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1 Purpose and Scope

Customer satisfaction is the result of an extensive and complex process which depends on various factors. Customer satisfaction can be characterized by a comprehensive profile of different features. The most important criterion is fulfilling the customer's requests, expectations and requirements regarding the products.

In order to verify that the quality requirements of a product have been met, its properties are tested.

The quality of the test methods and used inspection, measuring and test equipment is an essential factor for the reliability of the test results and the decision on the conformity of the products with the quality requirements.

The prerequisite for using an inspection, measuring and test equipment is the knowledge of its capability. The measured values determined using this test method are the basis for the evaluation and shall reflect the true facts in a suitably reliable manner. An unsuitable test method blurs the true facts and does not allow reliable conclusions. In order to determine the capability of an inspection, measuring and test equipment, it is subjected to a measurement system analysis according to AIAG MSA (Cg/Cgk study, Tpye 2 – ANOVA tolerance and Type 3 – ANOVA tolerance).

Deviations from the specifications according to VDA 5 have not been considered.

Determination of measurement system capability is performed on all workpiece-related inspection, measurement and test systems. For workpiece-unrelated test systems and portable measuring equipment, the measurement system capability is determined on the basis of at least one measuring equipment per measuring equipment group.

Analysis is performed:

- On every new workpiece-related inspection, measuring and test equipment
- On every new measuring equipment group
- After changing the measuring task
- After a change in the inspection, measuring and test equipment
- According to customer requirements

The procedures set in this standard reflect the minimum required by the measuring system analyses of ETO MAGNETIC.
In-depth analyses must be applied in case of corresponding customer specifications.
The ETO standard Q-008 contains the customer specifications.

2 Change history

Issue	Change Description
March 2013	Standard distribution in: - ETN012 operating instructions_machines_and_process capability and - ETN021 measuring system analysis (new facility)
December 2014	Complete revision
June 2018	Addition ndc-value
January 2020	Revision - Description of the procedures 1, 2 and 3 - Additionally: evaluation of the number of distinct categories (ndc) - Suggestions on how to proceed if the measured values are not adequate

3 Applicable Documents

- VDA Volume 5 Capability of Measurement Processes, Capability of Measuring Systems, measuring- and testing-process, expanded measurement uncertainty, conformity assessment
- MSA (AIAG) description of the different processes
- Q-008, customer requirements regarding to process capabilities

4 Description of the different studies

Types of Study	Objective	Indices
Type-1 study	Systematic error of measurement (bias) and repeatability	Cg Cgk
Type-2 study	Gage repeatability and reproducibility (with operator influence)	%GRR
Type-3 study	Gage repeatability and reproducibility (without operator influence)	%GRR

Calculation of the measurement system analyses is based on the evaluation strategies described (e.g. when using the Q-DAS software).
Non-conformance with these calculation methods and the corresponding minimum requirements for the capability indices shall be agreed upon with the customer and the Quality Services department shall be informed about this fact prior to performing the measurement system analysis.

Type-1, -2 or -3 studies can be used for continuous data.

4.1 Type-1 study (Cg/Cgk study)

Type-1 study serves to evaluate whether the selected measuring equipment is capable for its intended use. For this purpose, a measurement standard is used as measuring object. Evaluation is performed according to the capability indices C_g and $\mathrm{C_{gk}}$.

Step	Description/Q-DAS Configuration
1	Evaluate the measurement equipment resolution. The measurement equipment must have a resolution **(RE)** of %RE≤ 5% of the characteristic´s specified tolerance **(RF).** Calculation: **%RE=$\frac{RE}{RF}$ x 100%** Evaluation of results: **%RE≤5%** ► Appropriate resolution **%RE>5%** ► The measurement equipment is not suitable for the measuring task due to insufficient resolution.
2	Determine a measurement standard whose value is within the tolerance range of the test characteristic. If needed, the measuring position is marked on the standard. A measurement standard or reference part must be available whose true value is traceable to a national or international measurement standard through calibration and is not subject to changes during the study.
3	Within a short time interval, perform 25 repeat measurements on the measurement standard. During the study, no further adjustments of the measurement equipment are permitted.
4	Calculate the average measurement value **($\bar{X}_g$)** and the repeatability standard deviation **(S_g)** of the measurement values.

Step	Description/Q-DAS Configuration
5	Calculate **Bi**, the difference between the average measurement value$(\overline{X}_g)$ and the standard's value (X_m): **Bi=**$\overline{X}_g$**-** X_m
6	Configuration • Determine the capability index $\mathbf{C_g}$: $C_g = \frac{0.2xT}{4xS_g}$ Expected amount of variation: 99.73% • Determine the capability index $\mathbf{C_{gk}}$**:** $\mathbf{C_{gk}} = \frac{0.1xT - \lvert \overline{X}_g - X_m \rvert}{3xS_g}$ • Reference value (or reference interval): Simple standard deviation total variance (TV), established from tolerance. • Calculation of gpp with unilateral tolerance: gpp=2U/T
7	Evaluation of results: $\mathbf{C_g}$ ≥ 1.33 ► The measuring equipment is capable. $\mathbf{C_g}$ < 1.33 ► The measuring equipment is not capable. $\mathbf{C_{gk}}$ ≥ 1,33 ► The measuring equipment is capable. $\mathbf{C_{gk}}$ < 1,33 ► The measuring equipment is not capable. The minimum requirements for $\mathbf{C_g}$ **and** $\mathbf{C_{gk}}$ must be fullfilled

4.2 Type-2 study – ANOVA (tolerance)

The Type-2 study determines the operator influence.

If a measurement equipment is not subject to operator influence (e.g. automatic parts feed), Type-3 study shall be used.

Precondition for carrying out the Type-2 study or Type-3 study is proof of a successful capability using the Type-1 study.

Step	Description/Q-DAS Configuration
1	Specification of the parameters: Number of appraisers ► 3 appraisers Number of measuring objects ► 10 objects Number of measurements per appraiser ► 2 measurement series
2	Numbering and marking of the parts. In order to ensure proper allocation of the measured values, the parts must be numbered. In order to eliminate the influence of the measuring object geometry (i.e. geometrical deviation), the measuring position is marked on the measuring objects.
3	The first appraiser measures the characteristics of the measuring objects in the sequence given by the numbering. The measured values are recorded. The first appraiser measures the measuring objects a second time in the same sequence, following the same procedure. The results of the second measurement run must not be affected by the results of the first run. During the study, adjustments of the measurement equipment are not permitted.
4	Step 3 should be repeated with the other appraisers. The respective measuring results must not be available to the other appraisers during measuring.
5	Determine the ranges from the first appraiser's results for each measuring object.
6	Calculate the average $\overline{\mathbf{X}}_1$ of the individual results of the first appraiser and the average $\overline{\mathbf{R}}_1$ range from the measurement series of the first appraiser.
7	Repeat steps 5 and 6 for the other appraisers.
8	Configuration • Calculation Method: Variance analysis ANOVA/expected amount of variation: 99.73% F-test on the influence of interaction/level: 95% • Reference value or reference interval Simple standard deviation total variance (TV), established from tolerance • Calculation of gpp with unilateral tolerance: gpp=2U/T
9	Calculate the part variation **PV**.

Step	Description/Q-DAS Configuration
10	Calculate the appraiser variation **AV**.
11	Calculate the equipment variation **EV**.
12	Calculate the gage repeatability and reproducibility **%GRR**.
13	Evaluation of results: 1. Case: **%GRR ≤ 10%** ► The measurement system is capable 2. Case: **%GRR >10% to ≤ 30%** ► The measurement system is of limited capability 3. Case: **%GRR >30%** ► The measurement system is not capable.

4.3 Type-3 study – ANOVA (tolerance)

The Type-3 study is used for measurement systems which are not subject to operator influence (e.g. automatic parts feed).

Precondition for carrying out the Type-2 study or Type-3 study is proof of a successful capability using the Type-1 study.

Step	Description/Q-DAS Configuration
1	Specification of the parameters: Number of appraisers ► 1 appraiser Number of measuring objects ► 25 objects Number of measurement series ► 2 measurement series
2	Numbering and marking of the parts. In order to ensure proper allocation of the measured values, the parts must be numbered. In order to eliminate the influence of the measuring object geometry (i.e. geometrical deviation), the measuring positions are marked on the measuring objects.
3	The operator measures the characteristics of measuring objects in the sequence given by the numbering. The measured values are recorded. The operator measures the measuring objects a second time in the same sequence, following the same procedure. The results of the second measurement run must not be affected by the results of the first run. During the study, adjustments of the measurement equipment are not permitted.
4	Determine the range for each measuring object.
5	Calculate the average range $\overline{R}$ from the measurement results.
6	Configuration • Calculation Method: Variance analysis ANOVA/expected amount of variation: 99.73% • Reference value or reference interval Simple standard deviation total variance (TV), established from tolerance • Calculation of gpp with unilateral tolerance: gpp=2U/T
7	Calculate the part variation **PV**.
8	Calculate the equipment variation **EV**.
9	Calculate the gage repeatability and reproducibility **%GRR**.
10	Evaluation of results: 1. Case: **%GRR ≤ 10%** ► The measurement system is capable 2. Case: **%GRR >10% to ≤ 30%** ► The measurement system is of limited capability 3. Case: **%GRR >30%** ► The measurement system is not capable.

4.4 Testing of attribute characteristics (discrete data)

The result of attribute test methods is only a "good or bad" statement and/or "good, rework or bad". For this reason, the evaluation procedure used for variable test methods cannot be used.

Examples for measurements of attribute characteristics are, e.g. gauge measurement or parts recognition.

Step	Description
1	Specification of the parameters: Number of appraisers ► 2 appraisers Number of measuring objects ► 25 objects Number of measurement series ► 2 measurement series Note for the selection of parts: The parts must exhibit spread over the entire scope of application of the gauge in order to be able to distinguish between OK and NOK. Since the limits of the tolerance specifications are examined during attributive testing, these criteria must be checked. It must be ensured that also test specimens meeting the tolerance limits are included in the selection of parts.
2	Numbering and marking of the parts.
3	Appraiser 1 tests the parts in the sequence given by the numbering (part 1 to 20). The appraiser documents the result (OK or NOK) such that it can be allocated to the parts. Appraiser 1 repeats the test and documents the result.
4	Appraiser 2 performs the test according to 3. Important: The appraisers must perform the tests independently of each other such that they do not influence each other.
5	Evaluation of the results: The test process is capable if all results are in compliance. I.e. the decision as regards the test specimen must be identical in all performed test series.

Source: /2/ Measurement System Capability" Reference Manual. Issue 2.1 D/E. Dr. Edgar Dietrich. Q-DAS GmbH

4.5 Type-1 study for unilateral tolerances

The forms of distribution underlying these cases may be, for instance, binomial distributions. The standard described herein presumes one-sided consideration of the normal distribution. This simplified consideration is made acceptable by the fact that this method produces less favourable results than the calculation of real distribution. This ensures that the measurement task is fulfilled. Based on the given system requirements, mathematically correct calculation bases may be applied. If there are corresponding customer requirements, they must be applied.

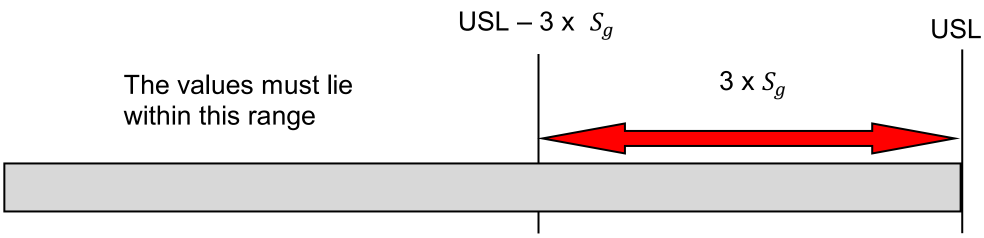
When expressing unilateral tolerances, two different situations must be distinguished:

- The upper and lower specification limits are predetermined. These natural tolerances are e.g.: Roundness, true running, positional tolerance, evenness, etc.

  It is only reasonable to determine the C_{gk} value from the tolerance limit.

  Calculation formula: $C_{gk} = \frac{0.1*T - |\bar{x}_g - x_m|}{2*S_g}$
- If only one limit (e.g. lower specification limit) is determined (i.e. measured values must be higher than one minimum value), then no determination of C_g and/or C_{gk} is possible.

  Proof of capability without calculating C_g and/or C_{gk}:
  In order to ensure that no values are above or below the maximum or minimum values, a distance of $3S_g$ is required as limit. (See figure)



The figure illustrates for C_g = 1.0 the true situation for an upper specification limit.

Source: /1/ Eignungsnachweis von Prüfprozessen. Dietrich und Schulze. Hanser Verlag

4.6 Assesment of ndc value

For type-1 and type-3 study the ndc value is assessed.

Calculation formula: $1{,}41 \times \frac{PV}{GRR}$

PV= part variation

GRR= gage repeatability and reproducibility

The value for ndc resulting from this calculation is rounded down to the next integral number and has to be greater than or equal 5.

ndc ≥ 5

If the ndc value is less than 5, the measurement system resolution from the type-1 study shall be consulted. If the resolution (RE) lies in the range required, i.e. %RE≤5% of the tolerance, the reason for the deviating ndc value does not lie in the measurement system. In this case, the ndc value is determined by the variation of the components used and thus allows to assess these components.

With the manufacturing process of the components producing a component-specific process variation and the measurement system resolution meeting the requirements, the ndc value shall not be assessed.

If, at the same time, the ndc value deviates and the required measurement system resolution is not met, the gage capability is <u>not</u> given.

5 Suggestions on how to procede with unsuitable measuring processes

5.1 Step 1: improve the measuring system

- **Measurement error, standards**
    - Measuring, clamping, holding forces
    - Measuring locations, definition of positions
    - Receptacles, subject alignment, measuring probe
    - Sensing element, quality of the measurement standard (surface, form)
- **Measurement procedure, strategy**
    - Reference element, measurement baseline
    - Measurement speed, filter settings, settling times
    - Multi-point measurements or scanning instead of individual measurements
    - Statistics software
    - Calibration chain
- **Environmental conditions**
    - Impacts, vibrations
    - Dust, oil mist, draught, humidity
    - Lighting conditions (with optical measurement systems)
    - Temperature fluctuations
    - Electrical interferences
- **Specimen**
    - Cleanliness
    - Surface condition
    - Geometrical deviations
    - Temperature coefficient
- **Operator**
    - Briefed, trained
    - Care, handling
    - Cleanliness

5.2 Step 2: obtain a more precise measuring system

- **Resolution <5% of the tolerance**
- **Use linear systems**
- **Use systems that measure absolute values**
- **Robust measuring equipment**
- **Measuring equipment independent of the operator**

5.3 Step 3: tolerance assessment

- **Check whether the criterion depends on the function**
- **Deduct the gage repeatability and reproducibility from the tolerance**
- **Take into consideration process control and capability**

6 Reference

The information contained in this company standard was taken entirely or in part from the following:

/1/ Eignungsnachweis von Prüfprozessen. Dietrich und Schulze. Hanser Verlag
/2/ Measurement System Capability" Reference Manual. Issue 2.1 D/E. Dr. Edgar Dietrich. Q-DAS GmbH