation (3). Furthermore, it can be proved that the greater the uncertainty of measurement, the greater the distance between the observed capability and the real capability; such difference is more pronounced in manufacturing processes of less dispersion.

With the aim of quantifying the adequacy of measurement systems in this context, the mentioned *ICC* index has been proposed by Equation (6):

$$ICC = \frac{\hat{C}_{p,obs}}{\hat{C}_{p,real}}100 \quad (6)$$

Is important to note that the *ICC* index can also be expressed - assuming the model of Equation (2) - as the ratio of the observed capability estimation and real capability estimation of C_{pk} index (defined for off-centred processes [10]), respectively [5]. Nevertheless, in present development only the expression of Equation (6) for *ICC* index has been used.

From the expression of *ICC* index in Equation (6) it can be obtained that the higher the effect of the measurement uncertainty on the capability of the manufacturing process, the lower the value of *ICC*. This index helps identity manufacturing processes quality risks associated with uncertainty in measurement systems.

4. Alternative method to metrological confirmation

The *ICC* index is online with the standard ISO 10012:2003 on measurement management systems, which suggests the establishment of indicators that show the effectiveness of measurement processes depending on the intended use of the measurements. In fact, as has been illustrated in previous section, *ICC* index quantifies the adequacy of measurement systems in the evaluation of the capability of manufacturing processes.

Therefore, taking into account the risk of bad measurements and the effects of these on the industrial companies, in order to confirm measuring equipment with respect to the task of measuring the manufacturing process capability it would be desirable that the *ICC* index be high. That is, it is interesting to establish a minimum value V_1 for *ICC* index, with which it is possible to conclude that the measuring equipment is in adequate state of metrological confirmation.

On the other hand, the *ICC* index represents, in an intuitive way, the degree of equilibrium between the manufacturing resources, responsible for the variability of the production process, and the measurement resources that are responsible for the uncertainty of the measurement process, in industrial measurement systems. Then, it would not be desirable form an economical point of view to control a manufacturing process by mean of a measuring equipment with which an excessive value of *ICC* is obtained. That is, it is also interesting to establish a maximum value V_2 for *ICC* index, with which it is possible to conclude that the measuring equipment is in adequate state of metrological confirmation.

Taking into account the producer risks and the economic considerations just mentioned on *ICC* index, an alternative method for metrological confirmation to the one of Equation (1) will be obtained from the operational limits $V_1 \leq ICC \leq V_2$. The minimum V_1 value can be fixed, for example, assuming that in case where a process capability C_p of 1.33 (value standard) is observed and taking 1-α=0.95, the minimum index agrees with the lower limit of the rank of values for the ratio of the tolerance to the uncertainty in Equation (1); From this condition and after some mathematical operations, a value for V_1 near 73 is obtained.

On the other hand, the maximum V_2 value can be fixed assuming that in case where a process capability C_p of 1.33 (value standard) is observed and taking 1-α=0.95, the maximum index agrees with the upper limit of the rank of values for the ratio of the tolerance to the uncertainty in Equation (1); From this condition, a value for V_2 near 98 is obtained.

Therefore, the alternative way for metrological confirmation based on *ICC* index, can be expressed in terms of the following permitted operational limits: $73 \leq ICC \leq 98$.

Fixing α=0.05, that is 1-α=0.95, it can be concluded that the range of values obtained for the *ICC* index is equivalent to the range of values given in Equation (7) which is expressed in terms of the tolerance to uncertainty ratio:

$$2.26\hat{C}_{p,obs} \leq \frac{T}{2U} \leq 7.52\hat{C}_{p,obs} \tag{7}$$

Then, the proposed method for metrological confirmation (expressed in Equation (7)) corrects the traditional method which is given in Equation (1), making that the intended use of the measuring equipment (determination of the capability of the manufacturing process) takes part in the permitted limits for the tolerance to uncertainty ratio, by means of the observed process capability $\hat{C}_{p,obs}$.

Therefore, if this alternative method is employed in measurement management systems, depending on the capability of the manufacturing process the measurement system will be or will not be in adequate state of metrological confirmation for the measurement process.

Table I. *Metrological requirements on tolerance to uncertainty ratio*

Observed capability	Lower limit	Upper limit
0.8	1.81	6.02
1.0	2.26	7.52
1.2	2.71	9.02
1.4	3.16	10.53
1.6	3.62	12.03
1.8	4.07	13.54
2.0	4.52	15.04
2.2	4.97	16.54

Table I illustrates the metrological requirements about the relationship between tolerance and measurement uncertainty obtained from the method for the verification process proposed in Equation (7), for different values of the observed capability of manufacturing process. It can be observed that more capable manufacturing processes result in a bigger range of values and are more demanding with tolerance to uncertainty ratio.

In order to illustrate the proposed way to metrological confirmation, a practical case is going to be briefly exposed.

Consider a manufacturing process where cylindrical bars are manufactured in a conventional lathe. To measure workpieces diameter with the aim of controlling the manufacturing process and evaluating its capability, a micrometer graduated in one-thousand of a millimeter, with an expanded uncertainty U=2.5 µm, is used. A manufacturing tolerance of 20 µm is also supposed. Therefore, with such a precision micrometer the tolerance to uncertainty ratio results in: $T/2U$=4. Suppose also that a capability of 1.2 is observed in the manufacturing process with the mentioned micrometer with micrometric readout. Then, by the Equation (7) it is obtained as the metrological requirements for the tolerance to uncertainty ratio: $2.71 \le T/2U \le 9.02$ (this interval can be seen in Table I). Because 4 lies within this permitted limits for the tolerance to uncertainty ratio, this suggests that the micrometer which is used to measure workpieces diameter is in adequate state of metrological confirmation to measure the manufacturing process, in order to evaluate its capability.

Nevertheless, the same precision micrometer would not be in adequate state of metrological confirmation for a manufacturing process with an observed capability of 2, because 4<4.52 (see Table I). Figure 4 shows this situation.

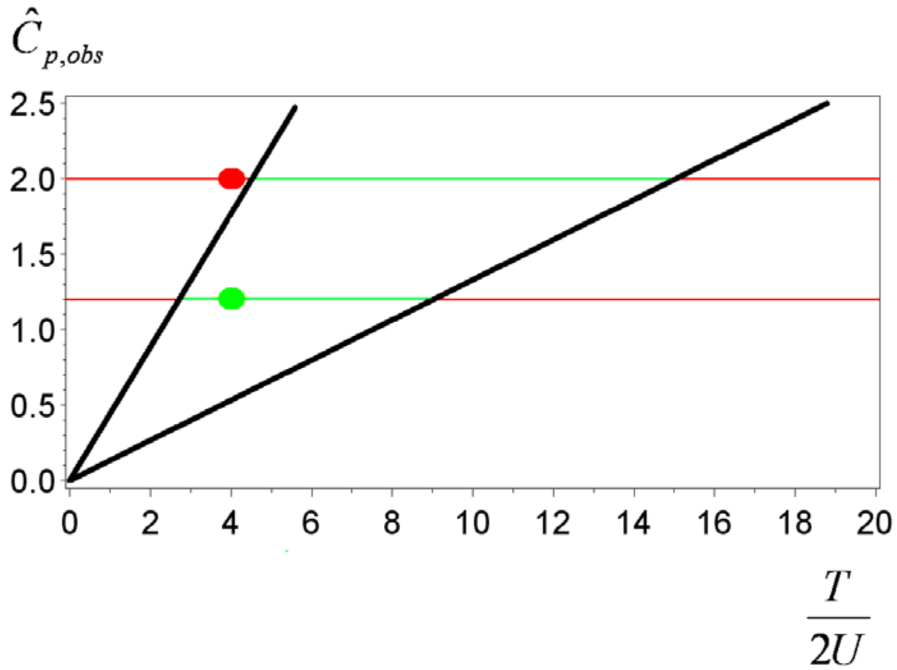

Figure 4. *Graphical representation of practical case*

5. Conclusions

The present work investigates the metrological confirmation process and focus on the metrological requirements about the relationship between tolerance and measurement uncertainty, considered in verification processes of measuring equipments applied to manufacturing systems. The following conclusions can be obtained from this investigation:

- An alternative method to the traditional metrological requirements about the tolerance to measurement uncertainty ratio, to carry out metrological confirmation processes, has been developed.
- The proposed method to achieve metrological confirmation status follows the recommendations of the international standards ISO 10012:2003 and ISO 9000:2005, because it aims to ensure that measuring equipment conforms to the requirements for its intended use; in this investigation, the determination of manufacturing process capability has been considered as the final purpose of performed measurements.
- The method is based on *ICC* index because it takes into account the risk of bad measurements and their effects on the organization and the business, as suggests the international standard ISO 10012:2003.

- As a result of applying this method, depending on the capability of the manufacturing process and on the uncertainty of measurement, the measurement system will be or will not be in adequate state of metrological confirmation for the measurement process.
- The permitted operational limits for metrological requirements on tolerance to uncertainty ratio result in a bigger range of values for more capable manufacturing processes, which will be more demanding with tolerance to uncertainty ratio.

Therefore, an alternative method to achieve metrological confirmation in measurement processes, which is based on the Index of Contamination of the Capability *ICC*, has been proposed. Such method is of special interest in practical applications of quality-oriented measurement systems used to improve industrial manufacturing processes, as well as in standardized activity of measurement management systems.

6. Acknowledgements

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