XX IMEKO World Congress
Metrology for Green Growth
September 9–14, 2012, Busan, Republic of Korea

CAPABILITY OF MEASUREMENT PROCESSES BASED ON ISO/FDIS 22514-7 AND VDA 5

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Abstract: Calculations of capability and performance indices are based on measurement results. The uncertainty of the measurement process used to generate capability and performance indices must be estimated before the indices can be meaningful. The actual measurement uncertainty needs to be adequately small.

To demonstrate the suitability of measurement processes, were in the industrial production process based on the MSA version 4 (AIAG Measurement System Analysis [1]) is used.

Another procedure is based on the ISO 98-3 ISO; Guide to the Expression of Uncertainty in Measurement (GUM) [2]. But this is not practical in production. Therefore, the ISO 22514-7 [3] was published. This document is in the FDIS (Final Draft ISO) status and will be official until mid-2012 as an ISO Standard. The VDA 5; Measurement Process Capability [4] is also based on this new standard.

Keywords: measurement system. measurement process, measurement capability, minimum tolerance

1. INTRODUCTION

The purpose of a measurement process is to produce measurement results obtained from defined characteristics on parts or processes. The capability of a measurement process is derived from the statistical properties of measurements from a measurement process that is operating in a predictable manner.

If the measurement process is used to judge whether a characteristic of a product conforms to a specification or not, the uncertainty of the measurement process must be compared to the specification itself. If the measurement process is used for process control of a characteristic, the uncertainty shall be compared with the process variation. Limits of acceptability should be stated for both cases.

The quality of measurement results is given by the uncertainty of the measurement process. This is defined by the statistical properties of multiple measurements, or estimates of properties, based on the knowledge of the measurement process.

ISO/FDIS 22514-7 describes methods to define and calculate capability indices for measurement processes based on estimated uncertainties. The approach given in ISO 98-3, Guide to the expression of uncertainty in measurements (GUM) is the basis of this approach.

2. MEASUREMENT SYSTEM AND PROCESS

The new ISO 22514-7 divides all influence components of a measurement process in two groups. There are the influence components of the measurement process mainly associated with the measuring system and any other influence components. The influence components of both groups put together represent the measurement process. Figure 1 shows typical influence components displayed in an Ishikawa diagram. The influence components displayed at the bottom are associated with the measuring system. Together with the influence components on top, they describe the entire measurement process.

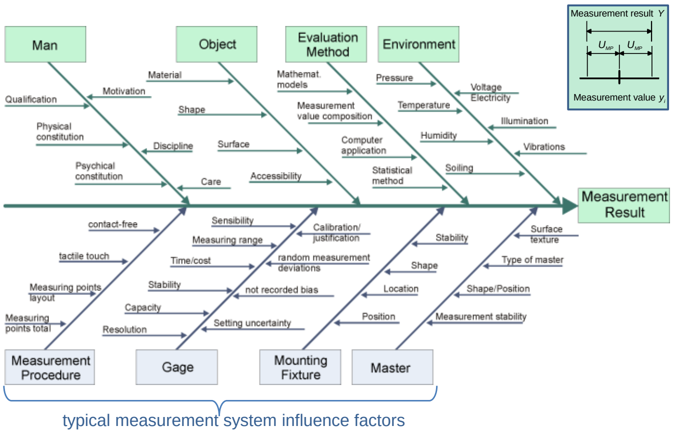

Figure 1: Definition Measurement System and Process

Since the measurement process is distinguished from the measuring system, the expanded measurement uncertainty is specified for both of them separately. This is reasonable in order to evaluate the measuring system independently of its application in production. This classification helps companies to choose suitable selection criteria. Thus, for each individual measurement process, the capability of the measuring system can be assessed. In addition, the manufacturers of measuring systems are able to specify the expanded measurement uncertainty of the measuring system without knowing its future applications.

Since not every influence component can be examined separately, they were combined into main influence quantities. A measuring system is affected by the uncertainty from the

- measurement standard
- mounting device
- measuring equipment and
- measurement method.

The measurement process is influenced by uncertainties from the

- environment
- evaluation method
- test part and
- operator.

Based on this difference, the expanded measurement uncertainty is determined for the measuring system U_{MS} and for the measurement process U_{MP} together with the corresponding capability ratios Q_{MS} or Q_{MP} . By comparing the capability ratio to a specified limit, the capability of the measuring system or measurement process is established. It is also advisable to calculate the minimum possible tolerance for the measuring system $TOL_{MIN\text{-}UMS}$ and the measurement process $TOL_{MIN\text{-}UMP}$ as an additional parameter.

In order to evaluate the impact of the combined influence component on the total uncertainty, a standard uncertainty is calculated for each main influence quantity. According to GUM, the standard uncertainty is estimated by means of the Type A evaluation (performing experiments) or the Type B evaluation (available information).

3. PROCEDURE

The ISO 22514-7 offers a well-structured procedure in order to determine the expanded measurement uncertainty. The same applies to the definition of the capability ratios of the measuring system or measurement process.

- First, check whether the resolution of the measuring instrument is lower than 5 % of the specification. If the resolution is inadequate, the variation will be estimated too low (it often approaches zero). In this case, a reasonable evaluation is not possible.
- If the *MPE* (maximum permissible error) of a measuring instrument is known from a continuous calibration or another inspection, it may be used in order to calculate the expanded measurement uncertainty. This usually applies to standard measuring equipment. However, the *MPE* must be documented and traceable. (Only apply this procedure in exceptional cases.)
- If the MPE is unknown, the expanded measurement uncertainty of the measuring system U_{MS} shall be based on available or new inspections according to the Type 1 study (repeated measurements on a reference standard in order to assess the variation of the measuring instrument or the systematic measurement error). By including the uncertainty of the measurement standard, and, if known, the linearity deviation, U_{MS} and the capability ratio Q_{MS} are calculated. The capability ratio is compared to a specified limit (VDA Volume 5 recommends 15 %).
- As soon as the measuring system meets this requirement, the expanded measurement uncertainty of the measurement process U_{MP} and/or the corresponding capability ratio Q_{MP} shall be determined. Inspections according to the Type 2 study (repeated measurements on test parts taken by several operators) lead to the GRR value (see MSA manual). In order to determine the expanded measurement uncertainty of the measurement process U_{MP}, this value can be used exactly as it is. The GRR value and the expanded measurement uncertainty both require the same formulas. In a final step, the uncertainty from test part inhomogeneity, temperature, reproducibility over time and, if required, even other influence components must be considered in order to determine U_{MP}. A comparison between the capability ratio Q_{MP} and the limit (VDA Volume 5 recommends 30 %) determines whether the measurement process is capable.
- If the measurement process meets all requirements, its capability is established. The stability of the measuring instrument must be proved and established in the running process. In case of significant changes, the measurement process shall be re-evaluated immediately.

For both, the measuring system and the measurement process, the statistical value of the minimum tolerance has turned out to be most useful in practice. Even though the calculation of the capability ratio of the measuring system Q_{MS} includes a certain tolerance *TOL*, it can be changed to a minimum tolerance. Based on an accepted limit of *x* percent (VDA Volume 5 proposes 15 %), the formula can be rearranged to solve it for the minimum tolerance $TOL_{MIN\text{-}UMS}$ required to establish the capability of the measuring system. The same applies to the measurement process. For the measurement process, the recommended limit amounts to 30%. This leads to the minimum tolerance $TOL_{MIN\text{-}UMP}$ required establishing the capability of the measurement process.

These statistical values for the measuring system and the measurement process allow for a clustering in such a way as to transfer the results to similar or the same measuring systems and measurement processes. Unnecessary and time-consuming inspections are not required any longer.

4. CALCULATION OF CAPABILITY INDICES

Table 1 shows how to determine the expanded measurement uncertainties and the capability ratios for the measuring system and the measurement process. The mathematical effort is reduced to the calculation of the standard uncertainty components corresponding to the respective main influence quantity. Table 2 and Table 3 outline the calculation methods for the measuring system and the measurement process.

Uncertainty components	Symbol	Test / model
Resolution of the measuring system	u_{RE}	%RE must be lower/equal than 5% of the specification $u_{RE} = \frac{1}{\sqrt{3}} \cdot \left(\frac{RE}{2}\right) = \frac{1}{\sqrt{12}} \cdot RE$ where RE is the resolution
Calibration uncertainty	u_{CAL}	Obtained from the calibration certificate of measurement standards. In cases where the uncertainty in protocol is given as an expanded uncertainty, it should be divided by the corresponding coverage factor: $u_{CAL} = U_{CAL} / k_{CAL}$
Repeatability on reference standard	u_{EVR}	Depending on the measuring system, repeated measurements are taken on one, two or three standards. On one measurement standard, at least 25 repeated measurements are taken whereby their spread $u_{EVR} = s_g$ can be estimated. On each of two standards, at least 15 repeated measurements are taken whereby their spread u_{EVR} can be estimated. The greatest one of the results is used. On each of three standards, at least 10 repeated measurements are taken whereby their spread u_{EVR} can be estimated. The greatest one of the results is used.
Uncertainty from bias	u_{BI}	From the measured values on a reference standard taken during a repeatability analysis, the standard uncertainty u_{BI} can be calculated based on the systematic measurement error from: $u_{BI} = \frac{\lvert \bar{x}_g - x_m \rvert}{\sqrt{3}}$ In case of two or three measurement standards, the greatest one of the results is used.
Uncertainty from linearity	u_{LIN}	In the calculation of linearity, u_{LIN} is determined by the method of ANOVA (lack-of-fit deviation). For measuring systems with linear material measure, the uncertainty from linearity is determined based on the results from the manufacturer’s or calibration certificate.
Uncertainty from other influence components	u_{MS_REST}	Any further influences on the measuring system, supposed or substantial, must be estimated separately by experiments or from tables and manufacturer’s specifications.

Table 1 Typical uncertainty components of a measuring system

Uncertainty components	Symbol	Test / model
Repeatability on test parts	u_{EVO}	Minimum sample size: 30 Always a minimum of 2 repeated measurements on a minimum of 3 test parts measured by a minimum of 2 operators (if relevant), measured by a minimum of 2 different measuring systems (if relevant) see “Type 2 study” MSA Estimation of uncertainty components by the method of ANOVA.
Reproducibility of operators	u_{AV}	
Reproducibility of measuring systems (place of measurement)	u_{GV}	
Reproducibility over time	u_{STAB}	
Uncertainty from interaction(s)	u_{IAi}	
Uncertainty from test part inhomogeneity	u_{OBJ}	$u_{OBJ} = \frac{a_{OBJ}}{\sqrt{3}}$ where a_{OBJ} is the maximum form deviation
Uncertainty from temperature	u_T	The influence from temperature can be calculated using different methods: • ISO 14253-2 • Uncertainty with correction of the different linear expansions • Uncertainty without correction of the different linear expansions
Uncertainty from other influence components	u_{REST}	Any further influences of the measurement process must be estimated separately.

Table 2 Typical uncertainty components of a measuring process

Uncertainty components	Symbol	Combined measurement uncertainties	Expanded measurement uncertainties	Capability ratio minimum tolerance
Calibration uncertainty on standard	u_{CAL}	$u_{MS} = \sqrt{u_{CAL}^2 + \max\{u_{EVR}^2, u_{RE}^2\} + u_{BI}^2 + u_{LIN}^2 + u_{MS\_REST}^2}$ or $\sqrt{\frac{MPE^2}{3}}$ or $\sqrt{\frac{MPE_1^2}{3} + \frac{MPE_2^2}{3} \ldots}$	$U_{MS} = k \cdot u_{MS}$ where k=2 (P=95%)	$Q_{MS} = \frac{2 \cdot U_{MS}}{TOL} \cdot 100\%$ $T_{MIN-UMS} = \frac{2 \cdot U_{MS}}{Q_{MS\_max}} \cdot 100\%$
Uncertainty from bias	u_{BI}			
Uncertainty from linearity	u_{LIN}			
Repeatability on standards	u_{EVR}			
Uncertainty from other influence components (measuring system)	u_{MS_REST}			
Maximum permissible error	MPE			
Repeatability on test part	u_{EVO}	$u_{MP} = \sqrt{u_{CAL}^2 + \max\{u_{EVR}^2, u_{EVO}^2, u_{RE}^2\} + u_{BI}^2 + u_{LIN}^2 + u_{AV}^2 + u_{GV}^2 + u_{STAB}^2 + u_{OBJ}^2 + u_T^2 + u_{REST}^2 + \sum_i u_{IA_i}^2}$	$U_{MP} = k \cdot u_{MP}$ where k=2 (P=95%)	$Q_{MP} = \frac{2 \cdot U_{MP}}{TOL} \cdot 100\%$ $T_{MIN-UMP} = \frac{2 \cdot U_{MP}}{Q_{MP\_max}} \cdot 100\%$
Reproducibility of operators	u_{AV}			
Reproducibility of measuring systems	u_{GV}			
Reproducibility over time	u_{STAB}			
Uncertainty from interaction(s)	u_{IAi}			
Uncertainty from test part inhomogeneity	u_{OBJ}			
Resolution of the measuring system	u_{RE}			
Uncertainty from temperature	u_T			
Uncertainty from other influence components	u_{REST}			

Table 3 Calculation of expanded measurement uncertainty

5. COMPARISON BETWEEN THE MSA MANUAL VOLUME 4 AND ISO 22514-7

The MSA manual assesses capability by comparing the calculated Gage Repeatability & Reproducibility value to the specified limit. Prior to its calculation, the MSA manual only observes whether the systematic measurement error (or the linearity, if available) is sufficiently small. Moreover, the number of data categories *ndc* is evaluated. The number must be greater than 5. This requirement is similar in its purpose compared ISO 22514-7 where the resolution must be lower than 5 % of the specification. If the %GR&R value exceeds the specified limit, the value itself will not indicate why the limit is violated. In order to find the reason for this exceeding, intermediate results must be consulted and, if necessary, further inspections are needed. This is a major disadvantage of the evaluation in accordance with the MSA manual.

ISO 22514-7 evaluates each component of the measurement process affecting the measurement uncertainty separately. The standard uncertainty u_i is calculated for each influence component. This uncertainty provides the basis for the calculation of the expanded measurement uncertainty and the capability ratios of the measuring system and the measurement process.

The advantages of the MSA manual are its high international recognition and the versatile application of the procedures it describes. The detailed observation of the influence components affecting the measurement process and their impacts on the expanded measurement uncertainty argue for ISO 22514-7. In addition, this document is an ISO standard, which might lead to a greater recognition of this approach. Time will tell which procedure will become more important in the future.

6. EXAMPLE

An instrument measuring boltholes requires that the capability of the measurement process for inside diameters should be established and documented. Uncertainties from test part or the temperature are regarded as negligible and are not considered in the evaluation.

Information about measuring system and measurement process	
Nominal dimension	30,000 mm
Upper specification limit U	30,008 mm
Lower specification limit L	30,003 mm
Resolution of the measuring system RE (1 digit = 0,0001mm)	0,1 µm
Calibration uncertainty U_{CAL}	0,026 µm
Coverage factor k_{CAL}	2
Linearity	0
Reference quantity value of the standard at the upper specification limit x_{mu}	30,0076 mm
Reference quantity value of the standard in the centre of the specification x_{mm}	30,0050 mm
Reference quantity value of the standard at the lower specification limit x_{ml}	30,0025 mm
Capability ratio limit measuring system Q_{MS_max}	15%
Capability ratio limit measurement process Q_{MP_max}	30%

In order to determine the standard uncertainties from repeatability on standards and from measurement bias, an experiment was conducted performing 10 repeated measurements on each of 3 reference standards.

	Standard 1	Standard 2	Standard 3
Reference value	30,0076	30,0050	30,0025
Trial 1	30,0075	30,0050	30,0025
Trial 2	30,0075	30,0051	30,0024
Trial 3	30,0077	30,0051	30,0024
Trial 4	30,0075	30,0050	30,0023
Trial 5	30,0076	30,0052	30,0025
Trial 6	30,0076	30,0051	30,0024
Trial 7	30,0076	30,0050	30,0023
Trial 8	30,0075	30,0051	30,0023
Trial 9	30,0076	30,0051	30,0024
Trial 10	30,0076	30,0052	30,0024

The information about the measuring system and the measured quantity values gained in the experiment leads to the following uncertainty budget and overview of results.

Due to a percentage resolution %RE of 2,00 % and a capability ratio QMS of 7,86 %, the capability of the measuring system of the instrument measuring boltholes is established.

Tolerance	TOL	=	0.0050	
Resolution	%RE	=	2.00%	0 5
Combined standard uncertainty	u_{MS}	=	0.0000982	
Expanded measurement uncertainty	U_{MS}	=	0.000196	
Capability ratio limit	Q_{MS_max}	=	15.00%	
Capability ratio	Q_{MS}	=	7.86%	0 15
Minimum tolerance	$TOL_{MIN-UMS}$	=	0.00262	

After the capability of the measuring system is established, the measurement process is analyzed. The operator influence, the repeatability on test parts and their interactions are determined experimentally under operational conditions. In this experiment, 2 repeated measurements are performed on each of 10 test parts by 3 operators.

	Operator A		Operator B		Operator C	
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
1	30,0054	30,0055	30,0057	30,0058	30,0058	30,0057
2	30,0056	30,0058	30,0059	30,0054	30,0057	30,0058
3	30,0053	30,0054	30,0055	30,0055	30,0056	30,0059
4	30,0041	30,0042	30,0043	30,0044	30,0045	30,0042
5	30,0051	30,0053	30,0055	30,0049	30,0052	30,0049
6	30,0050	30,0052	30,0054	30,0055	30,0055	30,0053
7	30,0049	30,0050	30,0049	30,0052	30,0051	30,0051
8	30,0056	30,0056	30,0057	30,0059	30,0058	30,0057
9	30,0054	30,0055	30,0056	30,0057	30,0054	30,0056
10	30,0057	30,0058	30,0059	30,0061	30,0057	30,0061

Based on the recorded measured quantity values, the individual standard uncertainties can be determined and allocated by using the method of ANOVA. This leads to the following uncertainty budget and overview of results for the measurement process.

Uncertainty components	Symbol	Type	u	Rank
Resolution of the measuring system	u_{RE}	B	0.0000289	5*
Calibration uncertainty	u_{CAL}	B	0.0000130	6
Repeatability on reference standard	u_{EVR}	A	0.0000738	3*
Uncertainty from linearity	u_{LIN}	B		
Uncertainty from Bias	u_{BI}	A	0.0000635	4
Measurement system	u_{MS}		0.0000982	
Reproducibility of operators	u_{AV}	A	0.0000892	2
Repeatability on test parts	u_{EVO}	A	0.000151	1
Uncertainty from interactions	u_{IAi}	A	[pooling]	
Measurement process	u_{MP}		0.000187	

Combined standard uncertainty	u_{MP}	=	0.000187	
Expanded measurement uncertainty	U_{MP}	=	0.000374	
Capability ratio limit	Q_{MP_max}	=	30.00%	
Capability ratio	Q_{MP}	=	14.98%	0 30
Minimum tolerance	$TOL_{MIN-UMP}$	=	0.00250	

Due to a capability ratio QMP of 14,98 % in case of a process capability ratio limit QMP_max of 30 %, the capability of the measurement process of the instrument measuring boltholes is established.

6. REFERENCES

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