VDA QMC
Verband der Automobilindustrie
Qualitäts-Management-Center

5 Part 1

Quality Management in the Automotive Industry

Traceable Inline Measuring Technology

Capability, Planning and Management

2nd revised edition, August 2023

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Traceable
Inline Measuring Technology

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Verband der Automobilindustrie e. V. (VDA)

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Contents

Foreword

Given that a new edition of VDA Volume 5 Measurement and Inspection Processes was published in July 2021, the obvious next step was to review the “supplementary volume” VDA Volume 5.1 as well.

As a result of the complete revision, the volume is no longer limited to geometric measuring technology in car body manufacture. Many examples are still explained based on the latter to ensure that they are easily comprehensible. However, the methodology can generally also be applied to other areas within the scope of inline measuring technology.

There has been a trend whereby measurements are increasingly taken by means of traceable inline measuring systems rather than offline in measuring rooms. Proofs of capability for inline measurement processes in accordance with VDA 5 are thus becoming more and more significant. In practice, the “traditional” use of measuring rooms is fading into the background. Despite this, having measurement options that are independent of the production line is sill helpful, especially when conducting analyses (e.g. when there are process fluctuations).

As was the case in the revision of the main volume, our focus during the revision of VDA Volume 5.1 was on the comprehensibility of the methodology in order to ensure that it is easily applicable in practice. Based on an eight-step model, inline measuring systems were considered from a holistic perspective, from inspection process planning to the end of use.

The proofs of capability thus obtained are part of the release of the plant. However, the latter also comprises further aspects that have not been taken into account in VDA Volume 5.1 (e.g. occupational safety).

Moving beyond the focus of VDA Volume 5.1, measurement data is being collected based on significantly larger sample sizes as a result of the above-mentioned trend, leading to substantially larger amounts of data with regard to process variation. It is therefore recommendable to develop and use intelligent evaluation methods or systems in order to adapt the speed of reaction to the increased amount of data.

1 Standards and guidelines

Various standards and guidelines require and promote familiarity with the concept and the determination of measurement uncertainty. The following ones shall be named here, in addition to VDA Volume 5 “Measurement and Inspection Processes. Capability, Planning and Management”. Only standards that are relevant to coordinate measuring systems are listed as examples here. For other influencing quantities, a separate check is necessary in order to determine whether relevant standards are available.

- DIN EN ISO 10360-3: Geometrical Product Specifications (GPS) – Acceptance and reverification tests for coordinate measuring machines (CMM) – Part 3: CMMs with the axis of rotary table as the fourth axis
- DIN EN ISO 10360-5: Geometrical Product Specifications (GPS) – Acceptance and reverification tests for coordinate measuring machines (CMM) – Part 5: Coordinate measuring machines (CMMs) using single and multiple stylus contacting probing systems using discrete point and/or scanning easuring mode
- DIN EN ISO 10360-8: Geometrical Product Specifications (GPS) – Acceptance and reverification tests for coordinate measuring machines (CMM) – Part 8: CMMs with optical istance sensors
- DIN EN ISO 10360-9: Geometrical Product Specifications (GPS) – Acceptance and reverification tests for coordinate measuring machines (CMM) – Part 9: CMMs with multiple robing systems
- DIN EN ISO 10360-10: Geometrical product specifications (GPS) – Acceptance and reverification tests for coordinate measuring systems (CMS) – Laser trackers for measuring point-to-point distances

- DIN EN ISO 10360-13: Geometrical product specifications (GPS) – Acceptance and reverification tests for coordinate measuring systems (CMS) – Part 13: Optical 3D CMS
- VDI/VDE 2617 Part 2.1: Accuracy of coordinate measuring machines – Parameters and their reverification – Code of practice for the application of DIN EN ISO 10360-2 for length measurement
- VDI/VDE 2617 Part 2.2: Accuracy of coordinate measuring machines - Characteristics and their testing – Form measurement with coordinate measuring machines
- VDI/VDE 2617 Part 4: Accuracy of coordinate measuring machines – Characteristics and their checking – Manual for the use of DIN EN ISO 10360-3 for coordinate measuring machines with additional axes of rotation
- VDI/VDE 2617 Part 5: Accuracy of coordinate measuring machines – Parameters and their reverification – Interim check with artefacts
- VDI/VDE 2617 Part 6.1: Accuracy of coordinate measuring machines – Characteristics and their testing – Code of practice to the application of DIN EN ISO 10360-7 for coordinate measuring machines equipped with image processing systems
- VDI/VDE 2617 Part 6.2: Accuracy of coordinate measuring machines – Characteristics and their testing – Guideline for the application of DIN EN ISO 10360-8 to coordinate measuring machines with optical distance sensors
- VDI/VDE 2617 Part 7: Accuracy of coordinate measuring machines – Parameters and their checking – Estimation of measurement uncertainty of coordinate measuring machines by means of simulation
- VDI/VDE 2617 Part 8: Accuracy of coordinate measuring machines – Characteristics and their testing – Test process

suitability of measurements with coordinate measuring machines

- VDI/VDE 2617 Part 10: Accuracy of coordinate measuring machines – Characteristics and their checking – Acceptance and reverification tests of lasertrackers
- VDI/VDE 2617 Part 11: Accuracy of coordinate measuring machines – Characteristics and their checking – Determination of the uncertainty of measurement for coordinate measuring machines using uncertainty budgets
- VDI/VDE 2617 Part 12.1: Accuracy of coordinate measuring machines – Characteristics and their checking – Acceptance and reverification tests for tactile CMM measuring microgeometries
- VDI/VDE 2617 Part 12.2: Accuracy of coordinate measuring machines – Characteristics and their testing – Acceptance and reverification tests for optical CMM measuring microgeometries according to DIN EN ISO 10360-8 and VDI/VDE 2617 Part 6.2
- VDI/VDE 2617 Part 13: Accuracy of coordinate measuring machines – Characteristics and their testing - Guideline for the application of DIN EN ISO 10360 for coordinate measuring machines with CT-sensors – VDI/VDE 2630 Part 1.3: Computed tomography in dimensional measurement - Guideline for the application of DIN EN ISO 10360 for coordinate measuring machines with CT-sensors
- VDI/VDE 2634 Part 1: Optical 3D measuring systems – Imaging systems with point-by-point probing
- VDI/VDE 2634 Part 2: Optical 3-D measuring systems – Optical systems based on area scanning
- VDI/VDE 2634 Part 3: Optical 3D-measuring systems – Multiple view systems based on area scanning

2 Benefits and scope

Inline measuring stations are integrated into the production process in order to measure selected geometric component characteristics. The results are used to control the manufacturing processes and to ensure product quality.

Within the sense of DIN EN ISO 10360-1, traceable inline measuring stations can be considered coordinate measuring systems, especially flexible stations with robots. An additional correlation measurement to the measuring room is not required.

VDA Volume 5 evaluates measuring systems and measurement processes via the relationship between the measurement uncertainty and the tolerance regarding the characteristics to be inspected. The evaluation of an inline measuring station is a complex task, both in terms of its use as a measuring system and in terms of its capability as a measurement process.

Following the framework of VDA Volume 5, the objective of VDA Volume 5.1 is to describe a methodology for obtaining a proof of measuring system and measurement process capability, taking the special operating conditions of inline measuring stations into account.

Compared to the almost perfect conditions in inspection laboratories and measuring rooms, additional influences must be taken into account in the production environment, e.g. temperature fluctuations, dirt, vibrations, lighting conditions, etc.
The assurance of the measurement process must be adjusted in accordance with the associated risks.

In the following, the individual steps for successfully implementing and operating a traceable inline measuring system are described, based on an eight-step process model.

Within the scope of inline measuring technology, “traceability” refers to the current best practice for proving the capability of the measurement process. For this purpose, suitable calibrated standards are used to check whether the measuring volume used meets the specifications defined by the user. The standards used must be traced back to SI units.

3 Terms and definitions

The fundamental terms and definitions can be found in VDA Volume 5 “Measurement and Inspection Processes”.

3.1 Integration of measuring systems into the production process

For a better understanding of the methodology described in VDA Volume 5.1, it is important to know how inline measuring technology can be integrated into production. In the following, examples of a possible integration of measuring systems into the production process are therefore provided.

Inline

“Inline” means that the measurement station is part of the production plant and its environmental conditions, through which every component is conveyed. The measuring station is cycle-based.

Figure 3-1: Inline measuring station

Bypassable Inline

Inline measuring station which can be bypassed in particular cases, e.g. when carrying out an analysis measurement in the line. Measuring stations can be bypassed automatically. The measurement processes that are used can be designed flexibly: In general, each component is measured in a short program in cycle time. However, it is also possible to carry out a more extensive analysis program or to implement integration / optimization measures during ongoing production. Production can continue as normal. However, the components produced pass the measuring station without measurement.

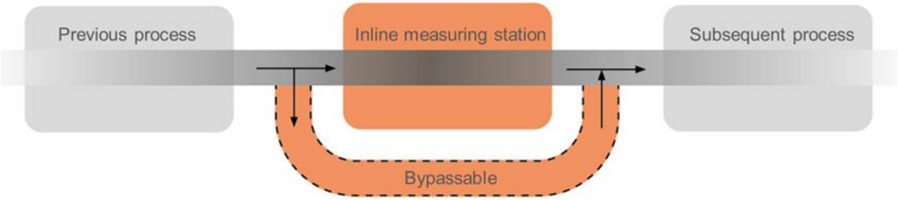

Figure 3-2: Bypassable inline measuring station

Bypass (like inline, without cycle time)

Complete bypass measuring stations are connected to the production plant fully automatically. However, not every component can be measured, given that feeding the station with components takes a lot of time. Parts can be removed for measurement in a flexible way. In many cases, buffer places/buffer positions are also included. Such stations are useful if measurements take place on a random basis and take longer than the cycle time.

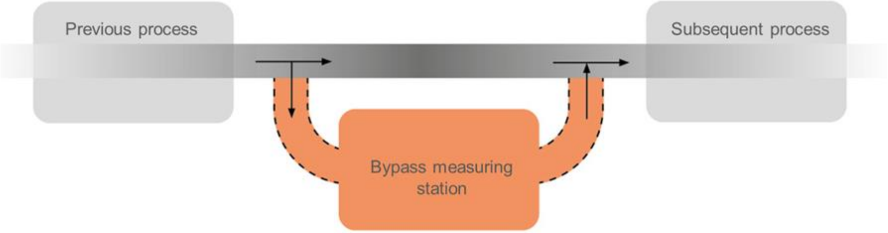

Figure 3-3: Bypass measuring station

At-Line

An “at-line” measuring station is located close to the production line and typically involves more extensive analysis programs, which are carried out on a very limited number of components.

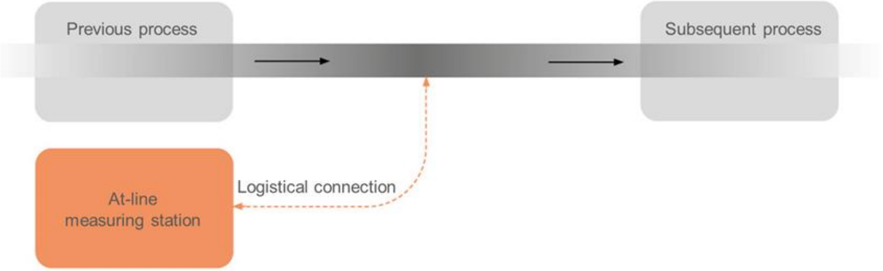

Figure 3-4: At-line measuring station

Offline/measuring room (away from the line). Separate measuring room – used concurrent to production

For a few years now, “offline” has been used as an umbrella term for measuring stations in climate-controlled measuring rooms. Such rooms provide controlled environmental conditions (e.g. temperature, air humidity, air pressure), such that their share in the measurement uncertainty can be reduced. Since cycle times do not have to be taken into account, extensive analysis measurements can be done. Offline measuring stations can also be used very flexibly, but they are usually associated with additional logistical and personnel requirements.

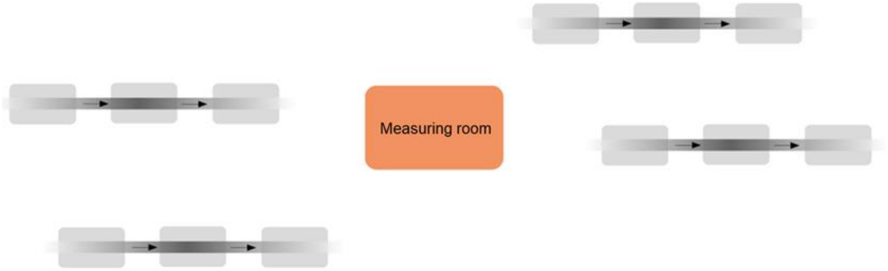

Figure 3-5: Offline measuring station / measuring room

3.2 Definition of measuring volume

According to the “VIM” [1] definition, a measuring interval is the “[...] *set of values of quantities of the same kind that can be measured by a given measuring instrument or measuring system with specified instrumental uncertainty, under defined conditions* [...]”. In case of temperature measurements, for example, this is the smallest and the largest measurable temperature for which the specified uncertainty is valid.

Insofar as the spatial distribution of the measuring points at which influencing quantities are measured is relevant, it is possible to distinguish between several types of measuring volumes.

According to DIN EN ISO 10360-1 [2], the measuring volume for coordinate measurements is the “*measuring range of a CMM [...], stated as simultaneous limits on all spatial coordinates measured by the CMM*“.

The measuring volume is thus the sum of the geometric positions at which a measurement of the influencing quantity to be analyzed is possible.

It is possible to distinguish between three types of measuring volume:

1. the theoretically feasible measuring volume mentioned above,
2. the measuring volume specific to the measuring task, and
3. the movement volume.

The measuring volume specific to the measuring task (2.) is the part of the theoretically feasible measuring volume (1.) that is relevant to the measuring task under consideration. Thus, the measuring volume specific to the measuring task is the part of the measuring volume that is actually used. It encloses the measuring points, taking the variations of the components, the precision and the repeatability of component and sensor positioning into account. Just like the theoretically feasible measuring volume, it is not necessarily cubic in shape (see Figure 3-6).

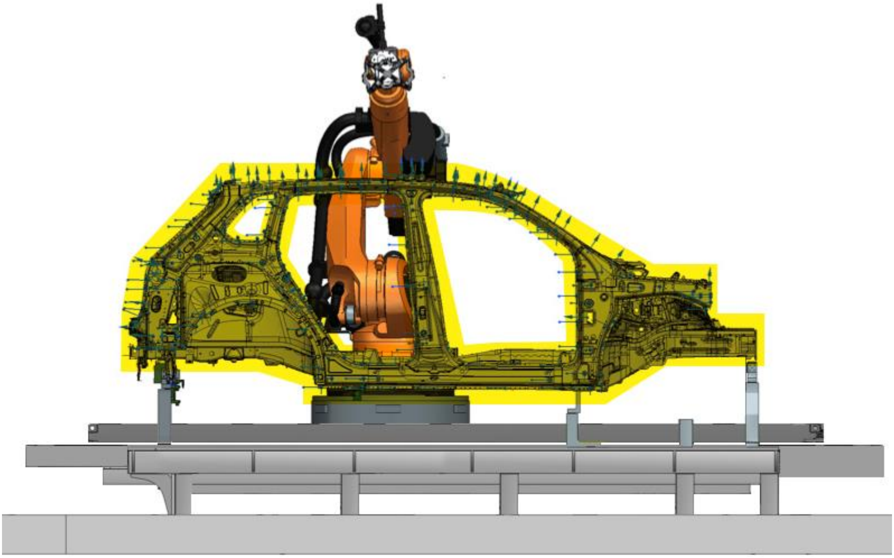

Figure 3-6: Measuring volume actually used

The movement volume (3.) is the overall volume which is comprised of the volume specific to the measuring task (2.), the required paths of motion, the volume of the measuring sensor, and the space required for the measurement (including the working distance), as shown in Figure 3-7.

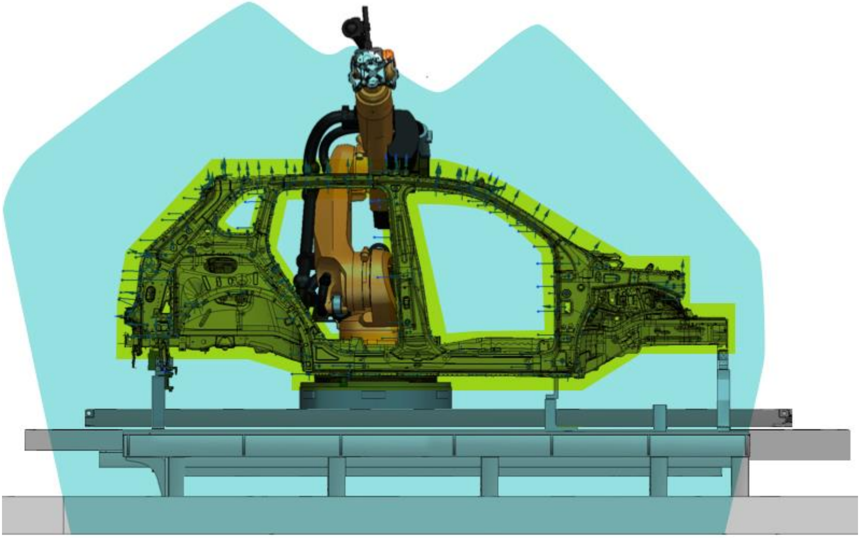

Figure 3-7: Theoretically feasible measuring volume

For the measuring volume specific to the measuring task, it must be checked (within the sense of transferability of uncertainty components, VDA Volume 5, chapter 4.7.4) whether measurements can be taken at different measuring points with the same measurement uncertainty. If this is not possible, it is sufficient to specify an extended measurement uncertainty that is representative of this part of the measuring volume.

When inspecting geometric characteristics, this can mean that when determining the extended measurement uncertainty, the part attributable to the length measurement error is determined representatively (once) for these characteristics.

Within the scope of planning a measuring system, the measuring volume specific to the measuring task is derived from the characteristics to be measured (the yellow outlines in Figure 3-6 indicate the measuring volume specific to the measuring task, based on the example of a car body). Afterwards, the movement volume can be determined.

The measuring volume specific to the measuring task constitutes the deciding factor with regard to the acceptance inspection (see chapter 6).

3.3 Further terms and definitions

Flexible mounting fixture

Equipment that is used to position a measured object and that can be changed geometrically between two measurement processes (e.g. in order to accommodate different measured objects).

Stable reference part

In addition to the definition provided in VDA Volume 5 (chapter 3.3), a reference part is considered stable if, during the time span from calibration to completion of the proof of measuring system capability, there are no significant changes to the original calibration value of the characteristic to be measured in relation to the measurement uncertainty of the measuring system.

4 Details regarding inspection process management according to VDA 5 in relation to inline measuring technology

In general, the inspection process management for inline measuring technology follows the specifications outlined in VDA Volume 5 and can be divided into eight steps.

When introducing an inline measuring system, measurement process planning is followed by an acceptance inspection and a proof of capability for the measuring system as well as the measurement process.

Within the framework of a risk-based approach, a proof of ongoing capability must be planned and obtained for the operation of the system. In addition, reactions to unexpected events, regular verification inspections and an inspection at the end of use must be taken into account.

4.1 Inspection process management sequence in eight steps

The following Figure 4-1 is a schematic representation of the sequence described above for traceable inline measuring technology:

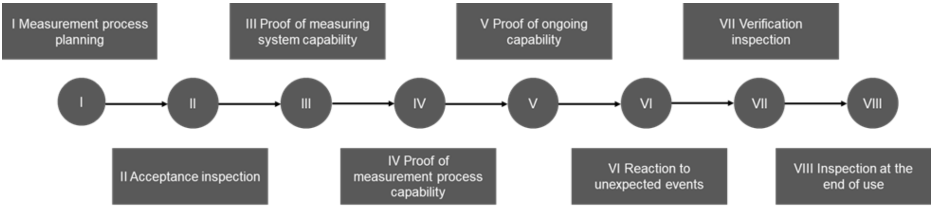

Figure 4-1: Schematic representation of the inspection process management sequence

I. During **measurement process planning**, a potential/suitable measuring system is planned based on the measuring task. Inline measuring technology is operated directly in the production environment. Therefore, the particular operating conditions, such as environmental influences (temperature, lighting, etc.) must be taken into account (chapter 5).
II. The **acceptance inspection** serves to prove that the manufacturer’s specifications regarding a new measuring system are met (chapter 6).
III. Within the scope of **measuring system capability**, the objective is to prove that the measuring system is capable of measuring the characteristics to be measured (chapter 7).
IV. In addition to measuring system capability, **measurement process capability** also takes process influences into account. Measurement process capability regarding the measurement of the characteristics to be measured can thus be proven (chapter 8).
V. In order to prove **ongoing capability** (e.g. daily reference measurements), the stability of the measurement process is checked during ongoing operation, and changes are identified (chapter 9).
VI. **Reactions to unexpected events** refer to reactions in scenarios where unforeseen incidents occur, e.g. defects to the plant or collisions (chapter 10).
VII. A **verification inspection** is a regularly repeated inspection proving that the specifications are met. It is generally equivalent to the acceptance inspection (chapter 6).
VIII. The **inspection at the end of use** describes the possible inspections of the measurement process carried out to safeguard the period between the last verification inspection and the end of use (chapter 11).

The requirements according to VDA 5, chapter 4.2 must be taken into account during inspection process planning. When it comes to inspection process planning, the various operator models must be taken into account, and the responsibilities regarding production and supporting departments must be defined precisely.

The user (i.e. the plant operator) should have extensive skills in terms of dealing with system failures (collision, faulty inspection equipment, etc.). Depending on the operator model, the user must have the necessary know-how regarding measuring technology, but must not necessarily be able to define measurement strategies or determine uncertainty components.

For inline measuring systems, risk-based assurance in accordance with VDA Volume 5, chapter 4.3 is applicable. In general, a measured object provides the basis for this (e.g. a component or an assembly). The characteristics/groups of characteristics to be measured, which require proofs of capability based on their risk assessment, are derived from the measured object.

4.2 Particularities of inline measuring systems regarding operating requirements

Inline measuring systems are typically operated by the production department or production-related departments within an organization. For seamless validation of measuring systems and measurement processes, as well as assistance in terms of measuring technology, support from personnel working in the area of measuring technology is required. To ensure smooth and accurate operation of the plants in terms of measuring technology, a sufficient level of qualification with regard to measuring technology is absolutely necessary in the departments responsible for operating the plants.

It is recommendable to plan and define the required level of support needed in terms of measuring technology, particularly if inline measuring systems are introduced for the first time within the organization. The acceptance of inline measuring systems can be significantly increased by prior planning and by ensuring that there is an adequate level of qualification with regard to measuring technology in the departments responsible for operating the plants.

Inline measuring systems are deeply integrated into the production process. This deep-level integration requires sufficient expertise regarding measuring technology as well as adequate knowledge of the relationships between the measuring system and the production plant. These relationships are of crucial importance when it comes to planning the measuring system as well as planning the qualification of the relevant support staff.

4.3 Particularities of inline measuring systems regarding requirements of production and inspection process planning

The production process planning (or plant design) and the inspection process planning must be coordinated with each other at an early stage, given that the environmental conditions in the production environment have a significant effect on the measuring technology.

During layout planning, it is therefore recommendable to take the particular requirements of inline measuring technology with regard to the environment into account, and (for example) to define exclusion areas based on environmental influences.

The influences of upstream and downstream process steps and adjacent production processes should also be taken into account in order to reduce the associated effects (e.g. vibrations due to conveyor technology or temperature fluctuations due to welding operations).

The specific environmental influences at the place of operation (e.g. sources of light, air circulation) must be taken into consideration when selecting the measuring method and the measuring technology to be used.

5 Particularities of inspection process planning for inline measuring technology

Inspection process planning according to VDA Volume 5 describes to the use of measuring technology under ideal conditions (i.e. in measurement laboratories or measuring rooms), see figure 4-12 in VDA Volume 5, chapter 4.4.1.

Similarly, the process steps for inspection process management in case of inline measuring technology are shown in Figure 5-1. When planning inline measurement processes, the eight steps described must be taken into account.

Inline measuring technology is typically integrated into the production environment. Consequently, stronger environmental influences, e.g. temperature fluctuations or air streams, must be anticipated. During the planning process, these environmental conditions must therefore be taken into consideration in addition to the procedure described in VDA Volume 5.

This can be done by identifying all potential influencing factors, their relevant evaluation, and – if necessary – the subsequent definition of measures.

It is preferable to follow an “ascending” avoidance strategy:

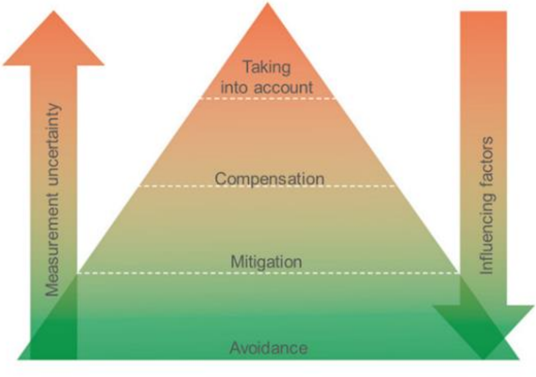

Figure 5-1: Avoidance strategies to reduce environmental influences from the production environment

Ideally, some environmental influences can be avoided altogether. If this is not possible, attempts can be made to mitigate the effects or to compensate for them mathematically. Only if these measures are not effective do the remaining influencing factors have to be taken into account regarding measurement process capability.

If the influences are so diverse that various measures have to be taken, it is generally possible to apply measures from multiple levels.

The objective should be to already counteract all influencing factors during the planning phase, to the extent possible. If influences cannot be avoided or mitigated to such an extent that they are negligible, this results in a greater measurement uncertainty regarding the proof of capability.

An example for the “avoidance” level is the installation of curtains in order to avoid contamination due to welding spatters.

An example for the “mitigation” level is to position the measuring system as far away as possible from the entrance to the hall (e.g. roller shutter) in order to minimize temperature influences.

On the “compensation” level, systematic shares in the determined measurement uncertainties can be reduced by means of mathematical compensation.

On the “taking into account” level, it is for example possible to take the influences into account when planning and implementing the tests, e.g. the opening and closing of the entrance door to the hall (e.g. roller shutters).

Preparatory measures in terms of maintenance, emergency strategies, preventative measures (e.g. training regarding the exchange of components, spare parts inventories, fallback strategies) must be included in the planning phase in case the measuring device cannot be used. This also includes measures/downtimes that can be planned, e.g. the verification inspection.

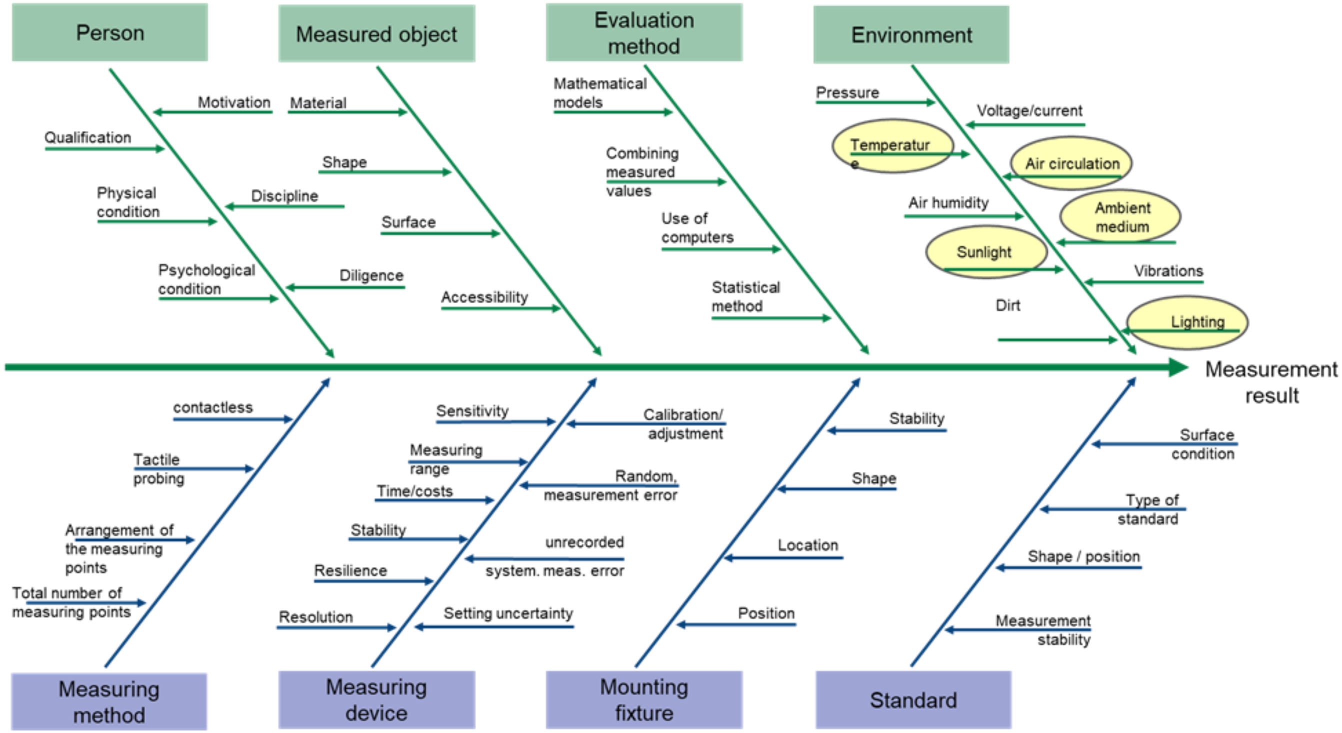

Figure 5-2: Ishikawa diagram with special emphasis on the environmental conditions as a particularity of inline measuring technology

Influences arising from the production process

In addition to the influences of the production environment, direct influences of the production process must also be taken into account during inspection process planning.

For example, the measurement time must be adjusted to the stipulated cycle time. Conveying times, i.e. the time it takes to make a measured object available, must be taken into consideration, among other things. As a result, it may not be possible to measure all of the desired measurement positions within the remaining net measurement time. During measurement process planning, the entire measurement can therefore be subdivided into partial measurements.

Taking the mounting and feed system into account

When carrying out certain measuring tasks, such as assessing the dimensional accuracy of car bodies, the mounting fixture can have a considerable effect on the capability of the measurement process. Generally, there is an increased risk that influences of or changes to the environmental conditions in the production environment have short-term or long-term effects on the mounting fixture, which can manifest itself in a higher measurement uncertainty.

During the planning phase, potential risks related to the mounting fixture and feed system must already be determined, eliminated by means of design measures wherever possible, and assessed with regard to their long-term or short-term impact (where appropriate).

Examples for the assessment of risks and measures with regard to the mounting fixture:

- In terms of design, the diameter of fixing pins must be undersized in relation to the diameter of the receiving hole in order to prevent jamming when inserting and removing the part to be inspected.

- At the same time, the receiving hole is the agreed alignment characteristic for RPS alignment.
  → Risk: The actual position of the component on the mounting fixture is undefined (pin “swims” due to undersize in relation to receiving hole).
  → Measure: Using a pre-alignment guide, the same side of the pin is always inserted up to the stop.
  - Consequential risk 1: Increased wear of the fixing pin → Assessing the wear of the fixing pin on an annual basis and replacing, preventive replacement (if necessary)
  - Consequential risk 2: Increased abrasion, with residues/abraded material remaining on the Z-support → this can be mitigated by means of design measures, i.e. a groove or hole in the Z-support, and daily cleaning of the Z-supports.
  - Consequential risk 3: Pre-alignment guide is subject to wear over time → Annual inspection for wear

This example also shows that the feed system for components can have a substantial influence on the capability of the measurement process. This is particularly the case if the component is aligned physically by means of the mounting fixture, and a deformation and/or play in the component support cannot be compensated for metrologically.

Sporadic, short-term effects (e.g. unstable component support) often increase the measurement uncertainty of repeat measurements and can be identified by means of suitable test scenarios of the entire measurement process (including shuttling the component back and forth).

Long-term effects, such as wear and the setting behavior of the mounting fixture, which can have actual effects on the bias, can for instance be identified by means of periodic calibration of the mounting fixture.

If calibrated, dimensionally stable reference parts are available, it is recommendable to carry out the periodic inspection according to VDA Volume 5, chapter 10.1, by means of an ongoing verification inspection with stability parts.

In case of alignment by means of calculation – i.e. defined alignment points are measured directly – the influence due to play in the component support is negligible. If alignment by means of calculation is a substantial part of the measuring task, it must be checked in terms of measuring system and measurement process capability in accordance with VDA Volume 5 (where applicable).

A further effect that should be analyzed in the risk assessment is the risk of distortion of the component, especially in case of components that are not dimensionally stable. It is usually impossible or very difficult to compensate for distortions (depending on the relationship between the effect and the tolerance), and distortions must therefore prevented conceptionally or by means of design measures for the mounting fixture.

Flexible mounting fixtures (typically movable systems with one to three axles) should be inspected in terms of short-term and long-term repeatability. For the proof of measurement process capability, flexible mounting fixtures must be dynamically moved between the measurement cycles in order to replicate actual use.

Monitoring

It is recommendable to take monitoring for unexpected events into account during the planning phase, e.g. crash warnings or functional monitoring of components that influence the capability of the measuring system (e.g. cable breaks, camera function).

6 Acceptance and verification inspection

This section describes the acceptance and verification inspection in relation to the proof of capability concept outlined in VDA Volume 5 “Measurement and Inspection Processes”. It also provides information on how it can be used appropriately in the proof of capability process for traceable inline measuring technology.

The acceptance or verification inspection proves that the manufacturer’s specifications regarding this coordinate measuring system are met. This inspection is carried out using calibrated working standards (see VIM [1]). It is also referred to as the calibration of the metrological characteristics in accordance with DIN EN ISO 10360.

Thanks to the calibration[1], the traceability to SI units is ensured. Only “final” measurements that have been taken within the scope of the acceptance inspection can be used for parts of the proof of capability process.

The verification inspection serves to verify at regular intervals that the measuring system meets the specifications regarding the MPE (Maximum Permissible Error, see VDA Volume 5, chapter 6.3.1). The implementation and evaluation generally corresponds to the acceptance inspection. The verification inspection does not equate to a proof of ongoing capability (see chapter 9).

The acceptance inspection comprises standardized tests using traceable standards, which verify the performance of the measuring system. During the acceptance inspection, it is determined whether one or several MPEs of the measuring system are adhered to.

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[1] The system audit standard IATF 16949, chapter 7.1.5.3.2 (Sanctioned Interpretations) must be complied with accordingly if the organization is certified according to IATF 16949.

The acceptance inspection is generally carried out in accordance with the relevant applicable ISO standards and VDI/VDE guidelines. The MPEs are specified by the supplier of the measuring system and are agreed upon by the supplier and the customer. The acceptance specification does not serve to determine new, system-specific MPEs.

The acceptance inspection is not the same as the process to determine measuring system capability. Despite this, the MPE can be used to determine the measuring system capability Q_{MS} in accordance with VDA Volume 5, chapter 7.1.1 (method B). Chapter 6.3.1 of VDA Volume 5 must be applied accordingly.

VDA 5 states that the MPEs of complex measuring systems cannot be applied exactly when determining the uncertainty of the inspection characteristics. It may be necessary to combine MPE values in order to map the characteristic to be inspected. For example, the error limits for determining perpendicularity can be estimated by combining the length measurement error and the probing error (see VDI/VDE 2617 Part 11).

Significance and implementation of the acceptance inspection/verification inspection

- The calibration certificate from the acceptance and verification inspections provides audit-proof documentation of the traceability of the measuring system.
- The acceptance inspection is usually part of the agreed-upon acceptance process.
- To ensure that the components of the measuring system comply with equipment-specific parameters before they are installed into the plant, it can be useful to carry out the acceptance inspection outside of the plant (note 2).

Note 1: *In case of geometric measuring systems, the acceptance inspections described in the DIN EN ISO 10360 series of standards and in the supplementary VDI/VDE guidelines are used. If there is no such standard for the measuring system, an individual acceptance inspection, preferably based on an appropriate DIN EN ISO 10360 standard, must be agreed upon between the customer and the system supplier.*

Note 2: *It can thus be ensured that, if no proof of measuring system or measurement process capability can be obtained, the measuring system component is not itself the cause. This presupposes that the measuring system component is suitable for the actual measuring task (this can for example be established by means of previous validation of the measuring system component with regard to the measuring task).*

7 Measuring system capability

It is recommendable to initially conduct risk assessments for all measuring systems in accordance with VDA Volume 5, chapter 4.3. For all relevant characteristics, the scope of the measures related to measuring system capability must be adapted according to the result of the risk assessment.

In accordance with VDA Volume 5 chapter 4.4, the proof of measuring system capability must be taken into account during inspection process planning.

The suggested limit value is a Q_{MS} of 15 % (see VDA Volume 5, chapter 7.2). In case of characteristics that exceed this limit value even after optimization, a risk-based evaluation can be carried out. If necessary, the limited value can be increased (see chapter 8, Figure 8-3).

These characteristics must be recorded in the documentation regarding measuring system capability, including the risk assessment, the increased limit values, and the relevant releases.

Conducting the "measuring system test" according to VDA Volume 5, chapter 6.3.8 requires calibrated reference parts or standards[2]. If this is not technically feasible in inline measuring systems, or if it is not appropriate in a risk-based approach, particular substitute procedures can be used. The options regarding measuring system capability are described in the following table.

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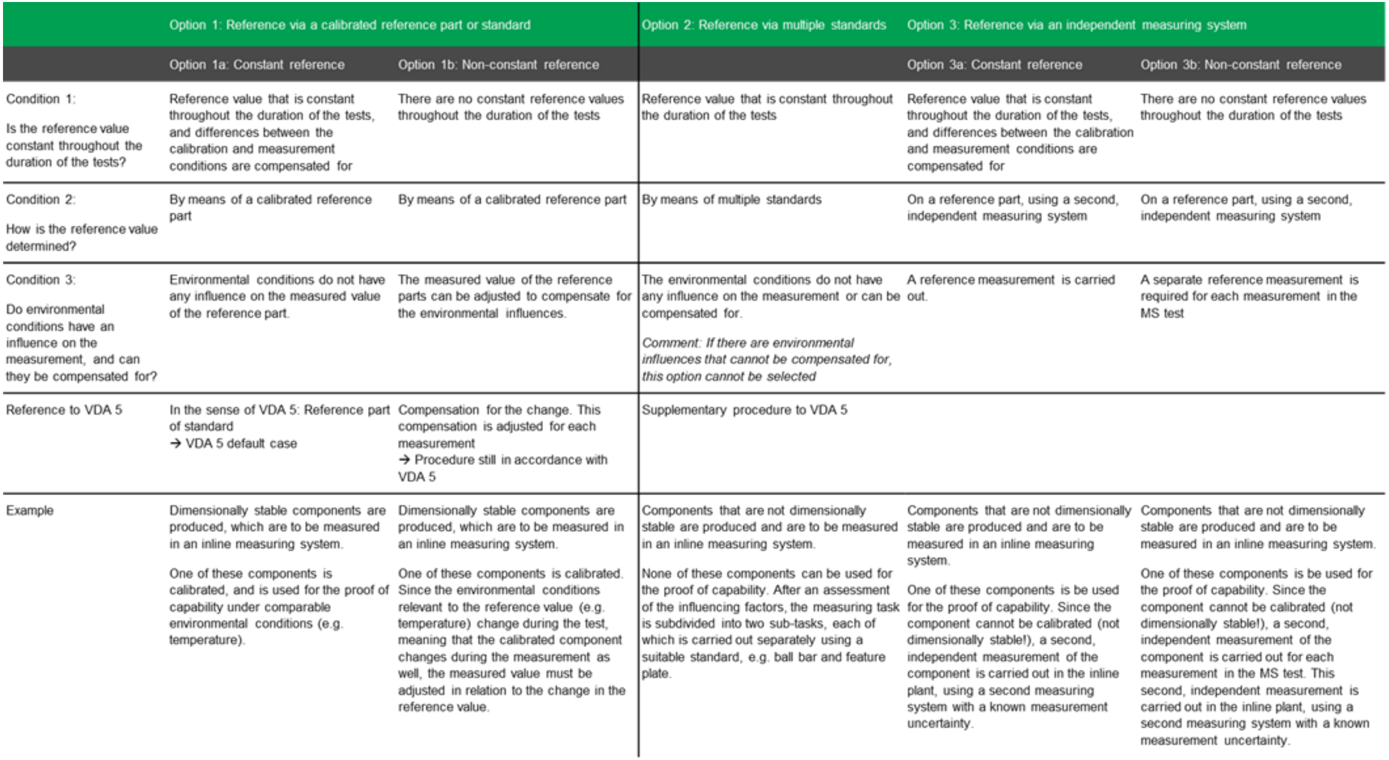
[2] Reference parts or standards can change over time. If there is a suspicion of a significant influence on the measurement uncertainty, this can be taken into account in the calibration uncertainty of the standard. For this purpose, the calibration uncertainty is increased by the change in the calibration values of the standard.

Table 7-1: Options regarding measuring system capability



	Option 1: Reference via a calibrated reference part or standard		Option 2: Reference via multiple standards	Option 3: Reference via an independent measuring system	
	Option 1a: Constant reference	Option 1b: Non-constant reference		Option 3a: Constant reference	Option 3b: Non-constant reference
Condition 1: Is the reference value constant throughout the duration of the tests?	Reference value that is constant throughout the duration of the tests, and differences between the calibration and measurement conditions are compensated for	There are no constant reference values throughout the duration of the tests	Reference value that is constant throughout the duration of the tests	Reference value that is constant throughout the duration of the tests, and differences between the calibration and measurement conditions are compensated for	There are no constant reference values throughout the duration of the tests
Condition 2: How is the reference value determined?	By means of a calibrated reference part	By means of a calibrated reference part	By means of multiple standards	On a reference part, using a second, independent measuring system	On a reference part, using a second, independent measuring system
Condition 3: Do environmental conditions have an influence on the measurement, and can they be compensated for?	Environmental conditions do not have any influence on the measured value of the reference part.	The measured value of the reference parts can be adjusted to compensate for the environmental influences.	The environmental conditions do not have any influence on the measurement or can be compensated for. *Comment: If there are environmental influences that cannot be compensated for, this option cannot be selected*	A reference measurement is carried out.	A separate reference measurement is required for each measurement in the MS test
Reference to VDA 5	In the sense of VDA 5: Reference part of standard → VDA 5 default case	Compensation for the change. This compensation is adjusted for each measurement → Procedure still in accordance with VDA 5	Supplementary procedure to VDA 5		
Example	Dimensionally stable components are produced, which are to be measured in an inline measuring system. One of these components is calibrated, and is used for the proof of capability under comparable environmental conditions (e.g. temperature).	Dimensionally stable components are produced, which are to be measured in an inline measuring system. One of these components is calibrated. Since the environmental conditions relevant to the reference value (e.g. temperature) change during the test, meaning that the calibrated component changes during the measurement as well, the measured value must be adjusted in relation to the change in the reference value.	Components that are not dimensionally stable are produced and are to be measured in an inline measuring system. None of these components can be used for the proof of capability. After an assessment of the influencing factors, the measuring task is subdivided into two sub-tasks, each of which is carried out separately using a suitable standard, e.g. ball bar and feature plate.	Components that are not dimensionally stable are produced and are to be measured in an inline measuring system. One of these components is be used for the proof of capability. Since the component cannot be calibrated (not dimensionally stable!), a second, independent measurement of the component is carried out in the inline plant, using a second measuring system with a known measurement uncertainty.	Components that are not dimensionally stable are produced and are to be measured in an inline measuring system. One of these components is be used for the proof of capability. Since the component cannot be calibrated (not dimensionally stable!), a second, independent measurement of the component is carried out for each measurement in the MS test. This second, independent measurement is carried out in the inline plant, using a second measuring system with a known measurement uncertainty.

Option 1 (see table 7-1) constitutes the default case according to VDA 5: In case of inline measuring systems, the various options must be evaluated in terms of feasibility, starting with the default case. As options 2 and 3 are associated with a higher risk and require more time/effort, option 1 is preferable – provided it is feasible. Regardless of the option that is used, what is of importance here is that the agreed capability ratio limits Q_{MS} and Q_{MP} are achieved.

The MS test is carried out in the production environment. Consequently, it cannot be completely ruled out that the MS test is impacted by environmental influences. Depending on the option that is chosen in order to carry out the MS test, these influences can be more or less significant. These environmental influences can lead to a higher combined measurement uncertainty of the measuring system u_{MS}, and can thus make the capability ratio Q_{MS} worse.

In order to minimize this effect, the impact of the environmental influences must be analyzed, and this analysis must be taken into account when selecting the option to be used. However, it is still possible that $Q_{MS.max}$ is exceeded due to the environmental influences. If during the inspection of a limit value for measurement process capability, the limit value $Q_{MP.max}$ is fallen short of, the measuring system can still be released. The actually achieved values for Q_{MS} and Q_{MP} must then be documented accordingly, along with the environmental conditions that caused the exceedance.

7.1 Option 1: Reference via a calibrated reference part or standard

7.1.1 Option 1a: Constant reference

Proof of measuring system capability is obtained using standards or reference parts. They must allow for reproducible measurement results. See VDA Volume 5, chapter 5.1.1.1 for the types of reference.

7.1.2 Option 1b: Non-constant reference

There are no reference parts that are stable throughout the duration of the test to prove measuring system capability. Unstable reference parts which change the true value by a known value can be used for carrying out the test, provided that the known change in the true value is compensated for.

For example, temperature changes during the test can alter the dimensions of the reference part. This can be compensated for mathematically, if necessary. If mathematical compensation is not possible, the influence can be taken into account as an uncertainty component in the measurement uncertainty budget.

7.2 Option 2: Reference via multiple standards

If no reference according to options 1a or 1b is available, an alternative procedure can be implemented after thorough assessment and evaluation.

The general strategy of the alternative procedure is to subdivide the measurement of the characteristic to be inspected into several partial measurements that meet the requirements set out in chapters 7.1.1 and 7.1.2, and to assess the uncertainty of each partial measurement separately. The combination of the partial measurements must allow for a sufficiently accurate approximation of the characteristic to be inspected. Based on the combination of the partial measurements, the uncertainty of the characteristic to be inspected can also be assessed. In this regard, it is important to ensure that the alternative procedure covers the relevant uncertainty influences regarding the measuring system for the characteristic to be inspected, and that – if possible – uncertainty influences are not factored in more than once. An example of an alternative procedure is provided below, based on an inline geometry inspection in car body construction.

In this example, the characteristic to be measured is the distance between a rectangle characteristic and a polygon characteristic (see Figure 7-1). As no reference is available in relation to the characteristics to be inspected, it must be analyzed whether an alternative procedure is feasible.

The analysis indicates that the measurement of the characteristic to be inspected (“distance between rectangle and polygon”) can be obtained based on the following three partial measurements:

a) Volumetric length measurement of a ball bar with a calibrated length similar to the nominal distance of the characteristic to be inspected

b) Determining the probing uncertainty on a characteristic standard that maps the rectangle characteristic of the measuring task sufficiently accurately.

c) Determining the probing uncertainty on a characteristic standard that maps the polygon characteristic of the measuring task sufficiently accurately.

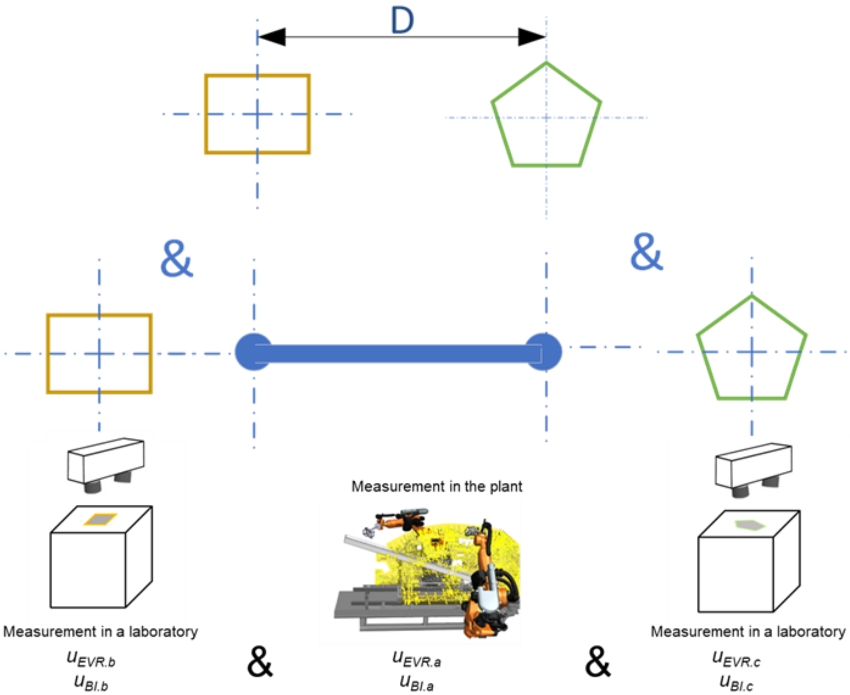


Figure 7-1: Example of two-step procedure

The three partial measurements are taken separately, and the relevant uncertainties (the uncertainty of the volumetric length measurement as well as the probing uncertainties) are determined. For each partial measurement, a calibrated reference is required.

When using this procedure with three separate tests, there is a risk that influences are factored in multiple times (for example, the probing certainty has an effect on the measurement uncertainty of the length measurement) and that the combined uncertainty is therefore overestimated.

In order to minimize this effect, it is important to reduce the contributions of the length measurement as much as possible during the test determining the probing uncertainty (e.g. by means of calibrated reference points in immediate proximity to the characteristic under consideration), and to also reduce the contributions of the probing uncertainty as much as possible when determining the uncertainty of the length measurement (e.g. by selecting suitable characteristics with the smallest possible probing uncertainty).

In the following, the combined uncertainty of the measuring system u_{MS} comprises the contributions of the length measurement (a), the probing of the rectangle (b) and the probing of the polygon (c) (see Figure 7-1).

$$u_{MS} = \sqrt{u_{CAL}^2 + max\,(u_{EVR}^2, u_{RE}^2) + u_{BI}^2 + u_{LIN}^2 + u_{MS.REST}^2} \qquad (1)$$

These uncertainty contributions of the repeatability on the three standards (a, b, and c) are combined into one uncertainty component.

$$u_{EVR} = \sqrt{u_{EVR.a}^2 + u_{EVR.b}^2 + u_{EVR.c}^2} \qquad (2)$$

The same procedure is followed with regard to the uncertainty contributions due to the bias.

$$u_{BI} = \sqrt{u_{BI.a}^2 + u_{BI.b}^2 + u_{BI.c}^2} \qquad (3)$$

The formula provided above constitutes the general approach to determining the uncertainty component that results from the bias.

It is permissible to disregard individual components if relevant prior knowledge is available or if relevant tests have been carried out.

In the example of the length measurement discussed here, the bias influence on standards b and c can be disregarded for the measuring system used. It follows that the uncertainty component u_{BI} is exclusively derived from component a (ball bar).

$$u_{BI} = u_{BI.a} = u_{BI.Länge} \qquad (4)$$

An overview of the uncertainty components and their classification is provided in VDA Volume 5, table 6-1.

When determining the individual contributions due to systematic errors, none should be factored in more than once. This influence can be minimized by using standards adapted to the measuring system (e.g. vision volume of sensor) and suitable test setups.

When combining the measurements, it can be unavoidable to factor in identical measurement uncertainty components more than once. It is therefore possible to overestimate the measurement uncertainty of the measuring system.

Note 1: *An example for factoring measurement uncertainty components more than once is the probing error when measuring the balls on the ball rod and the individual measurements on the characteristics.*

Note 2: *When implementing the alternative procedure, it is permissible to use measurements that have already been carried out with the measuring system. This also includes measurements that have been carried out* *within the scope of the acceptance inspection/calibration of the measuring system. It is important that these measurements allow for an assessment of one or more relevant uncertainty contributions of the characteristic to be inspected.*

7.3 Option 3: Reference via an independent measuring system

If a suitable reference measuring system with an adequate and known level of accuracy is available, it can be used to assess measuring system capability. Depending on the period of validity of the measured values, it is possible to distinguish between two cases here, both of which are described in the following two subsections.

For the calibration uncertainty u_{CAL}, which is usually taken over from the measurement standard, the $u_{MP.REF}$ of the reference measuring system is used here.

$$u_{CAL} = u_{MP.REF} \qquad (5)$$

With regard to the reference measuring system, the measurement process uncertainty is used, given that the environmental conditions and the particularities of the measured object must be adequately taken into account.

Alternatively, it is also possible to use the MPE of the reference measuring system as the calibration uncertainty.

$$u_{CAL} = \frac{MPE_{REF}}{\sqrt{3}} \qquad (6)$$

A requirement is that the MPE is convincing/sound – within the sense of the measuring system test – regarding the measuring task to be inspected. In addition, the MPE must be valid for the environmental conditions prevailing during the test.

7.3.1 Option 3a: Constant reference

If there is an option to use a constant reference value $x_{REF.m}$ for the entire tests for determining the measuring system and measurement process capability, a simple procedure can be followed. Repeat measurements with the measuring system to be inspected are always compared to the same value *(7)* of the reference measuring system or the mean value of a sequence of valid values *(8)*.

The part of the measurement uncertainty budget that represents the systematic measurement error is calculated as follows:

$$u_{BI} = \frac{|\overline{x}_g - x_{REF.m}|}{\sqrt{3}} \qquad (7)$$

$$u_{BI} = \frac{|\overline{x}_g - \overline{x}_{REF.m}|}{\sqrt{3}} \qquad (8)$$

$\overline{x}_g$ is the mean value of the measured values of the measuring system to be inspected.

$\overline{x}_{REF.m}$ is the mean value of the measured values of the reference measuring system.

7.3.2 Option 3b: Non-constant reference

The reference generated by the reference measuring system is used as a reference value $x_{REF.m}$ (VDA 5, chapter 6.3.5) when conducting the measuring system test. If it cannot be ensured that the reference value will remain valid throughout the entire duration of the test, a reference value must be determined for each measured value.
The measurement uncertainty resulting from the systematic measurement error is calculated based on the mean difference between the measured values and the relevant associated reference values:

$$u_{BI} = \frac{|\overline{x}_{\Delta}|}{\sqrt{3}} \qquad (9)$$

with

$$x_{\Delta.i} = x_{g.i} - x_{REF.m.i} \quad (10)$$

7.4 Proof of capability – applicability to non-geometric characteristics

The procedures described in the previous chapters can be applied in order to obtain proofs of capability for non-geometric characteristics. In this context, it must be checked whether suitable standards, reference parts or reference measuring systems are available, and if the requirements for the measurements are met (e.g. repeatable measurement).

This can also include leakage measurements, electrical values, imbalance, and – to a limited extent – force measurements in joining processes (see VDA 5 Practical Handbook), which are usually carried out 100% on each component.

Non-geometric characteristics often have one-sided specification limits, and the measurement uncertainty is only relevant in the area of the specification limits, e.g. in case of:

- Leakage measurements → max. leakage,
- Measuring electrical values → max. resistance/current/ voltage,
- Balance → max. imbalance,
- Joining processes → max. force.

The calculation of capability ratios in case of one-sided specification limits is described in VDA Volume 5, chapter 7.1.3.

7.5 Transferability of proofs of measuring system capability

Proofs of capability are also transferable in inline measuring technology. The basic considerations in this regard are outlined in VDA Volume 5, chapter 4.7.4.

If the measuring system test is carried out in the production line, the environmental conditions must be taken into account in relation to the scope of the proof of capability (VDA-Band 5, chapter 4.7.1).

8 Measurement process capability

Measurement process capability must be proven for all relevant characteristics.
The suggested limit value is a $Q_{MP.max}$ of 30 % (see VDA Volume 5, chapter 7.2). For characteristics that exceed this limit value, a risk-based evaluation can be carried out. These characteristics must be recorded in the documentation regarding measurement process capability, including the risk assessment, the increased limit values, and the relevant releases.

Note: *During capability tests for new plants, comparative measurements using a suitable alternative measurement process can show whether there are potentials for optimization. These comparative measurements neither replace the proof of capability nor serve to evaluate the measurement process to be tested.*

8.1 Taking the mounting and feed system into account

When carrying out certain measuring tasks, e.g. assessing the dimensional accuracy of car bodies, an unsuitable mounting fixture can lead to a higher measurement uncertainty (see chapter 5). The mounting fixture must therefore be taken into account accordingly when conducting the measurement process test with series components.

When it comes to the practical implementation, return feeding into the previous station between all measurement cycles should therefore be planned. If this is technically or conceptionally impossible, the component must be lifted out of the mounting fixture between two measurement cycles and then put down again.

If adjustable mounting fixtures are used in the measuring system, the mounting fixture must be adjusted between two measurement cycles in order to assess influences on the measurement process.

8.2 Temperature influence

The temperature influences many measurement processes significantly and in a variety of different ways. It can influence the measured object, the measuring system, but also the medium in the measurement environment. Consequently, a standard reference temperature for measurement processes is usually defined (e.g. 20°C when measuring metal components according to DIN EN ISO 1:2022-10).

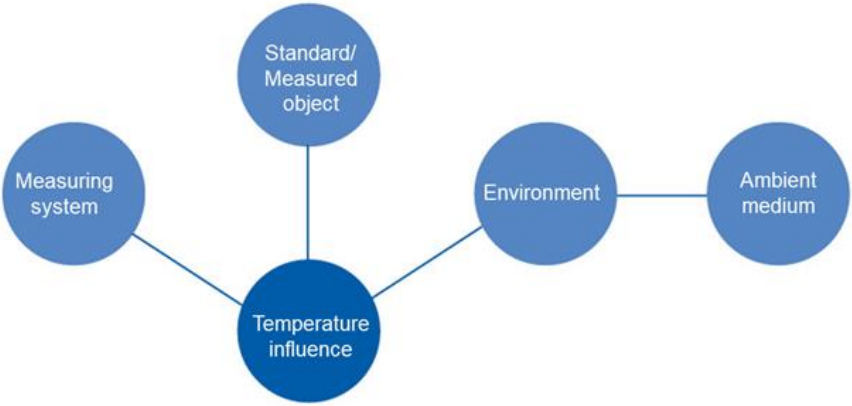


Figure 8-1: Influence of the temperature on the measuring process

In inline measurement processes, it is not always possible to meet these requirements due to the complex environmental conditions at the measurement location. Taking the temperature into consideration is therefore essential.

The temperature is an influencing factor that is considered when it comes to proofs of measurement process capability (see VDA Volume 5, chapter 6.4.7). The basic considerations regarding this topic are outlined in VDA Volume 5, in the chapter named above, as well as in VDA Volume 5.3[3], chapter 5.1.2 “Measurement process” for measurement processes with optical measuring systems.

8.2.1 Influence of temperature on the measuring system

In contrast to the considerations in VDA Volume 5, the particular environmental conditions represent an additional challenge in inline measurement processes. Given that the tests to prove measuring system capability generally take place under the climatic conditions of the measurement location (installation location of the measuring system within the production environment), temperature influences already play a role during these tests.

If there is no option to compensate for these temperature influences, this typically leads to an increase in the uncertainty components u_{EVR} and u_{BI} (see Figure 8-2). This happens as a result of temperature fluctuations (u_{EVR}) or due to the fact that the mean measurement temperature deviates from the standard reference temperature (u_{BI})). The value of this influence cannot be quantified. Consequently, the capability ratio Q_{MS} gets worse.

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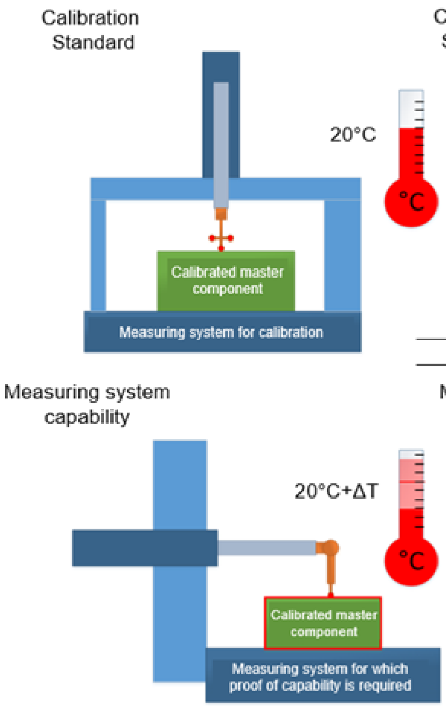
[3] VDA Volume 5.3 is still being worked on at the time of the yellow band phase of this volume.



Calibration Standard	Environmental conditions	Result	Uncertainty component in the proof of capability
Calibrated master component in a calibration laboratory	Laboratory conditions → Temperature does not have any influence on the calibration	Measured value (calibration value) + calibration uncertainty	Calibration uncertainty of the calibrated master component (standard) u_{CAL}

Measuring system test	Environmental conditions	Result	Uncertainty component in the proof of capability
Repeat measurements on the master component using the measuring system for which the proof of capability is to be obtained	Environmental conditions at the installation location of the measuring system → Temperature has an influence on the measuring system	Variation of the measured values	Repetition on the standard u_{EVR}
		Shift of the mean value of the measured values to the calibration value	Bias u_{Bi}

Figure 8-2: Influence of the temperature on the determination of uncertainty components

Ideally, the influences of the temperature or temperature fluctuations on the measuring system are compensated for.

This will in many cases be impossible due to the complexity of the measured object or the influence of the temperature on the measuring system and the environment. In such cases, it is recommendable to minimize the effects of temperature influences. This can for example be achieved by selecting a suitable time for conducting the measuring system test. Other influencing parameters that must be analyzed specifically during the tests must not have an influence on the measuring system due to the minimization of the temperature influence.

8.2.2 Influence of temperature on the measurement process

When determining measurement process capability, the uncertainty component u_{EVO} from the measurement process test must be evaluated in addition to the uncertainty components u_{BI} and u_{EVR} from the measuring system test. Given that these are uncertainty components which are determined experimentally, they are also affected by temperature influences.

Only the larger value of u_{EVR} and u_{EVO} is used to determine the combined measurement uncertainty of the measurement process:

$$max\ (u_{EVR}^2, u_{RE}^2, u_{EVO}^2)$$

(see VDA Volume 5, chapter 7.1.2).

Especially if

$$u_{EVR} \approx u_{EVO}\ \ bzw.\ u_{EVR} > u_{EVO} \qquad (11)$$

it must be checked whether

- the mean temperature and the temperature fluctuations were comparable during the two tests, and whether
- u_{EVR} was primarily influenced by this effect.

In case u_{EVR} is predominantly determined by the temperature influence and the temperature influence was larger during the measuring system test than it was during the measurement process test, it is recommendable to repeat the measurement process test under temperature conditions that are comparable to those of the measuring system test.

If this is not possible, the temperature must be evaluated as a separate uncertainty component u_{TEMP} in the measurement process, and the above-mentioned maximum condition must be extended:

$$max\ (u_{EVR}^2, u_{RE}^2, (u_{EVO}^2 + u_{Temp}^2)) \qquad (12)$$

This will prevent losing uncertainty contributions of the repeatability on the measured object due to the over-estimation of the temperature influence during the measuring system test.

The influence on the uncertainty component u_{BI} results from the difference between the mean temperature prevailing during the measuring system test and the standard reference temperature of 20°C.

This influence thus constitutes part of the influence on the combined measurement uncertainty of the measurement process, which is assessed via the uncertainty component u_{TEMP}. Consequently, there is a risk of overestimation if no further measures are taken.

A possible intervention is to determine the mean temperature during the measuring system test, and to mathematically compensate for the mean change of the standard due to the temperature difference in relation to 20°C.

8.3 Evaluation of capability ratios

The two-step process for proving and evaluating measuring system and measurement process capability is described in VDA Volume 5, chapters 4.7.3 and 7.2. According to VDA Volume 5, measuring system capability is proven without taking uncertainty contributions of the environment into account. However, this is usually not possible when it comes to inline measuring systems, given that the measuring system test is carried out in the production environment. For inline measuring systems, a measurement process can therefore overall be classified as capable even if $Q_{MS} > Q_{MS.max}$, provided that $Q_{MP} \leq Q_{MP.max}$. In this case, the reasons for exceeding $Q_{MS.max}$ should be documented if possible, and the risk assessment must absolutely be documented. In this case, only the capability ratio Q_{MP} is used to release both the measuring system and the measurement process. This procedure is excluded for the “high” risk class.

Example:
It is assumed that $Q_{MS.max}$ is 15% (see VDA Volume 5, chapter 7.2). For one of the characteristics allocated to the “medium” risk class as part of the assessments of measuring system/measurement process capability, the capability ratio $Q_{MS} = 20\%$ (not capable) was determined for the measuring system, and the capability ratio $Q_{MP} = 28\%$ (capable) was determined for the measurement process.

Despite the fact that the capability ratio limit of the measuring system was exceeded, the measurement process can be released after a risk assessment and (if necessary) an adjustment of the capability ratio limit (measuring system), provided that the insights from the measuring system and measurement process tests carried out are taken into account.

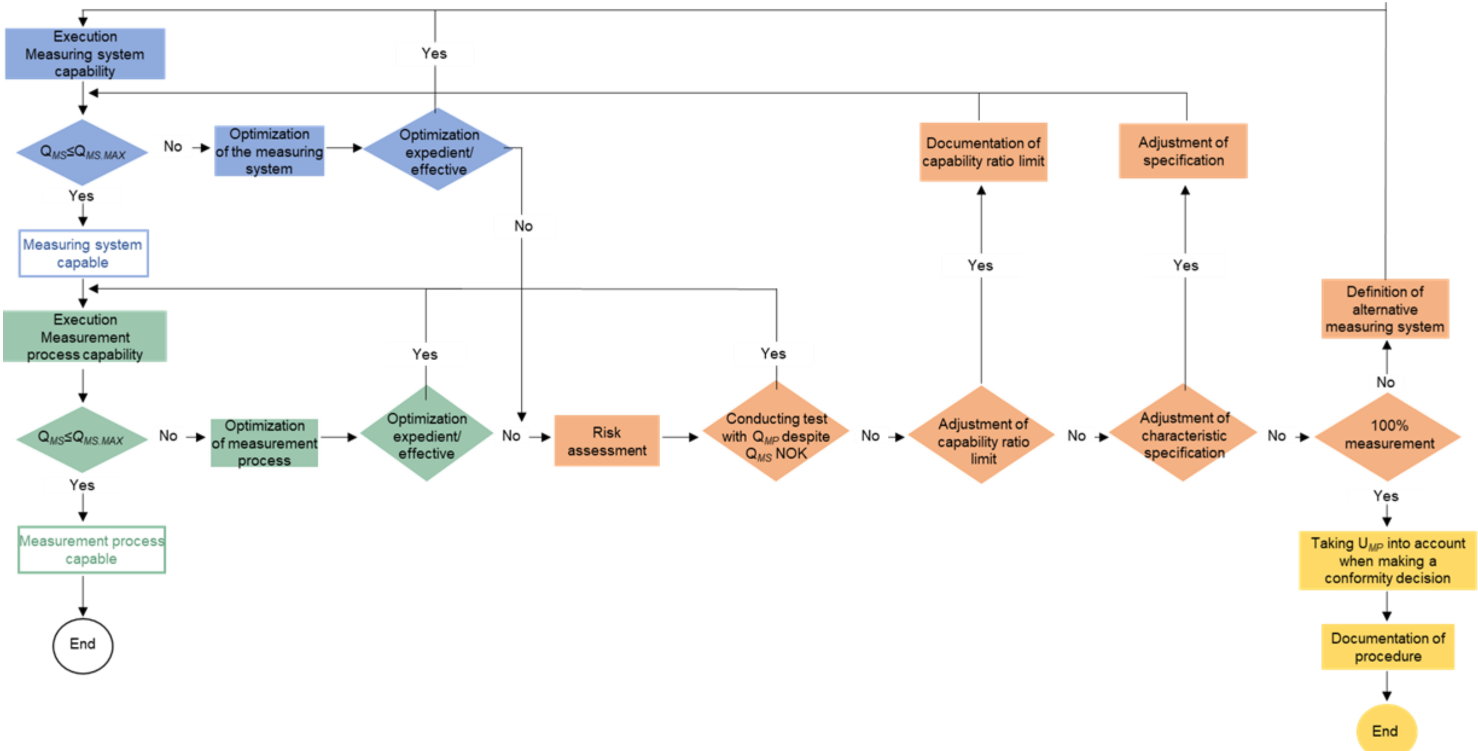


Figure 8-3 Assessment of measuring system / measurement process capability

8.4 Procedure to follow in case proof of capability cannot be obtained

If a process capability test is carried out, the variation of the measuring system and thus the measurement uncertainty influence the process capability observed.

If the capability ratio is not reached, this effect gets stronger due to the measurement uncertainty being larger in relation to the tolerance (U_{MP}). This may mean that the process capability of the production process cannot be proven (see VDA Volume 5, chapter 7.1.5).

The following options are available:

- Adjusting the measurement strategy, e.g. reducing the number of measuring points per cycle and simultaneous repeat measurement → Rolling measurement, such that all measuring points are measured → Statistical process control required. This makes it necessary to obtain a new proof of capability.
- Risk assessment and verification of measurement process capability (Q_{MP}). Once measurement process capability is proven, the measurement process can be released.
- Risk assessment and adjustment of the capability ratio limit for the measurement process ($Q_{MP.max}$), taking the process capability index into account (c_p,c_{pk}).
- Adjustment of the characteristic specification (e.g. tolerances).
- Assurance of conformity by means of 100% measurement (the inspection characteristic is measured on each component): the respective specification limit must be adjusted in accordance with DIN EN ISO 14253-1 (also see VDA Volume 5, chapter 5.7). This ensures that no incorrect conformity statement is made.

8.5 Transferability of proofs of measurement process capability

Proofs of capability are also transferable in inline measuring technology. The basic considerations in this regard are outlined in VDA Volume 5, chapter 4.7.4.

Given that the measurement process test is carried out in the production line, the environmental conditions must be taken into account in relation to the scope of the proof of capability (VDA-Band 5, chapter 4.7.1).

9 Proof of ongoing capability

Proof of ongoing capability is obtained at regular intervals, with the aim of “confirming the proof of capability” (see chapter 7). The assessment of ongoing capability is no substitute for regular calibration (see VDA Volume 5, chapter 10.1).

Proof of ongoing capability can be obtained using

- standards,
- calibrated reference parts,
- reference measuring systems, or
- a second, independent measuring system.

When using standards or calibrated reference parts, regular measurements are carried out in order to monitor the stability of the measurement process (depending on the time / number of components, in case of temperature fluctuations, or other environmental influences).
When using reference measuring systems or an independent second measuring system, the differences between the values are documented.

Intervention limits must be defined for these measured values, and the results must be documented, e.g. in the form of a control chart (see VDA Volume 5, chapter 10.3). The intervention limits must be oriented towards the maximum permissible measurement uncertainty.

Standards can also be permanently installed into the inline measuring system in order to ensure a smooth production process.

Note: *Due to the frequent use/environmental conditions, and in order to ensure ongoing capability, regular*

> *cleaning and visual inspections (TPM = Total Productive Maintenance) must be carried out.*

For the proof of ongoing capability of an inline measuring system, it is recommendable to use representative characteristics from the proofs of capability obtained. The standards, the calibrated reference parts, or the reference measuring system must be designed accordingly. If there are further components (e.g. component holding fixtures, component carriers) which have an influence on the measurement process, they must be checked on a regular basis as well.

10 Reactions to unexpected events

The following section outlines the aspects that should be taken into account if unexpected events occur during the measurement process.

Unexpected events can either occur “suddenly” or “gradually”.

Some examples of suddenly occurring events include:

- Collisions
- Questionable measurement results during ongoing inspection
- Major changes to the environmental parameters (e.g. a sudden drop in temperature)
- Operator errors
- Influences due to vibrations (e.g. construction work, earthquakes)

Some examples of gradually occurring events include:

- Defects to the plant (e.g. due to wear and tear)
- Major changes to the environmental parameters (e.g. prolonged dryness)
- Setting behavior of the building (e.g. Greenfield)
- Dirt

In each of these cases, it must be determined which measures are required in order to return to a full series measurement process.

Based on the measures taken, it must be checked whether the proof of capability assessment must be repeated (completely or partly).

Every time there is a gradually occurring event, there is a risk that incorrect conformity evaluations have been made for previously measured parts.

As long as there are no insights regarding the chain of effects associated with the gradually occurring event, all measurements since the last proof of capability, the last successful verification inspection or assessment of ongoing capability must be considered questionable.

In order to be able to assess the impact of an unexpected event, a risk assessment is carried out in accordance with VDA Volume 5, chapter 4.3.

Appropriate measures must be taken according to the risk associated with the potentially incorrect conformity decisions. It may be necessary to get the customer involved, both when conducting the risk assessment and when deriving or implementing the measures.

If it is not possible to return to the series measurement process within a sufficiently short period of time, emergency strategies may be required.

Possible emergency strategies can include:

- Temporary use of a replacement measuring system in the production flow
- Discharging of components and periodic offline measurement
- Assurance by means of monitoring downstream process steps

Given that an emergency strategy may be associated with a higher risk and can be based on another measuring system, an emergency strategy must already be taken into account during the planning phase (see chapter 5) and must also be coordinated with the customer.

Plant-specific arrangements must be made for the implementation of emergency strategies, e.g.:

- Discharging options
- The plant control is able to deselect the station completely or partly
- Reserving offline measurement capacities

These requirements must be met when planning and validating the emergency strategy.

11 Verification inspection at the end of use

Once inline measuring systems have reached their end of use, it must be checked whether a final verification inspection is required. This verification inspection serves to safeguard the inspection results during the period between the last verification inspection and the end of use, given that undetected changes in the measurement process could have led to incorrect conformity decisions.

With regard to the end of use, it is possible to distinguish between:

1. Decommissioning of the measuring system:
   The plant is disassembled. There are no plans to use it any further, and the measuring system may be dismantled.

2. Change of the characteristics to be inspected:
   The current product is discontinued, but the measuring system will continue to be used in another way.

In case the system is dismantled, it must be taken into account that it is no longer possible to conduct a later verification inspection in order to prove that no incorrect conformity decisions were made during the service life of the system.

If, however, various characteristics to be measured change or are no longer applicable/are dropped, a verification inspection can generally still be carried out.

A risk assessment must be carried out in order to determine whether a full final verification inspection is required:

- High risk:
  If the inspection characteristics involve legally required or safety-relevant inspections that must absolutely be carried out, a final verification inspection must be conducted and documented. An example are electrical inspections, which

are carried out 100% in the inline measuring system and serve to safeguard against dangers to life and limb (Isofix connection, insulation resistance / dielectric strength, etc.).

- Medium risk:
  In case of characteristics that are not safety-relevant and that cannot lead to product failures (look and feel of the product, etc.), it may be possible to omit a complete final verification inspection. Alternatively, a scaled-down verification inspection can be carried out, or the last results from the assessments of ongoing capability can be used.

- Low risk:
  At worst, an incorrect inspection decision leads to disruptions in the subsequent manufacturing process. However, this does not mean that the customer receives an NOK component. The final verification inspection must not necessarily be carried out.

If the final verification inspection indicates that the measurement process was not capable since the last verification inspection, a new risk assessment must be carried out. In the worst case, a recall of the components is required after this assessment (see chapter 10).

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