Measuring Systems and Measurement Processes Are Very Different Animals

After ISO/TS 14253-1 was developed and published in 1999, the VDA "measurement uncertainty" work group was founded leading to the publication of the first edition of VDA Volume 5 "Capability of Measurement Processes" in 2003. Now, VDA Volume 5 was completely revised and has been available as draft version since November 2010. In general, a new aspect is the differentiation between measuring system and measurement process.

The new VDA Volume 5 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. 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 $T_{MIN-UMS}$ and the measurement process $T_{MIN-UMP}$ 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).
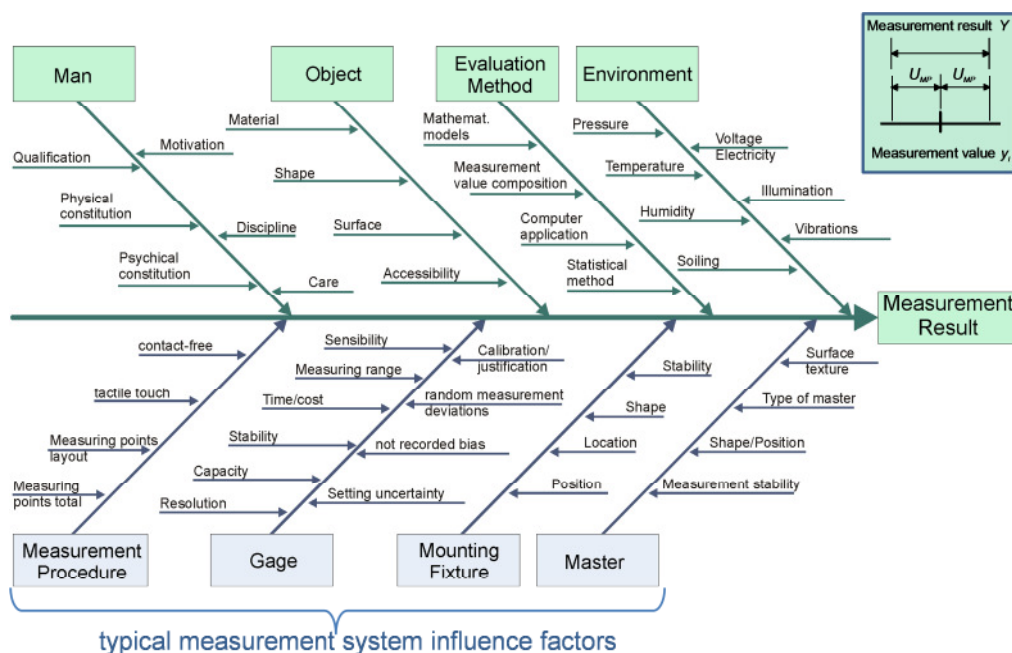

Figure 1: Definition Measurement System and Measurement Process

Well-structured procedure recommended

The completely revised edition of VDA VOLUME 5 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 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 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 $TOL_{MIN-UMS}$ 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 $TOL_{MIN-UMP}$ required to establish 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.

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 $u_{RE} = \frac{1}{\sqrt{3}} \times \left(\frac{RE}{2}\right) = \frac{1}{\sqrt{12}} \times RE$ 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: $$u_{BI} = \frac{\left| \overline{x}_g - x_m \right|}{\sqrt{3}}$$ 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

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

Table 2: Typical uncertainty components of the measuring system

Uncertainty components	Symbol	Test / model
Repeatability on test parts	u_{EVO}	Minimum sample size: 30
Reproducibility of operators	u_{AV}	Always a minimum of 2 repeated measurements on a minimum of 3 test parts
Reproducibility of measuring systems (place of measurement)	u_{GV}	measured by a minimum of 2 operators (if relevant), measured by a minimum of 2 different measuring systems (if relevant)
Reproducibility over time	u_{STAB}	see "Type 2 study" MSA **Fehler! Verweisquelle konnte nicht gefunden werden.**
Uncertainty from interaction(s)	u_{IAi}	Estimation of uncertainty components by the method of ANOVA.
Uncertainty from test part inhomogeneity	u_{OBJ}	$u_{OBJ} = \dfrac{a_{OBJ}}{\sqrt{3}}$ 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 3:   Typical uncertainty components of the measurement process determined in experiments (Type A evaluation)

International acceptance expected

The first positive reports about capability analyses, particularly due to their software support, suggest a high acceptance among users of this guideline. Combined with the new ISO/WD 22514-7 standard, VDA Volume 5 may also gain in importance internationally.

VDA Volume 5

Why a revised guideline?

The 2nd edition of VDA Volume 5 contains a number of changes needed for a further development and an internationalization of measurement procedures:

- consistent terms and definitions based on standards like ISO 3534 ff. and VIM
- recommendations for a well-structured procedure in order to determine the expanded measurement uncertainty and capability ratios
- calculations of standard uncertainty components based on GUM and ISO/WD 22514-7 formulas
- available data from previous inspections according to the MSA manual may be included
- software support in calculating statistical values
- examples based on one another for a better understanding of the subject

Training concept: The VDA QMC now offers trainings to become a VDA test equipment representative. After passing an oral and written examination, each participant receives a certificate. The training includes three modules.

- basic training: "Metrology for Newcomers"
- "VDA 5 Capability of Measurement Processes"
- "VDA Test Equipment Monitoring"

At the same time, the Q-DAS GmbH provides e-learning courses covering each of the three modules. The VDA QMC approves these courses.

Sources

- A.I.A.G. – Chrysler Corp., Ford Motor Co., General Motors Corp.: Measurement Systems Analysis, Reference Manual, 4th edition, Michigan, USA, 2010
- DIN ISO/IEC Guide 99:2007: International vocabulary of metrology (VIM). Beuth Verlag, Berlin, 2010
- ISO/WD 22514-7: Capability and performance – Part 7: Capability of Measurement Processes. Geneva, 2008
- ISO/IEC Guide 98-3 (2008): Guide to the expression of uncertainty in measurement (GUM:1995). International Organization for Standardization, Geneva, 2008
- ISO 3534-1 to 3534-3: Statistics – Vocabulary and symbols. Beuth Verlag, Berlin, 2006
- ISO/TS 14253-1: Geometrical product specifications (GPS). Inspection by measurement of workpieces and measuring equipment. Part 1: Decision rules for proving conformance or non-conformance with specifications. Beuth Verlag, Berlin, 1999
- VDA Volume 5 – Capability of Measurement Processes. 2nd edition, VDA, Berlin 2010

"Measurement uncertainty" work group

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