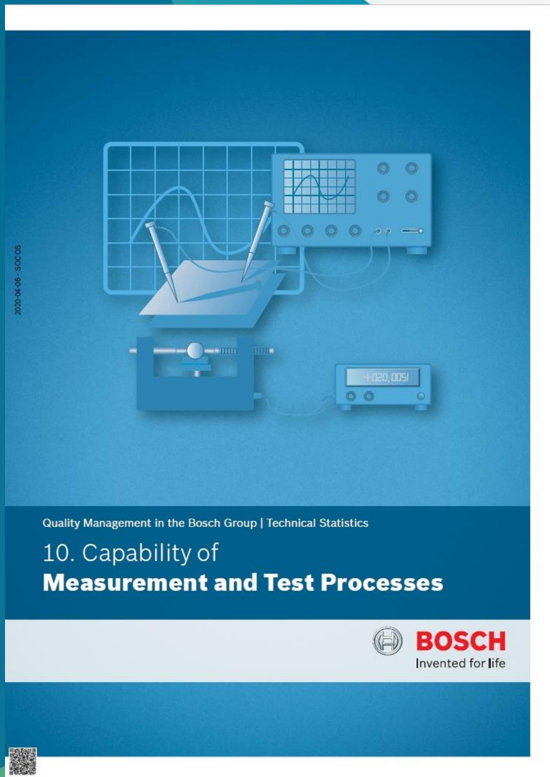

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TQ038 – Capability of Measurement and Test Processes

Bosch Booklet 10 – Edition 2019

Notes:

Learning objectives

- To be able to select and use appropriate methods to verify the capability of measurement and test processes.
- To know all the methods described in Bosch Booklet 10 and know how to interpret and evaluate their results
- To know the methods' scope of application as well as their limits
- To know approaches for identifying the causes of non-capable measurement processes and be able to make approval decisions

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Notes:

Seminar Agenda

- Definitions and requirements from standards
- Resolution of a display
- Measurement uncertainty of the measurement standard
- Procedure 1 – Systematic error and repeatability
- Procedure 2 – Repeatability and reproducibility
- Procedure 3 – Appraiser-independent systems
- Procedure 4 – Linearity
- Procedure 5 – Stability
- Procedure 6 – Test processes for discretized continuous characteristics
- Procedure 7 – Test processes for discrete characteristics
- Assessment of non-capable measurement and test processes
  - Risk analysis and approval decision
  - Causes of non-capable measurement systems

Done first for didactic reasons

Notes:

Testing and measuring

- What is measuring - what is testing?

Testing

- subjectively
  - by sensory perception (visual, noise, haptic, …)
- objectively
  - by gauging
  - by measuring

Procedure 7
(Type 7 Study)

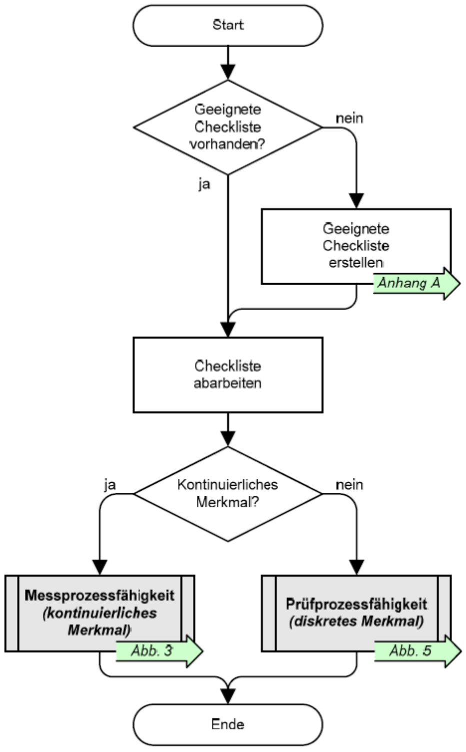
Procedures 6 / 7
(Type 6 / 7 Studies)

Procedures 1 – 5
(Type 1 - 5 Studies)

Notes:

Testing and measuring

- Standard-compliant definition (VDA 5, VIM, ...):
  - Measuring is the determination of a measured value
  - Testing is making a conformity decision
    - Based on a measurement or ...
    - … ... based on gauging/testing
- Common definition (Bosch booklet 10)
  - Measuring process capability for continuous characteristics
  - Test process capability for discrete characteristics
- Important note (booklet 10, chapter 5, first sentence): „ The analysis using discrete or discretized characteristics is generally not recommended, since meeting up-to-date requirements for error rates requires sample sizes which are economically not justifiable. The verification of capability by means of continuous characteristics using procedures 1 - 5 should always be preferred.“



Notes:

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Notes:

Definition: Measuring process and measuring system

- AIAG Core Tool MSA 4th Edition

Terminology

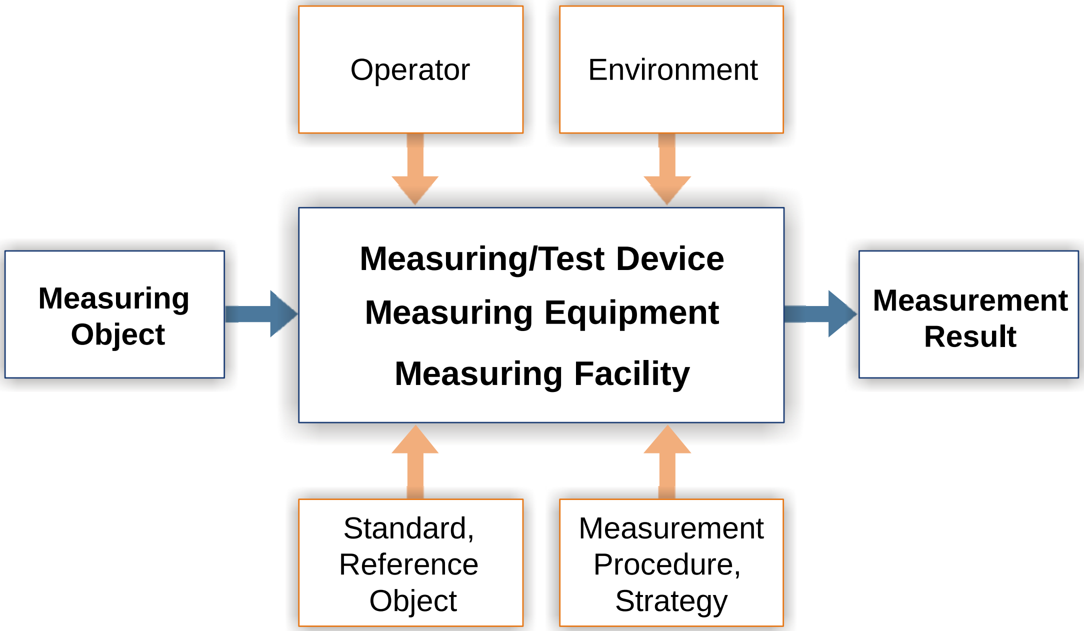
Chapter I – Section A
Introduction, Purpose and Terminology

- **Measurement System** is the collection of instruments or gages, standards, operations, methods, fixtures, software, personnel, environment and assumptions used to quantify a unit of measure or fix assessment to the feature characteristic being measured; the complete process used to obtain measurements.

From these definitions it follows that a measurement process may be viewed as a manufacturing process that produces numbers (data) for its output. Viewing a measurement system this way is useful because it allows us to bring to bear all the concepts, philosophy, and tools that have already demonstrated their usefulness in the area of statistical process control.

Definition: Measuring process and measuring system

- View according to standard (ISO/IEC Guide 99/VIM, ISO 22514-7)



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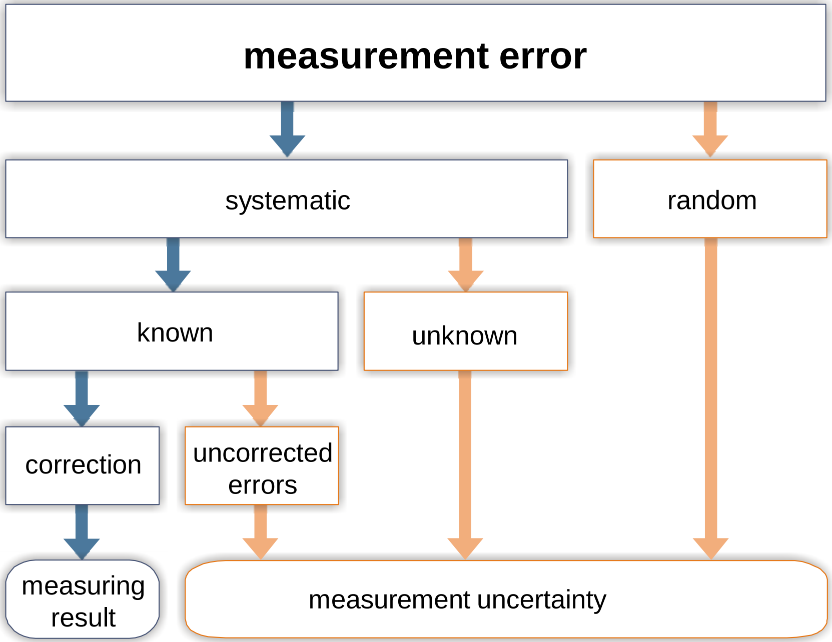
Notes:

Classification of measurement errors

- Systematic vs. random



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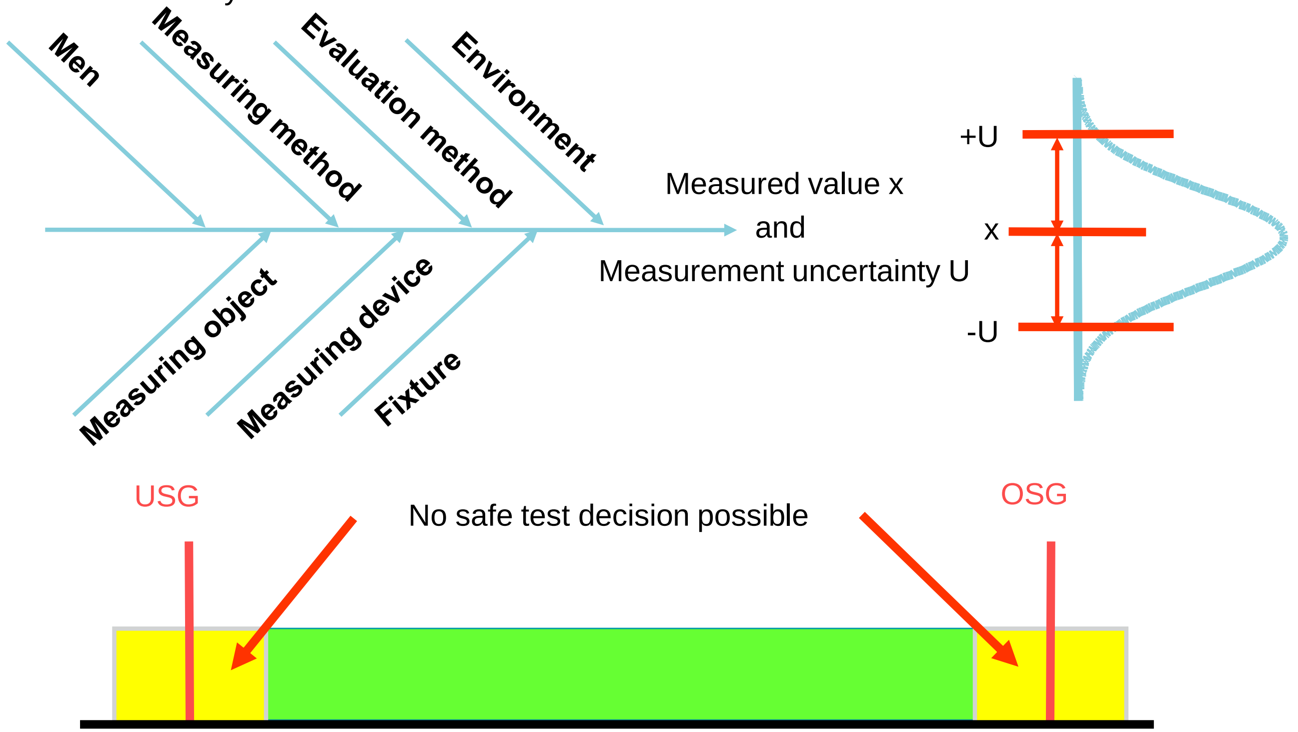
Notes:

Taking measurement errors into account

- Risk: uncertainty zones at tolerance limits



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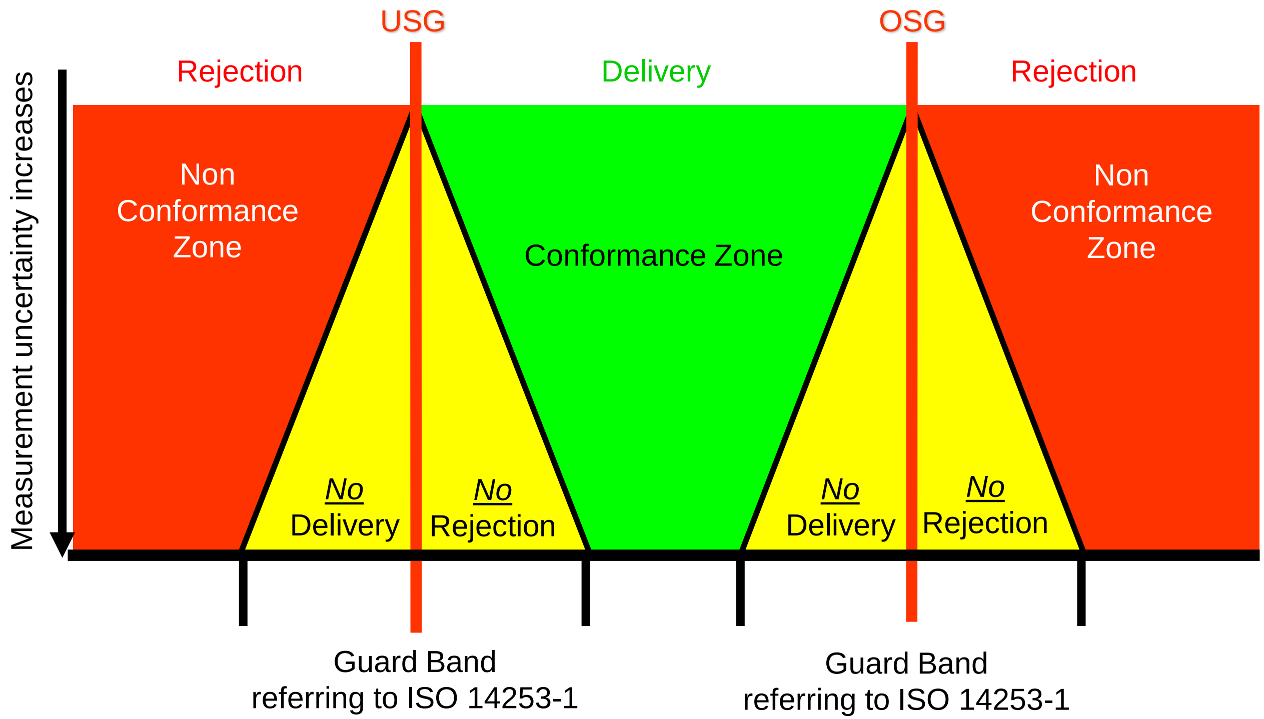
Notes:

Requirement according to ISO 14253-1

- Guard Bands



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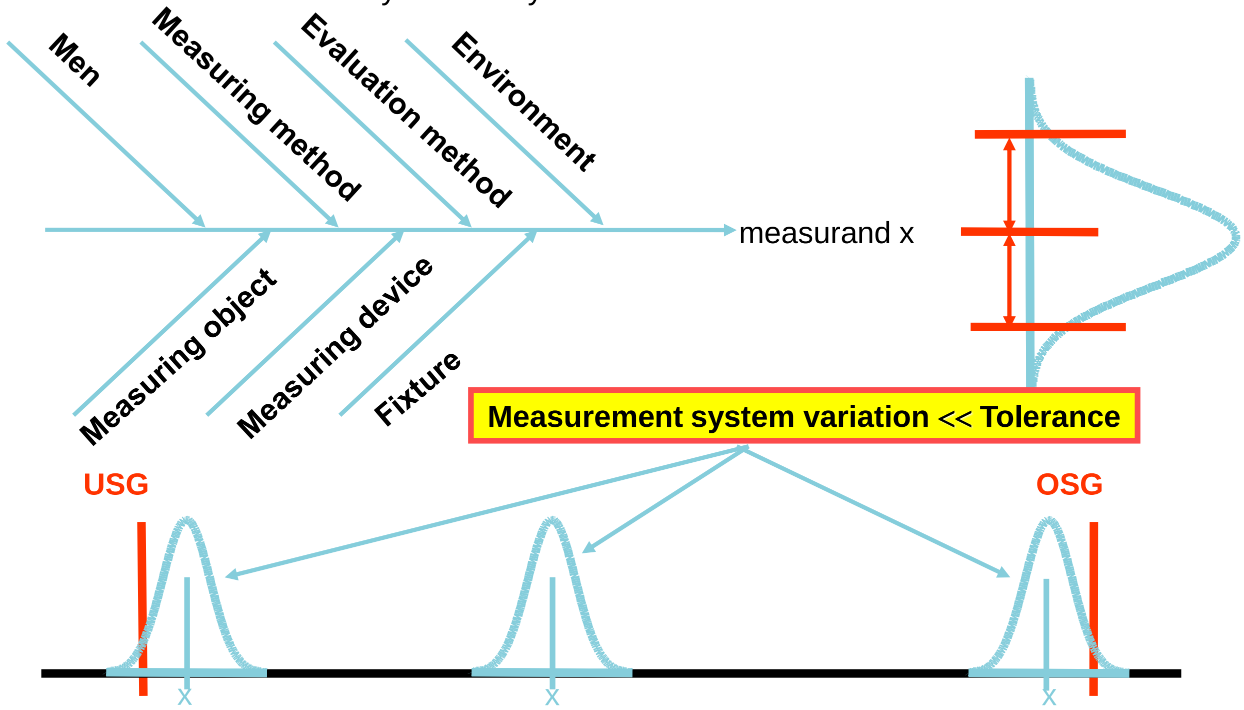
Notes:

Taking measurement errors into account

- View of the measurement system analyses



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Notes:

Scope

Quotes Booklet 10 Chapter 2

- The verification of capability has to be provided by means of measurements and tests at the place of operation of the measuring or test systems and statistical analyses of the results.
- It is only reasonable for measuring and test systems that conduct a sufficiently large number of similar recurring measurements and tests (e. g. in the production flow) and it is valid for the examined characteristic only.
- If measurements and tests of different characteristics are done with the same measuring or test system, an individual verification of capability is required for each characteristic.
- In case of frequently changing measurement tasks (e. g. in development and test departments), measurement uncertainties should be determined rather than capabilities.
- If conformity statements according to [ISO 14253] are required, measurement uncertainties have to be determined categorically instead of or in addition to capabilities.
- If procedures contained in this issue of booklet 10 cannot be applied for justified reasons, other procedures […] have to be examined for their applicability and used. […] As an exception, special procedures can be developed. The intended procedure has to be documented and agreed upon with the QM department and the customer.

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Notes:

Impact of measurement process variation

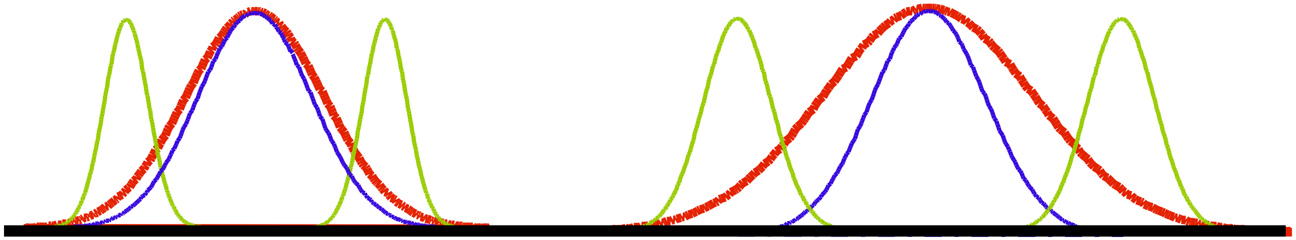
- Effect of measurement process variation on manufacturing process capability

$$\sigma^2_{observed} = \sigma^2_{actual} + \sigma^2_{measuring\ system}$$

Observed Process Variation

Actual process variation

Variation of the measuring system

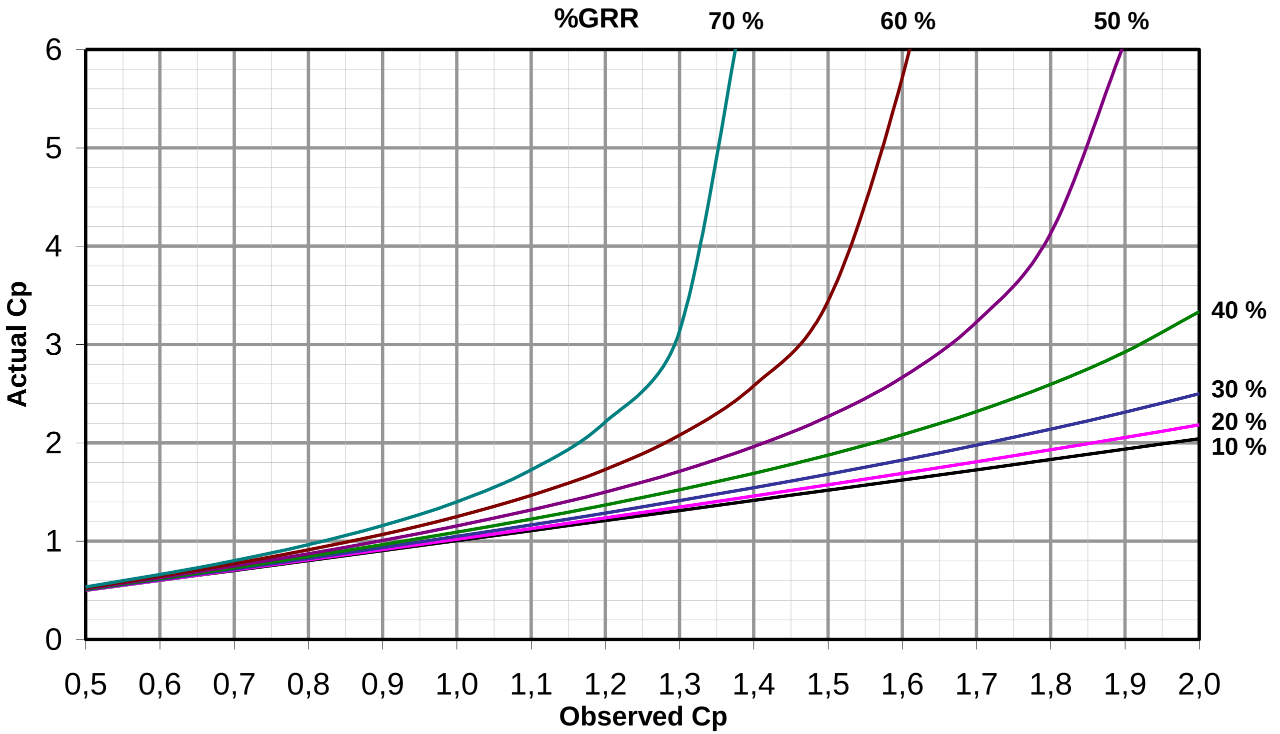


Small measuring system variation

Large measuring system variation

Notes:

Impact of measurement process variation



Notes:

Methods according to Booklet 10

- Procedure 1 – Measurement of standard/reference - Cg/Cgk
  - Prerequisite for procedures 2 to 5
- Procedure 2 – Repeatability and reproducibility - %GRR
  - Influence of real parts and appraisers
- Procedure 3 – Appraiser-independent systems - %GRR
  - Replaces procedure 2 for appraiser-independent systems
- Procedure 4 – Linearity study
  - If not investigated by manufacturer/at calibration

Standard methods for approval of variable measuring systems

- Procedure 5 – Stability
  - Long-term assessment/monitoring
- Procedure 6 – Discrete characteristics with continuous reference values
  - Determine “grey area” of uncertain decisions as “%GRR”
- Procedure 7 – Discrete characteristics with and without cont. ref. values
  - Assessment using a κ-value (Fleiss’ kappa)

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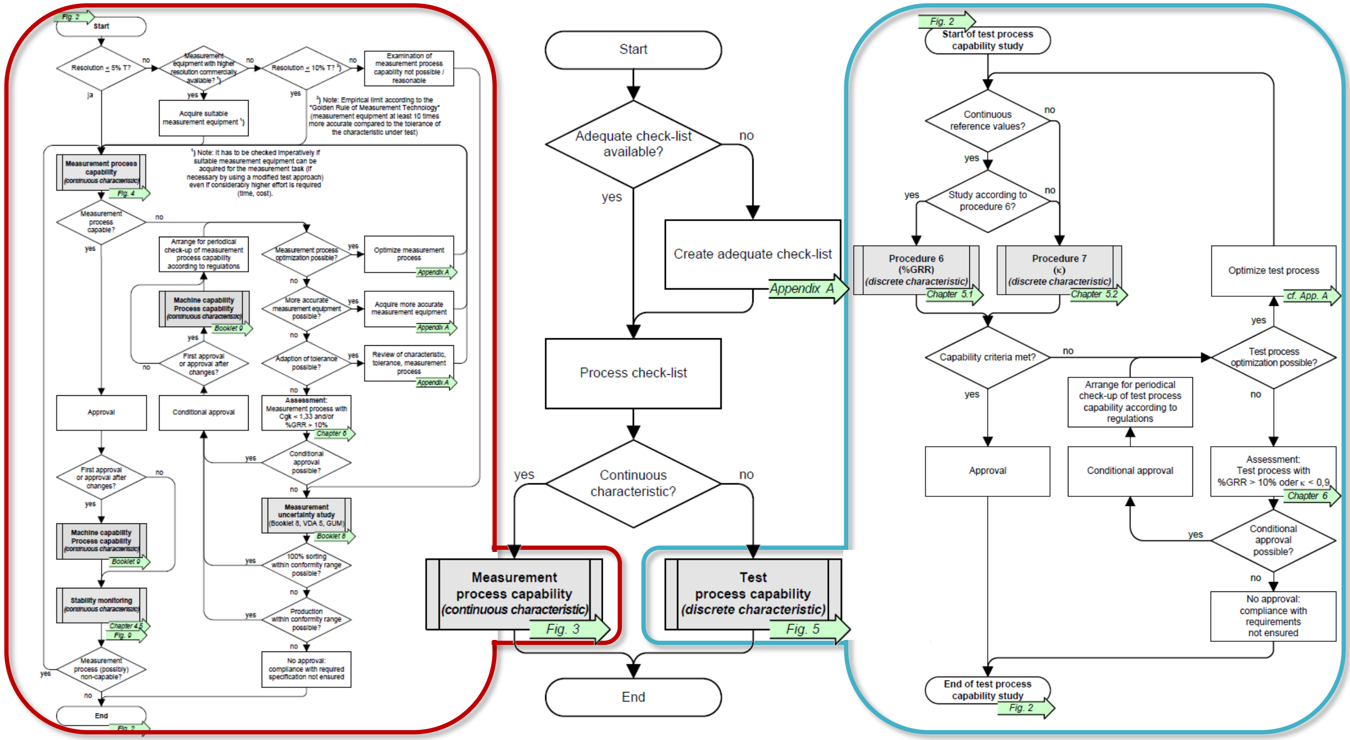
Notes:

Methods according to Booklet 10



Notes:

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Flow chart - Measurement processes

- Assess resolution
- Perform capability analyses
- If capable: use measurement systems and monitor stability
- If not capable:
  - Optimize
  - Risk analysis
  - Conditional approval and re-qualification

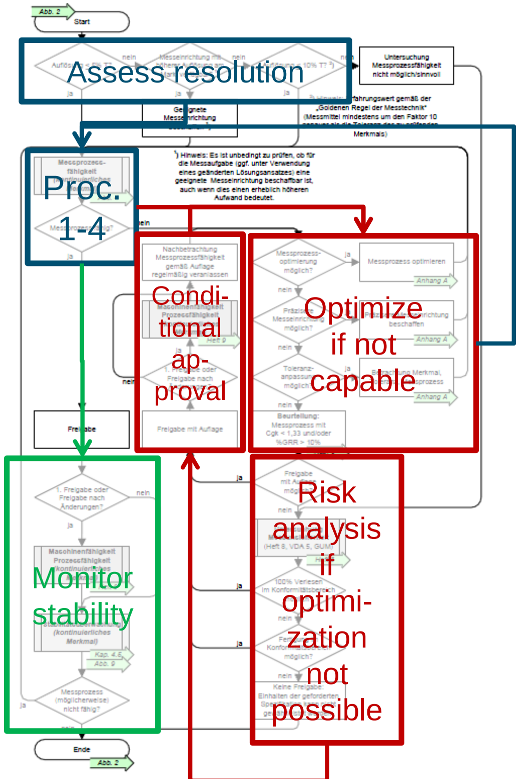
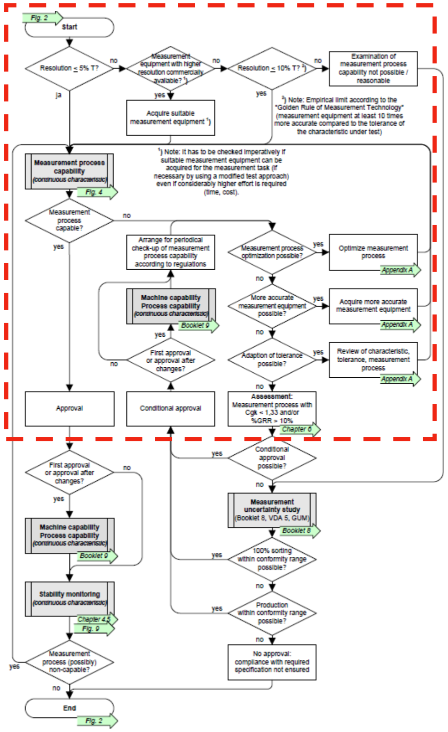


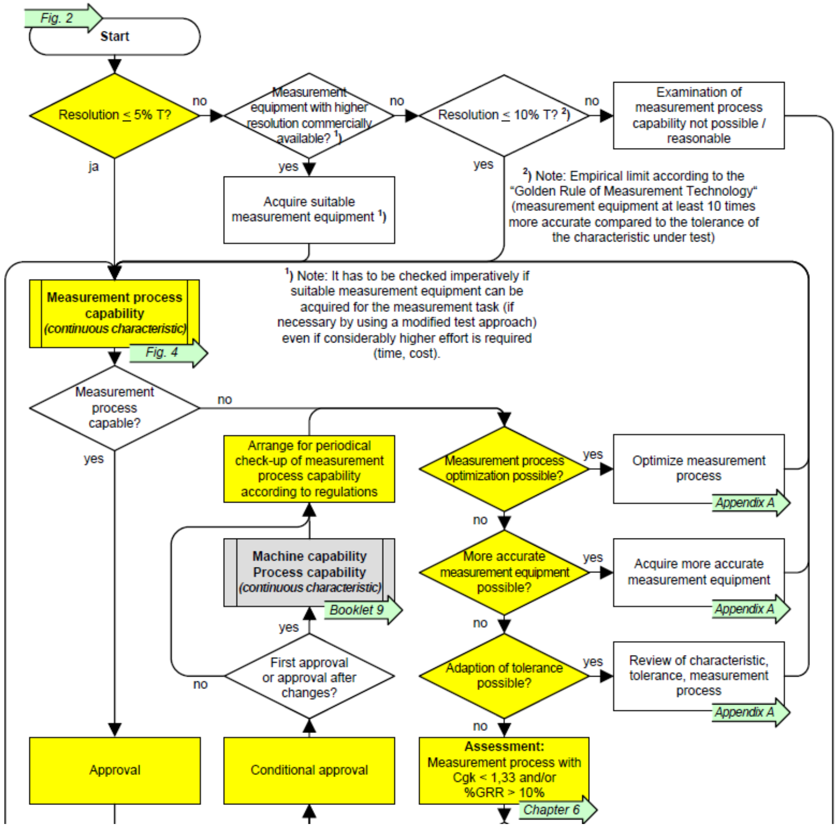
Abb. 3: Ablauf Messprozessfähigkeitsuntersuchung bei kontinuierlichen Merkmalen (Ebene 2)

Notes:

HEXAGON

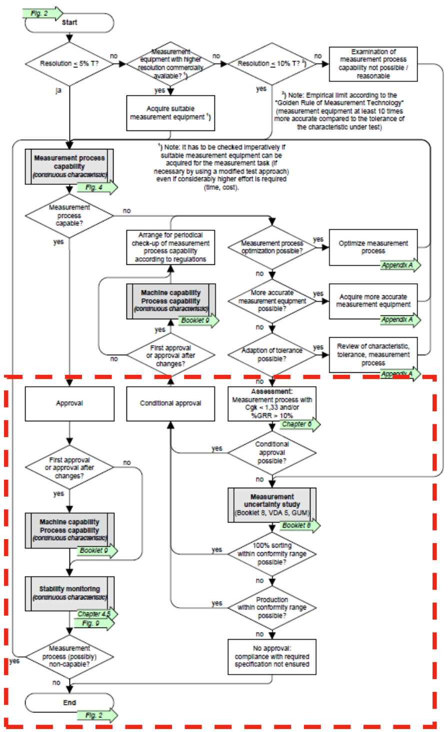
Flow chart

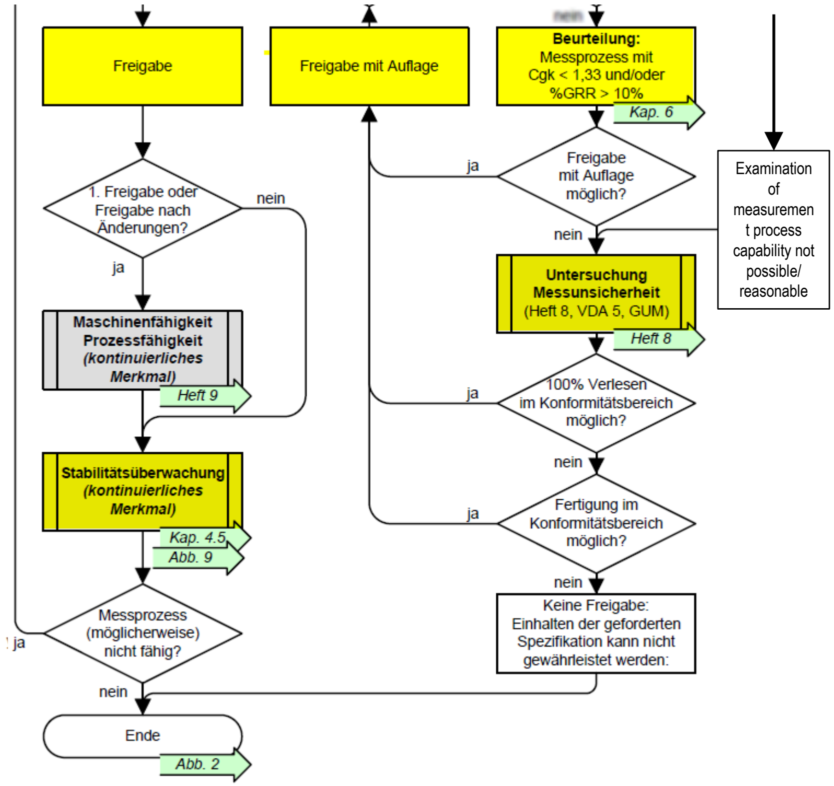




Notes:

Flow chart





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Notes:

Starting point of a measurement system analysis

- Purchase of a new measurement system
- New application of an existing measurement system
  - New products
  - New characteristics
  - New measurement strategies
  - …
- Revision of a measurement system
  - Regular maintenance
  - Repair
  - Expansion/change of a system
  - …
- Viewed as a study of a measurement “process” – whenever something might have changed about a process parameter/variable

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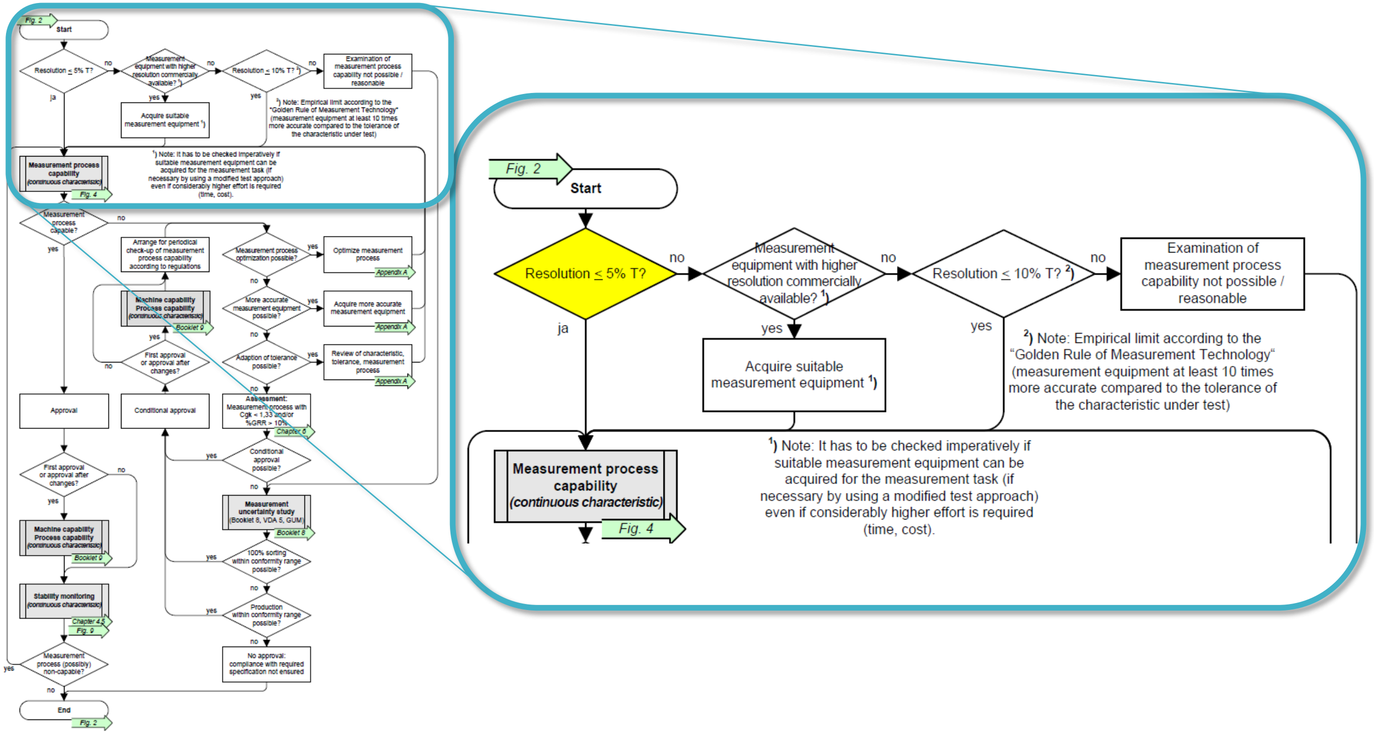
Notes:

Flow chart



Notes:

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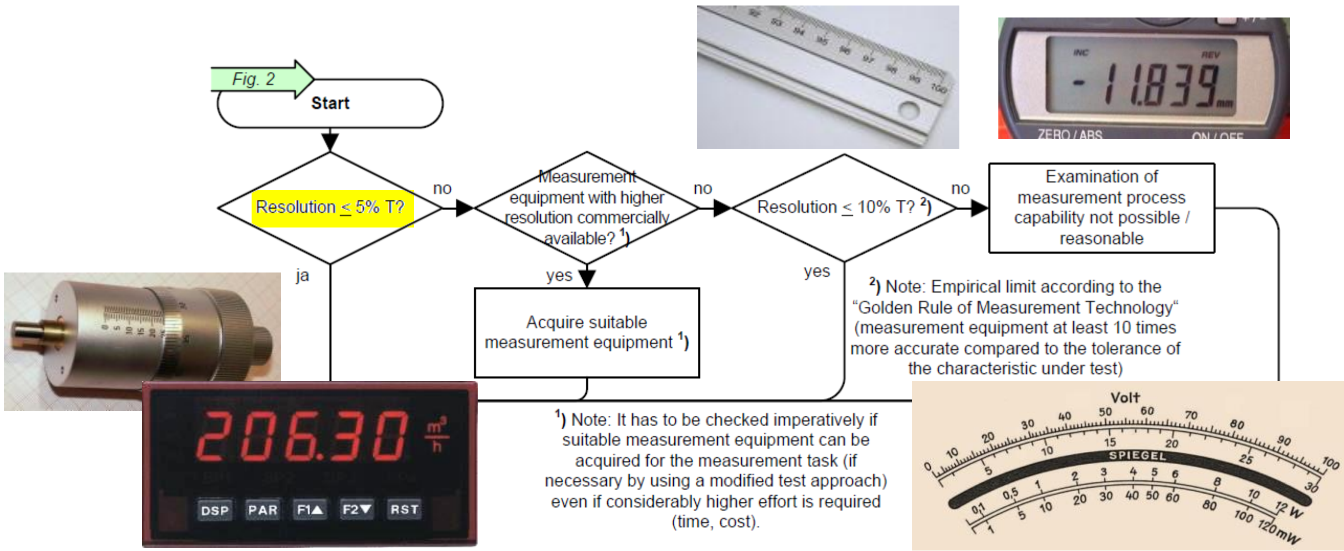
Notes:

Resolution of a display

- Booklet 10 Definition of terms

  Resolution of a displaying device
  smallest difference between displayed indications that can be meaningfully distinguished [VIM, 4.15]



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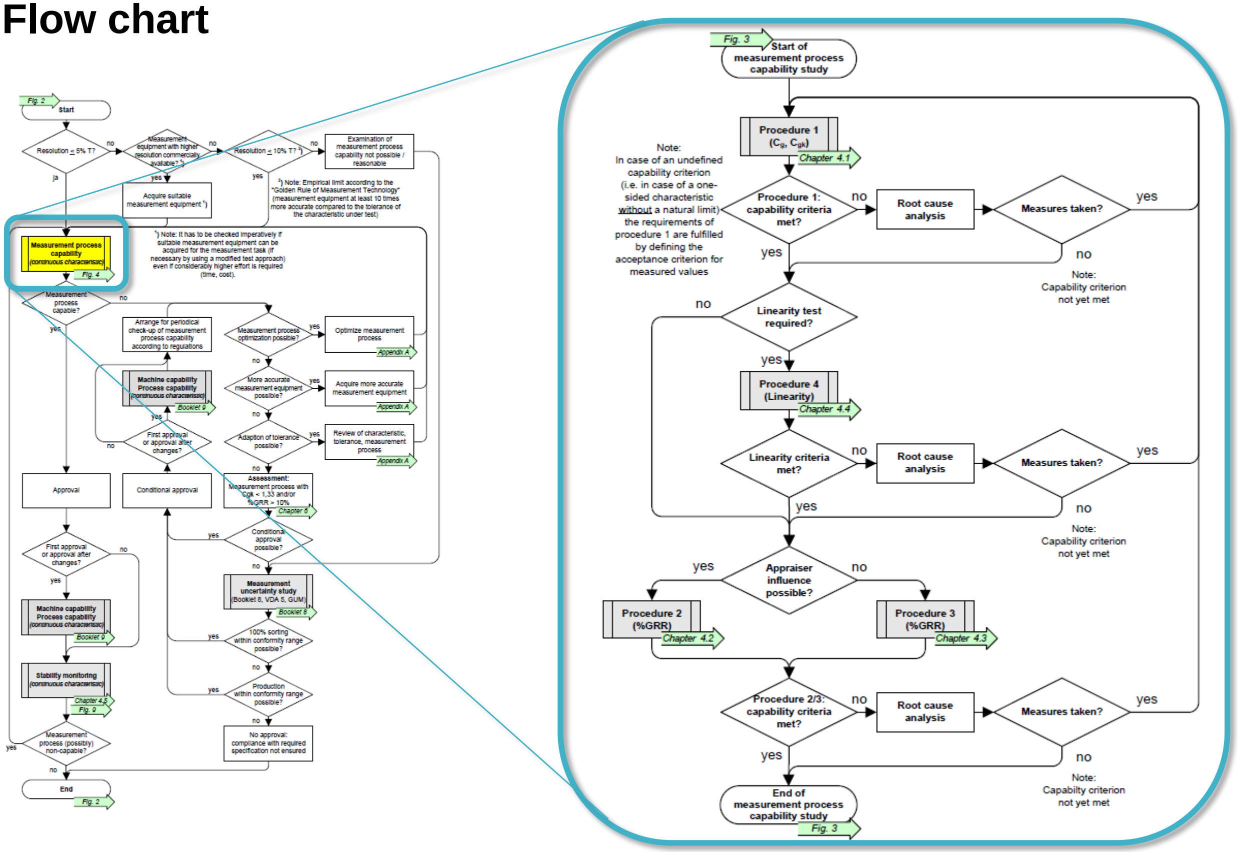
Flow chart



Notes:

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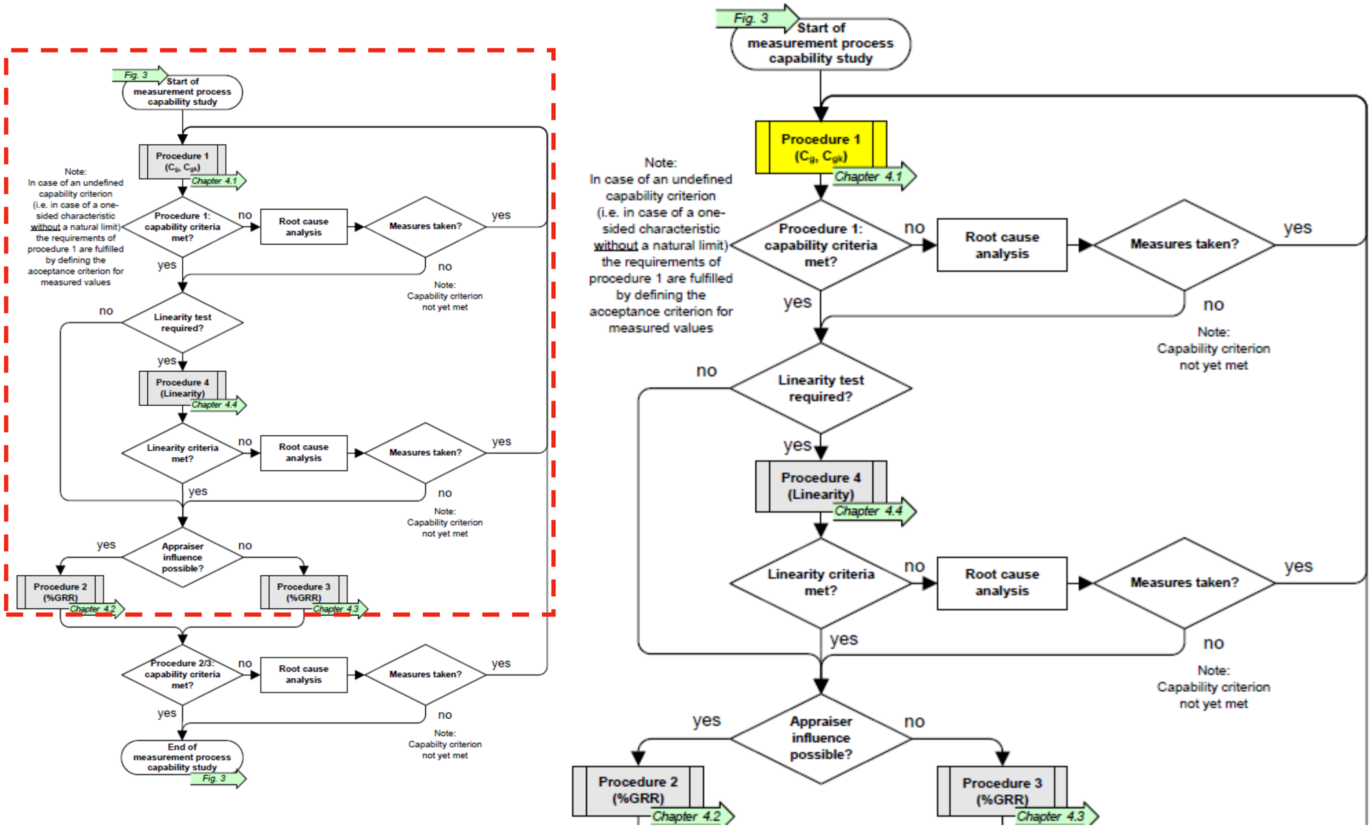
Flow chart



Notes:

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Procedure 1 – Using a measurement standard

- Objective
  To demonstrate the capability of a measurement process (as a test process for a certain characteristic) in terms of the location and variation of measured values within the characteristic's tolerance region.

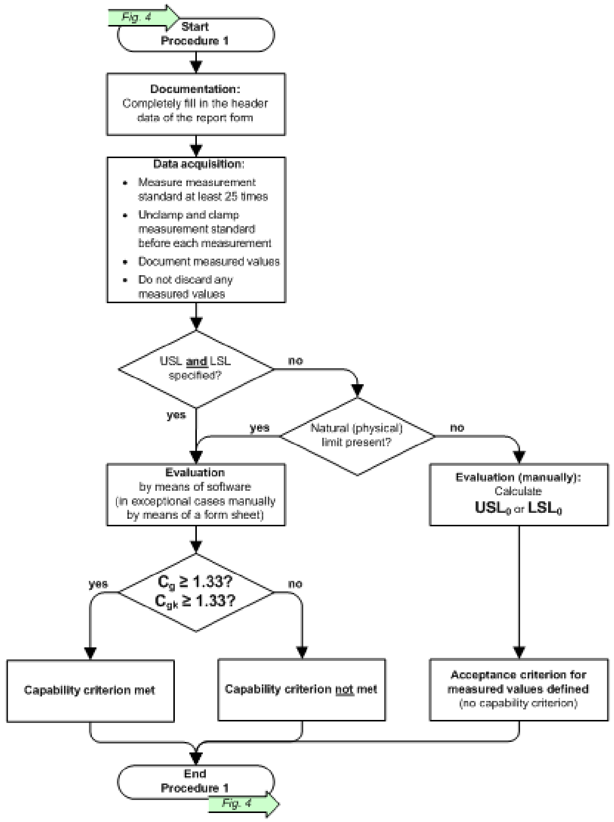
- Requirements
  - Product characteristics with a bilateral tolerance
  - If there is a natural limit, this is used as a replacement
    (e.g. gap width, roughness, evenness … USL is defined, LSL* = 0)
  - Calibrated measurement standard (reference part) available

- Conducting the study
  - The standard is measured 50 times (min. 25 times) under repeatability conditions

Notes:

Procedure 1 – sequence

- Documentation
- Data collection
- If T or T* (natural limit) is defined
  - Calculate capability indices
  - Assess capability indices
  - $Cg, Cgk \geq 1{,}33$
- If T is not defined
  - Calculate critical limits USL_0/LSL_0
  - Define acceptance criterion for measured values



Notes:

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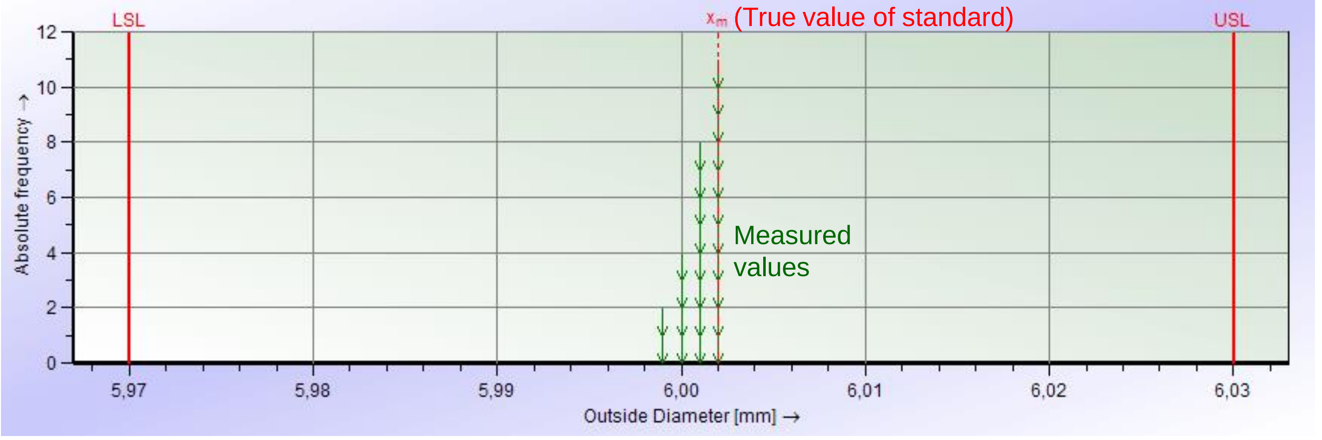
Procedure 1 – Data collection

- Typically 50 (min. 25) measurements
  - of a measurement standard
  - under repeatability conditions
- Defined measurement point on the standard
- Replace standard after each measurement (reinsert, reclamp, recontact)



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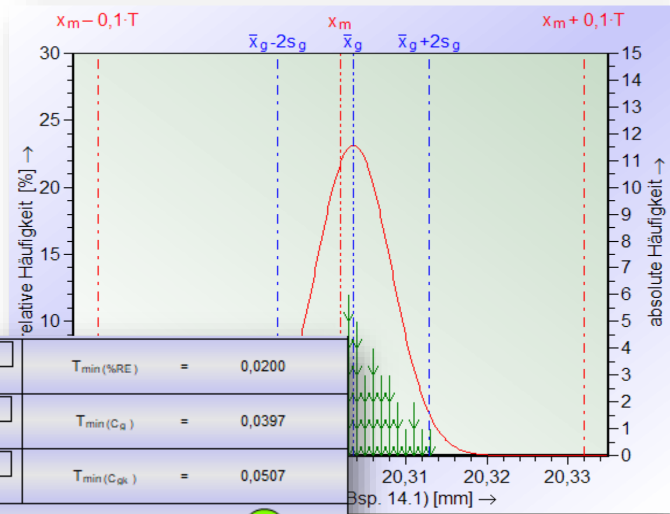
Notes:

Notes:

Procedure 1

- A reference part / master / standard is usually measured 50 times under repeatability conditions
- The measured values are generally ...
  - ... vary around the mean value (Repeatability)
  - … deviate on average from the reference value (Systematic measurement deviation)



Resolution	%RE = 1,67%	0 … 5	$T_{min(\%RE)}$	= 0,0200
$C_g = \frac{0{,}2 \cdot T}{6 \cdot s_g}$	= 1,61 ≤ **2,01** ≤ 2,41	0 … 1,33	$T_{min(C_g)}$	= 0,0397
$C_{gk} = \frac{0{,}1 \cdot T - \lvert \bar{x}_g - x_m \rvert}{3 \cdot s_g}$	= 1,30 ≤ **1,64** ≤ 1,98	0 … 1,33	$T_{min(C_{gk})}$	= 0,0507
Measuring System Capable (%RE,min,C_g,C_{gk})				☺
BOSCH 2018: Type 1				

HEXAGON

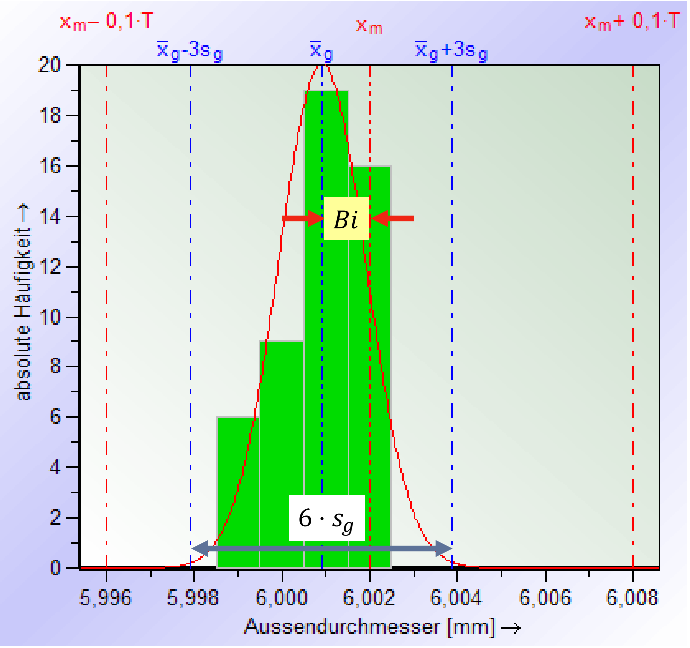
Procedure 1 – Components of uncertainty

- Results of the experiment for procedure 1
- Bias

$$Bi = \bar{x}_g - x_m$$

- Measuring system variation

$$6 \cdot s_g$$



- Reminder:
- Mean value $\bar{x}_g = \frac{\sum x_i}{n}$
- Standard deviation $s_g = \sqrt{\frac{\sum(\bar{x}-x_i)^2}{n-1}}$

HEXAGON

Notes:

Procedure 1 – Calculating the indices

- Capability indices Cg and Cgk

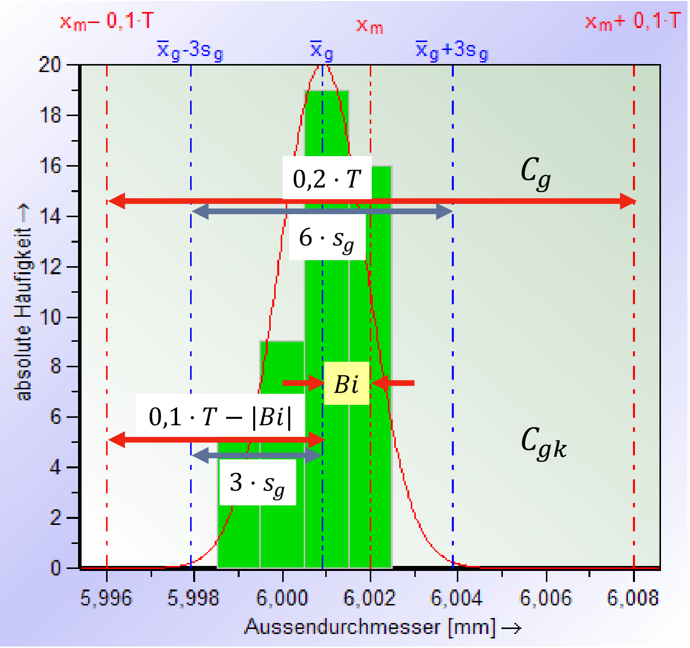
- Bias

$$Bi = \bar{x}_g - x_m$$

- Capability indices

$$C_g = \frac{0{,}2 \cdot T}{6 \cdot s_g}$$

$$C_{gk} = \frac{0{,}1 \cdot T - Bi}{3 \cdot s_g}$$



- Reminder:
- Mean value $\bar{x}_g = \frac{\sum x_i}{n}$
- Standard deviation $s_g = \sqrt{\frac{\sum(\bar{x} - x_i)^2}{n-1}}$

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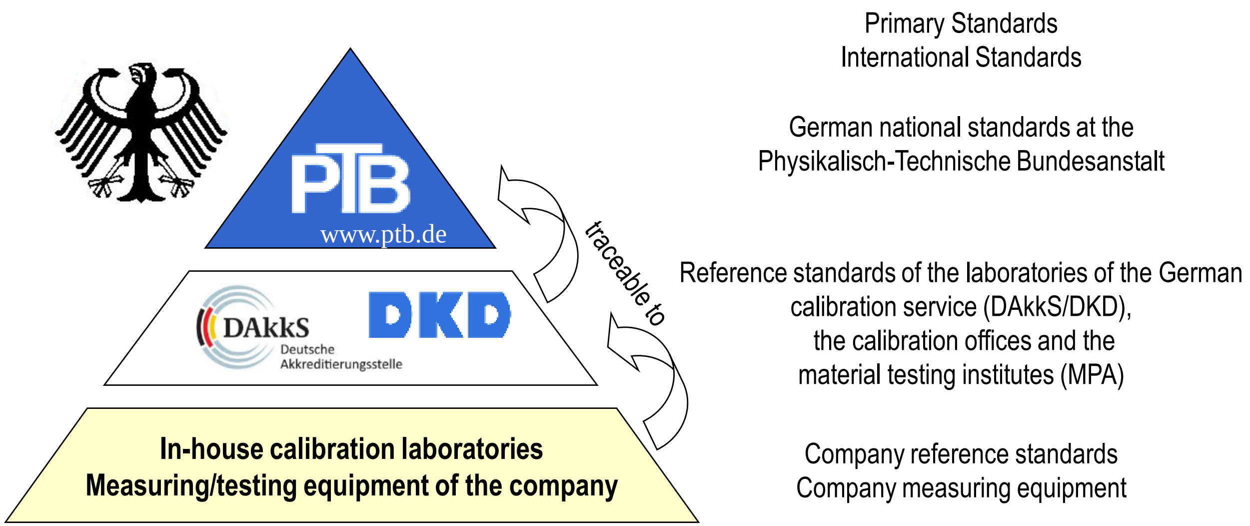
Notes:

Measurement standard

- ISO/IEC Guide 99:2007 (VIM)
  measurement standard / etalon
  realization of the definition of a given quantity, with stated quantity value and associated measurement uncertainty, used as a reference



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Notes:

Requirements for the standard

- Must enable an unambiguous result under repeatability conditions and be stable long-term
- Must have the same characteristic as the objects that the measuring equipment is later expected to measure
- Must be clearly marked as a standard, suitably calibrated, and included in the control of inspection, measurement and test equipment.
- The documented uncertainty U_{cal} of the standard should be significantly smaller than the specified tolerance T for the tested product characteristic
  - Ideal case $U_{cal} < 0{,}01 \cdot T = 1\%\ T$
  - Minimum requirement $U_{cal} < 0{,}1 \cdot T = 10\%\ T$
- If a corresponding object is not available, procedure 1 cannot be performed, and a suitable alternative method has to be found

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Notes:

Notes:

Procedure 1 - Assessment with Standard

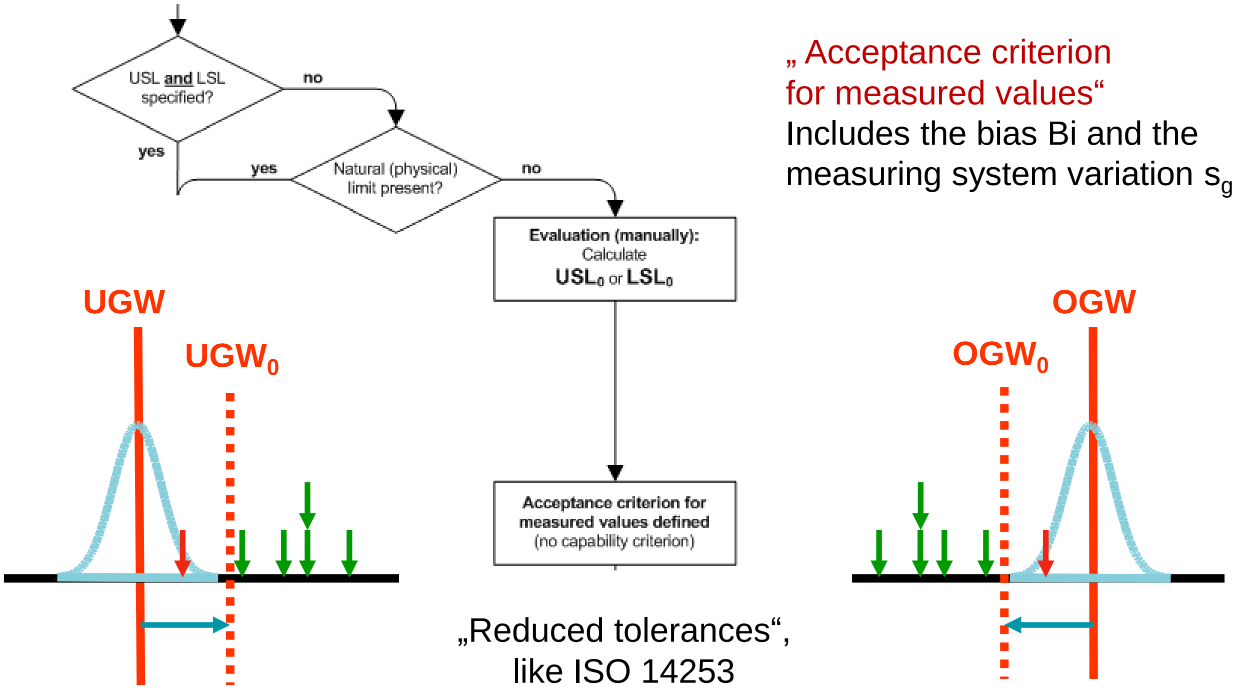
- Exemplary results with solara.MP

Drawing Values			Collected Values			Statistics		
$x_m + 0.1 \times T$	=	6.00800	$x_{max\,g}$	=	6.002	$\bar{x}_g + 3s_g$	=	6.00388
x_m	=	6.00200	$x_{min\,g}$	=	5.999	$\bar{x}_g$	=	6.00090
$x_m - 0.1 \times T$	=	5.99600	R_g	=	0.003	$\bar{x}_g - 3s_g$	=	5.99792
$0.2 \times T$	=	0.01200	n_{tot}	=	50	$6s_g$	=	0.00597
T	=	0.060				s_g	=	0.000995
Unit	=	mm				$\|Bi\|$	=	0.0011000
						n_{eff}	=	50
						Minimum reference figure for capable measuring system		
Resolution	%RE =	1.67%	0 … 5			$T_{min\,(\%RE)}$	=	0.0200
$C_g = \frac{0.2 \times T}{6 \times s_g}$		= 1.61 ≤ **2.01** ≤ 2.41	0 … 1.33			$T_{min\,(C_g)}$	=	0.0397
$C_{gk} = \frac{0.1 \times T - \|\bar{x}_g - x_m\|}{3 \times s_g}$		= 1.30 ≤ **1.64** ≤ 1.98	0 … 1.33			$T_{min\,(C_{gk})}$	=	0.0507
Measurement system capable (%RE,min,C_g,C_{gk})								
⊕ BOSCH 2018: Type 1								

HEXAGON

Procedure 1 – One-sided characteristics

- Determination of the acceptance criterion



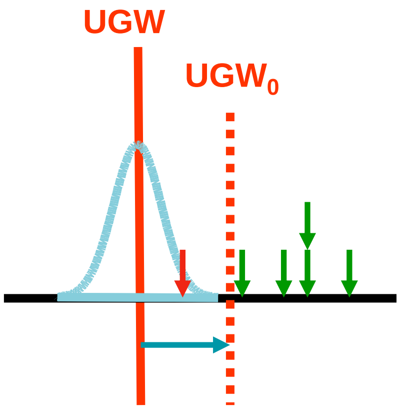
„ Acceptance criterion for measured values“
Includes the bias Bi and the measuring system variation s_g

„Reduced tolerances“, like ISO 14253

Notes:

Procedure 1 – One-sided characteristics

- Illustrative: "Critical limit is offset from the (drawing) limit by the bias and 4 times the standard deviation".
- Standard for procedure 1 should be within $\pm 10\%$ of the specification limit
- Bias Bi must enter the calculation with correct sign (!)
- $4 \cdot s_g$ for $C_g/C_{gk} \geq 1{,}33$; $5 \cdot s_g$ for $C_g/C_{gk} \geq 1{,}67$; $6 \cdot s_g$ for $C_g/C_{gk} \geq 2{,}0$



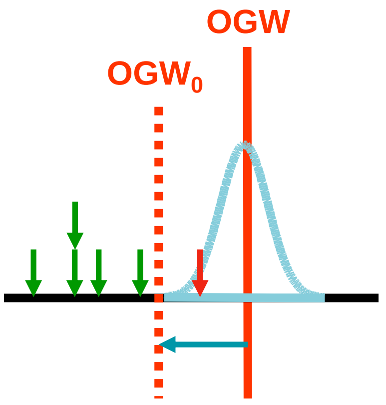
$$LSL_0 = LSL + Bi + 4 \cdot s_g$$

$$USL_0 = USL + Bi - 4 \cdot s_g$$

$$with$$

$$Bi = \bar{x}_g - x_m$$

„Reduced tolerances“,
like ISO 14253



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Notes:

Alternative method according to AIAG MSA

- AIAG MSA does not contain the procedure 1. Instead, it recommends testing systematic measurement errors $Bi = \bar{x} - x_m$ for significance (test for significant bias)
- Approach of the test for significant bias:
  - The bias in a procedure 1 is caculated from the 25 (50) measured values
  - Any further measurement would slightly change the bias
  - In other words, the present bias value is a random variable subject to random variation (confidence interval)
  - So a bias might show even for an ideal gauge If the bias is close to zero, so that zero is within the confidence interval, then the bias is negligible
  - If the bias is too large, i.e. significantly different from zero, action must be taken

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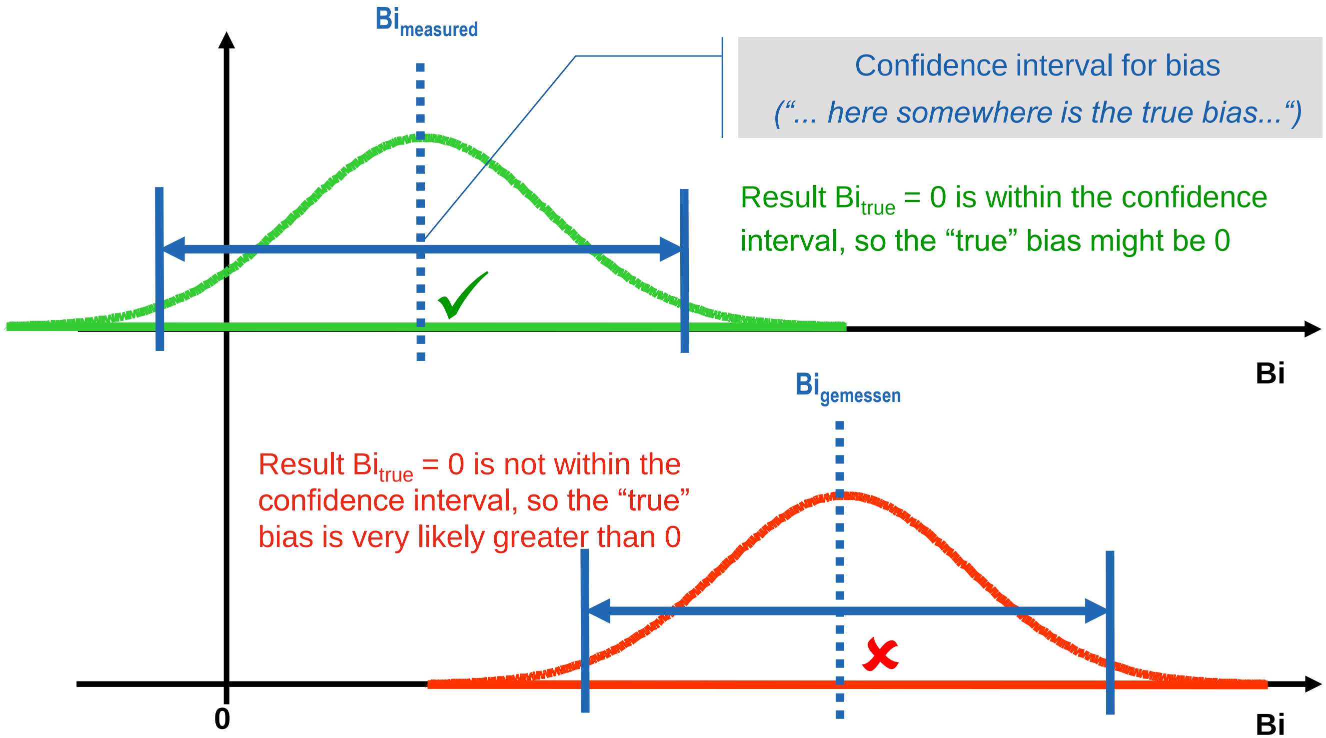
Notes:

Alternative method according to AIAG MSA

- Test for significant bias



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Notes:

Alternative method according to AIAG MSA

- Advantages of the test for significant bias
  - Statistical significance test (1-sample t-test)

- Limits/weaknesses of the test for significant bias
  - A (minimal) bias is generally unavoidable
  - A significant bias only says that there is a demonstrable bias, but does not assess it relative to a requirement (e.g. tolerance)
  - Experience has shown that it leads to problems in practice:
    - High-quality standards/measurement systems: the smaller the system variation, the more significant the bias ("… the more the systematic error stands out against the small amount of noise").
      → Criterion not satisfied, even though measurement error is very small
    - Low-quality standards/measurement systems: the converse case – the bias does not show up as significant
      → Criterion satisfied, even though error is unacceptably large
    - The more measurements are taken, the more significant the bias
      ("... the more the random variation averages out")

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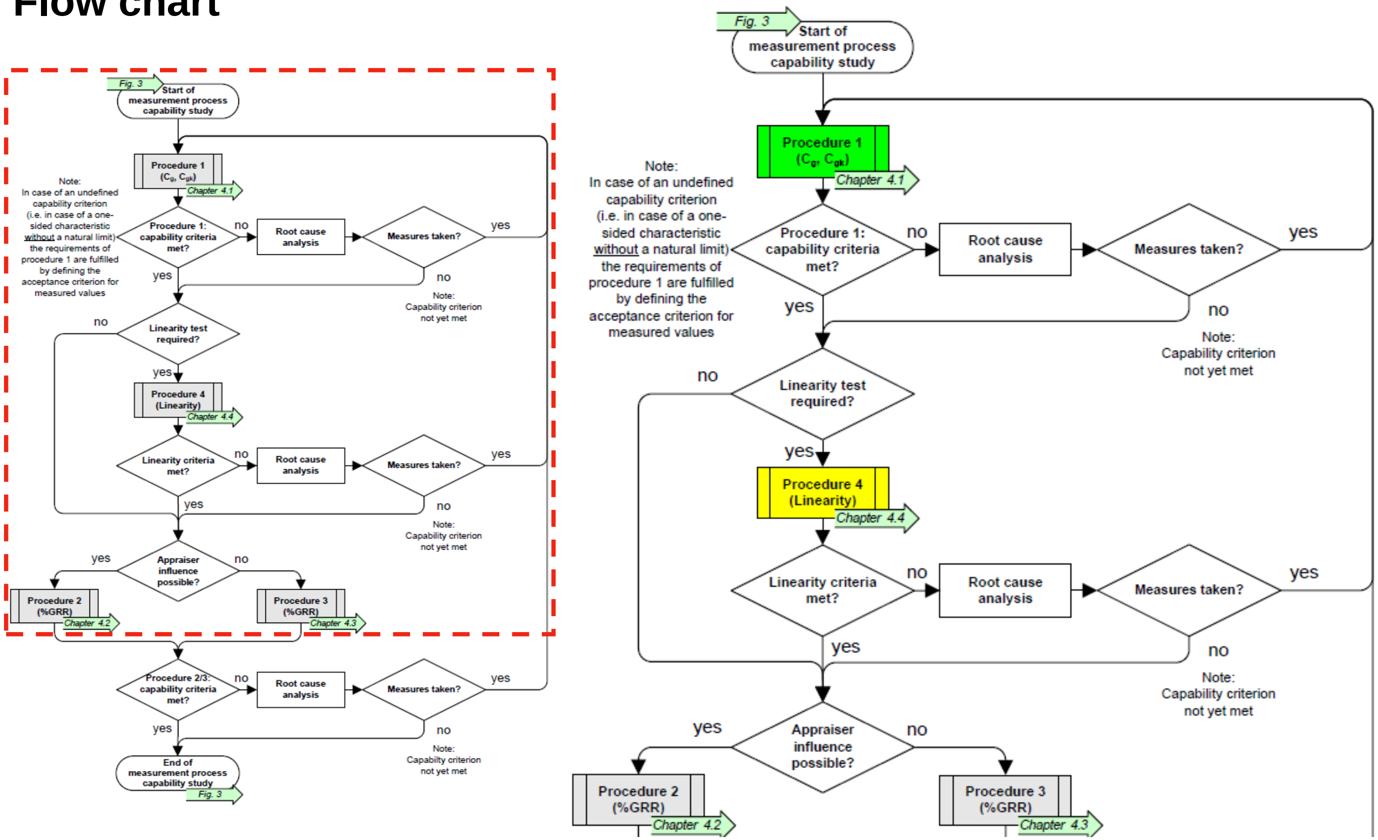
Notes:

Flow chart



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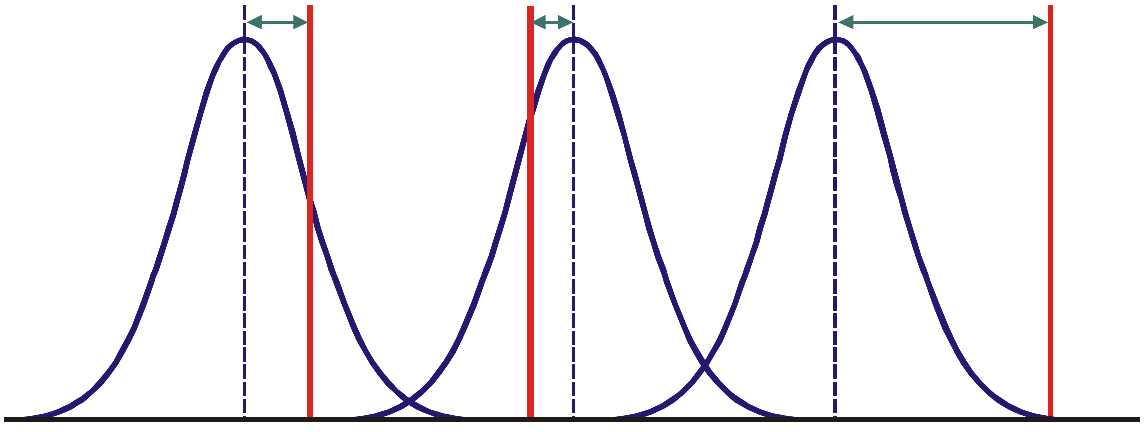
Notes:

Notes:

Procedure 4 – Linearity

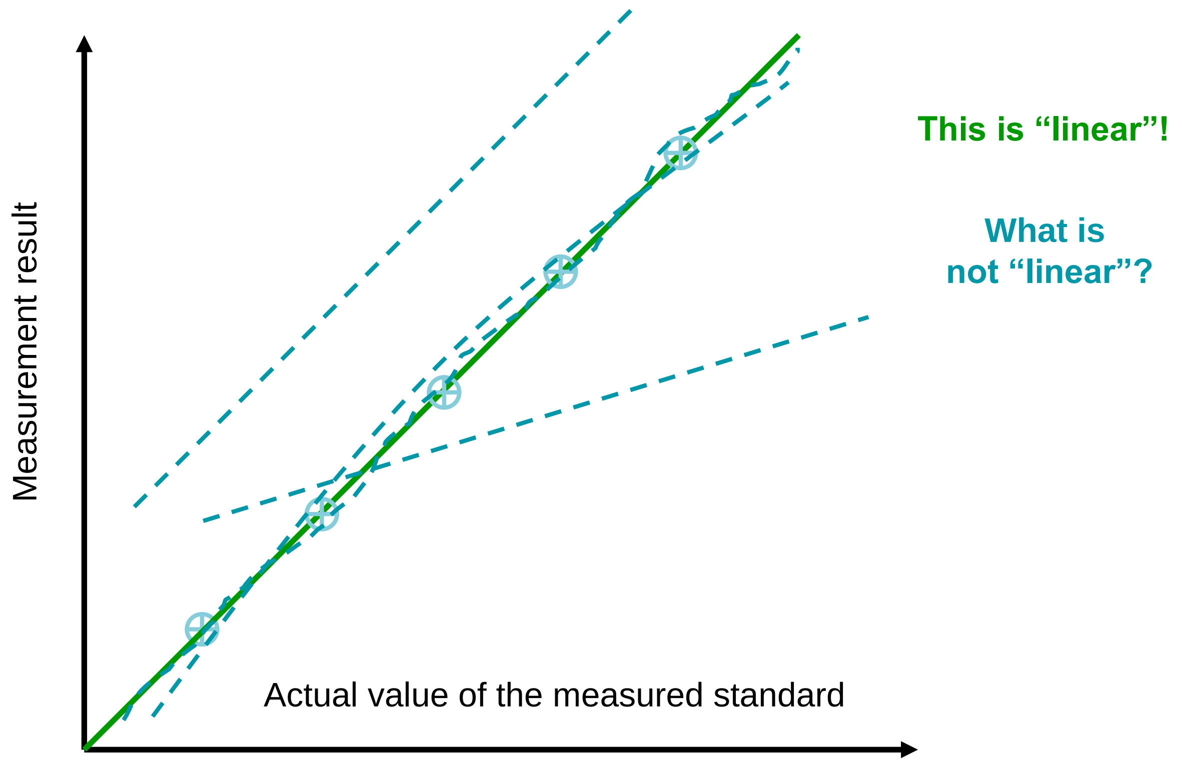
- Linearity is the variability of the bias over the application range (generally characteristic tolerance).



- Variability of dispersion (AIAG MSA: uniformity) is usually not assessed
- Constant dispersion (homoskedasticity) over the application range is usually assumed

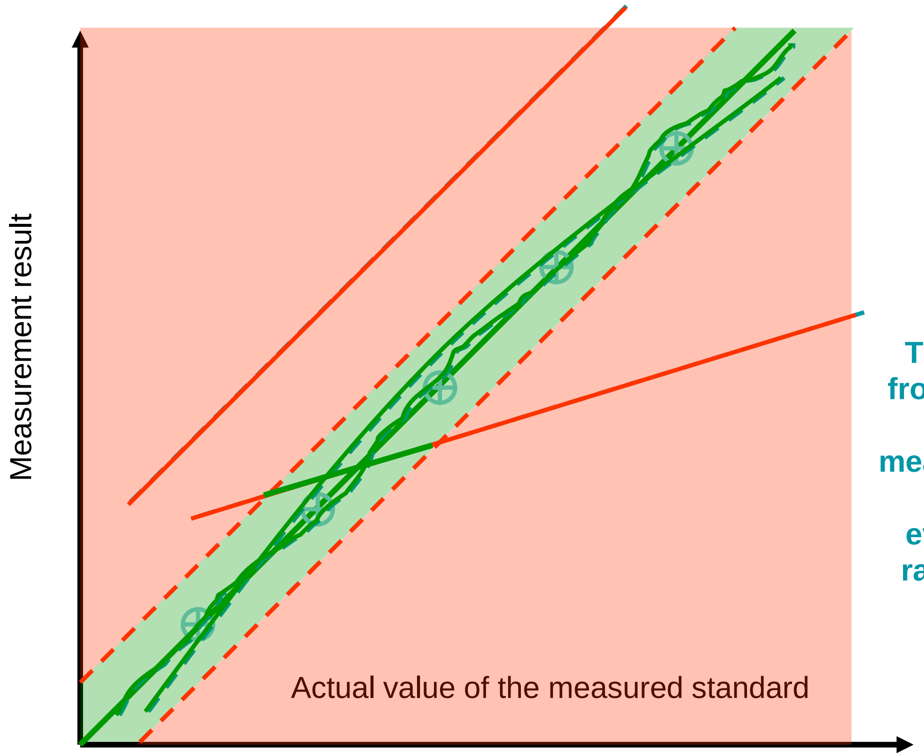
HEXAGON

Procedure 4 – Linearity



Notes:

Procedure 4 – Linearity



This is “linear”!

This is not “linear”!

The average deviation from the reference value and the variation of measured values must be sufficiently small everywhere within the range of measurement

HEXAGON

Notes:

Procedure 4 – Linearity

- Objective
  To demonstrate that there is a sufficiently linear relationship between the values of a physical quantity to be measured and the corresponding values determined by the measuring system (systematic measurement errors are within acceptable limits across the relevant range of measurement)

- Requirements
  Often checked by the manufacturer and then as part of regular calibration of the measuring system.
  Must be demonstrated in individual cases, e.g.
  - Adjustable gain
  - Logarithmic scale
  - Error limit related to full scale

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Notes:

Procedure 4 – Linearity

- Conducting the study
  Unlike the other study types, a wide variety of suggested methods can be found in the literature. These are mainly:

  - Methods using explicit analysis of a mathematical linearity function (regression analysis)
    - Very complex and thus prone to errors
    - Not very intuitive and therefore difficult to evaluate in practice

  - Methods based on a “band of variation” within which the results should lie
    - No linearity study in the strict sense
    - Easy standardized implementation

Notes:

Procedure 4 – Linearity

- Conducting the study according to Bosch Booklet 10
- Use
  - several standards (min. 5),
  - which are distributed in a suitable manner across the relevant measuring range (e.g. equidistantly in case of a linearly scaled range),
  - perform procedure 1 for each of these standards and
  - calculate the corresponding indices Cg and Cgk.
- If only 2 standards are available, it is best for these to correspond to the limits of the tolerance range

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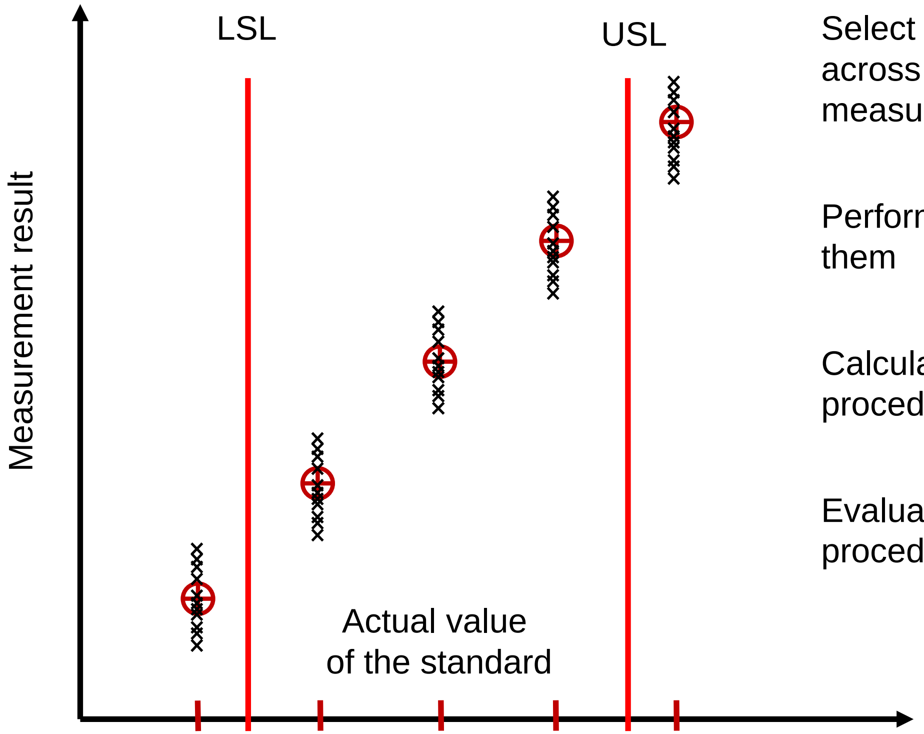
Notes:

Notes:

Procedure 4 – Linearity according to Bosch Booklet 10



Select at least 5 standards across the relevant measurement range

Perform procedure 1 for each of them

Calculate Cg and Cgk as in procedure 1

Evaluate Cg and Cgk as in procedure 1 ($C_g/C_{gk} \geq 1{,}33$)

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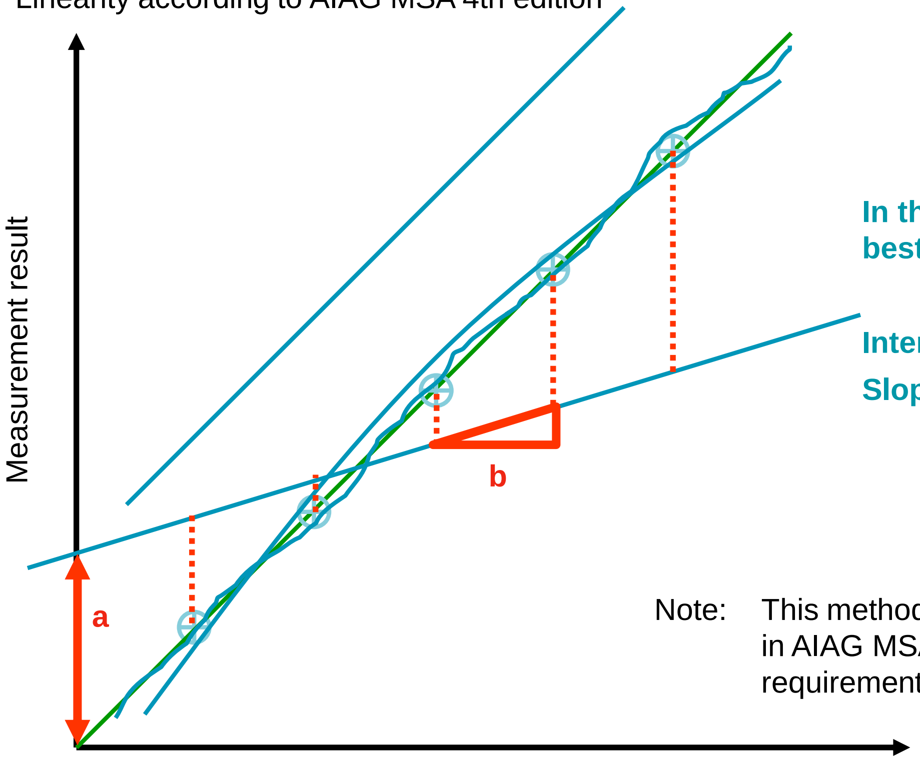
Procedure 4 – Linearity using regression line

- Linearity according to AIAG MSA 4th edition



In the ideal case, the line of best fit has:

Intercept	**a = 0**
Slope	**b = 1**

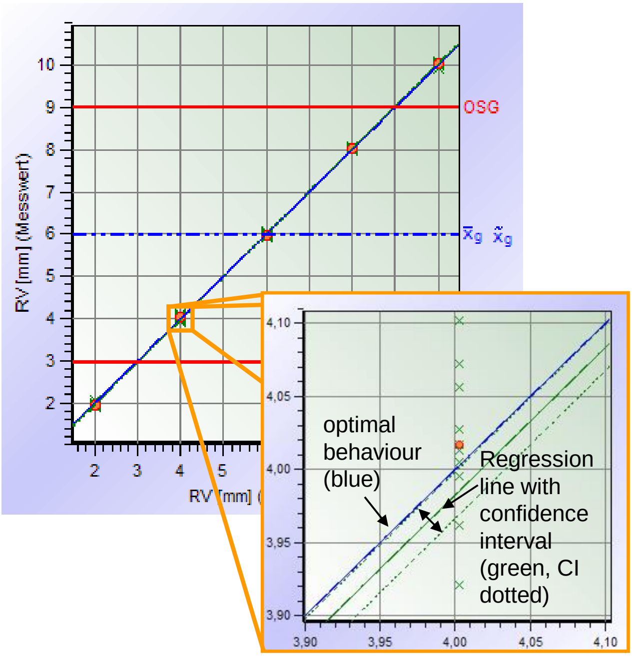
Note: This method corresponds to the method in AIAG MSA and may be a customer requirement

Notes:

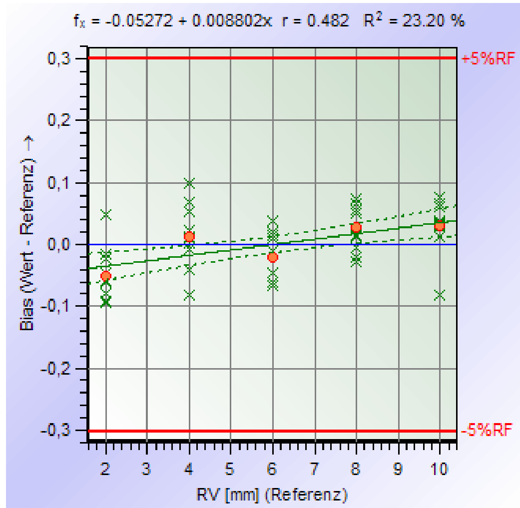
Notes:

Procedure 4 – Linearity using regression line

- Measured values



- Deviations



In the ideal case:
Intercept a = 0
Slope b = 0

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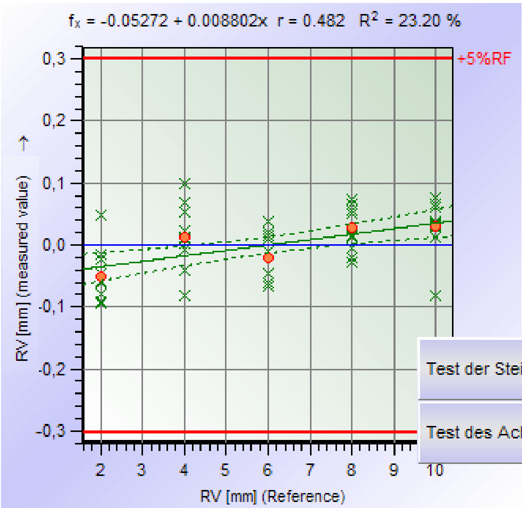
Notes:

Procedure 4 – Assessment per AIAG MSA

- Deviations



Test der Steigung bei lin. Regression	3,43826**
Test des Achsenabschnitts bei lin. Regression	3,80822***

The t-tests show:

The deviations from the ideal case are
- significant (**) for the slope b
- highly significant (***) for the intercept a

In the ideal case:

Intercept a = 0

Slope b = 0

So the measurement system is unsuitable!

Does not correspond to practice!

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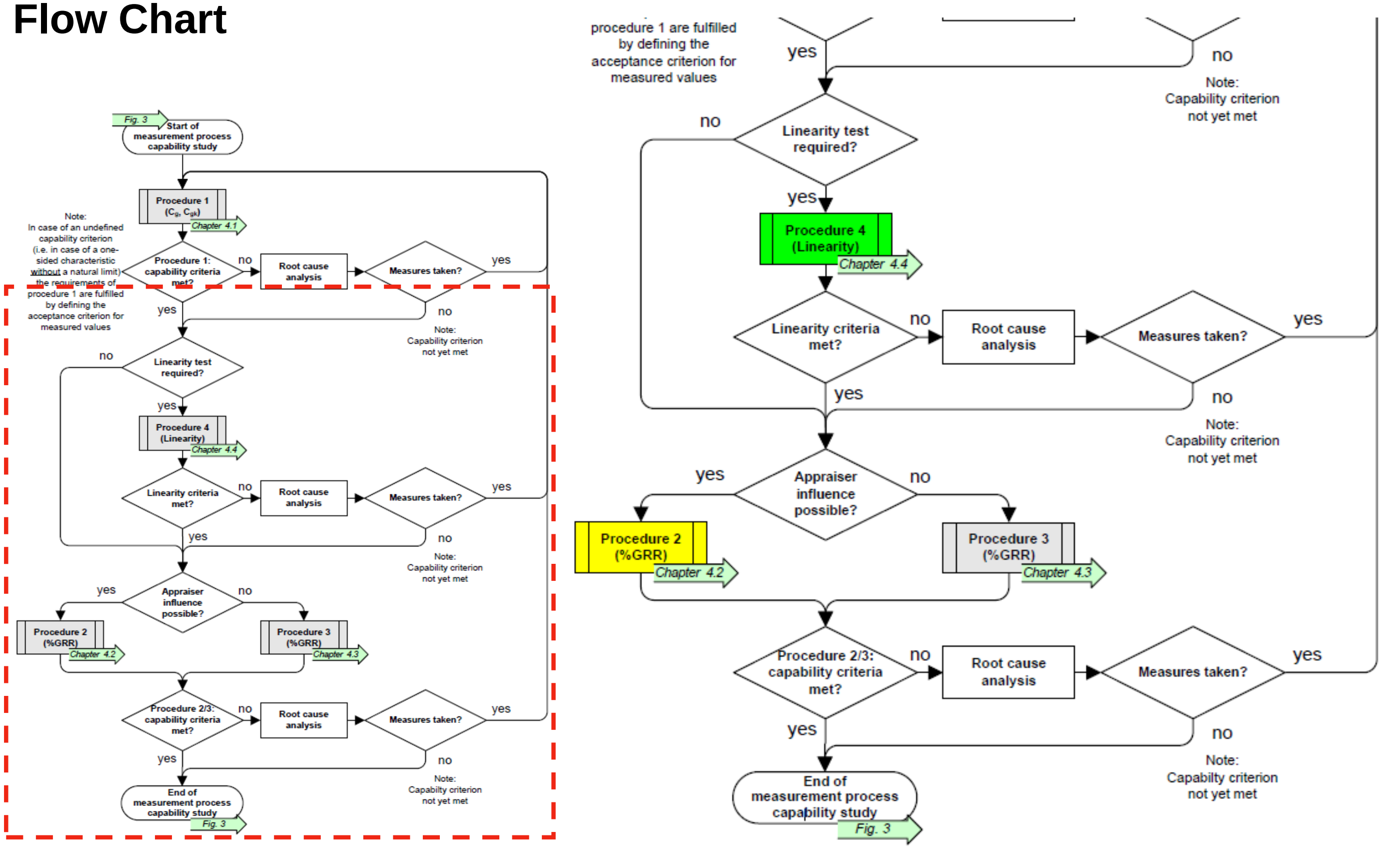
Flow Chart



Notes:

Procedure 2 – Repeatability and reproducibility with appraiser influence

- Objective
  - To demonstrate the capability of a measurement process (as a test process for a defined characteristic) in terms of its variability, using measurements of standard production parts.
- Requirements
  - Appraiser influence cannot be excluded
  - Production parts are available
  - Parts should be within tolerance
  - Measurements are repeatable

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Notes:

Procedure 2 – Repeatability and reproducibility with appraiser influence

- Conducting the study

- Performed under operating conditions which correspond to the later operational conditions of the measuring equipment.

- Measure –
  - At least 10 series production parts that are randomly selected and repeatably measurable
  - In random sequence
  - Using at least 3 appraisers
  - Using at least 2 measurement runs
  - Under repeatability conditions and at defined measurement points.

- A new measurement series may only be begun once the previous run has been completed.

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Notes:

Procedure 2 – Repeatability and reproducibility with appraiser influence

- Analysis
  There are two analysis methods (models)
  - ANOVA (ANalysis Of VAriance)
    - Recommended method
    - Identifies 3 components of variation (see following slides)
    - Requires computer assistance in practice
  - ARM (Average Range Method)
    - Was the previous standard in the old Booklet 10
    - “Out of date and no longer recommended”
    - Identifies only 2 components of variation
    - Can be performed manually, but uses various approximations, estimates and correction factors (historical reasons)

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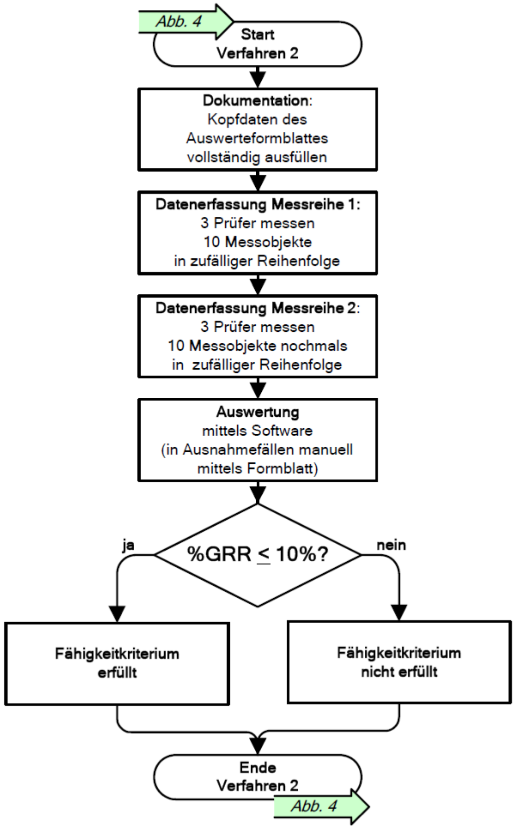
Notes:

Procedure 2 – Sequence

- Documentation
- Measurement series 1
  3 appraisers measure 10 parts
  in random order
- Measurement series 2
  3 appraisers measure the 10 parts
  again in random order
- Analysis
- Capability assessment



Notes:

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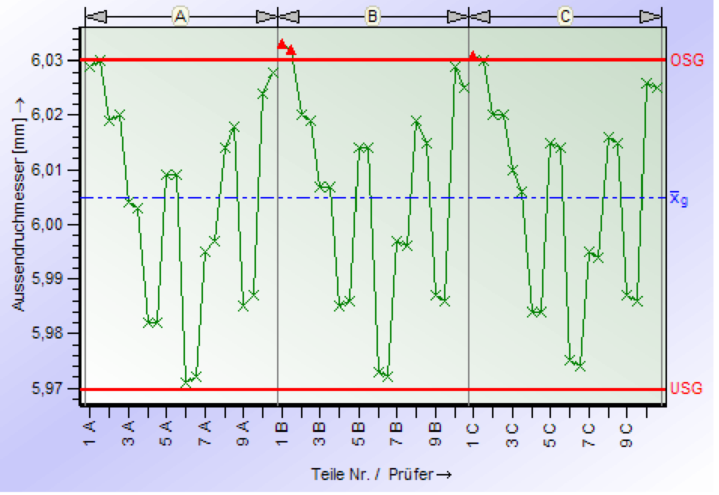
Notes:

Procedure 2

- The measurement results will generally …
  - … vary about a mean for each part (repeatability)
  - … have different means for each appraiser (reproducibility)
  - … have different means per part and per appraiser (interaction) [shown for two parts in the graph]



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Notes:

Procedure 2 – ANOVA calculation of statistics

Part	Appraiser A 1	Appraiser A 2	Appraiser B 1	Appraiser B 2	Appraiser C 1	Appraiser C 2
1	6,029	6,030	6,033	6,032	6,031	6,030
2	6,019	6,020	6,020	6,019	6,020	6,020
3	6,004	6,003	6,007	6,007	6,010	6,006
4	5,982	5,982	5,985	5,986	5,984	5,984
5	6,009	6,009	6,014	6,014	6,015	6,014
6	5,971	5,972	5,973	5,972	5,975	5,974
7	5,995	5,997	5,997	5,996	5,995	5,994
8	6,014	6,018	6,019	6,015	6,016	6,015
9	5,985	5,987	5,987	5,986	5,987	5,986
10	6,024	6,028	6,029	6,025	6,026	6,025

- Total variation is composed of
  - Part-to-part variation
  - Variation between appraisers
  - Interaction between appraiser and part
  - Measuring equipment variation (“the rest”)

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Notes:

Procedure 2 – ANOVA calculation of statistics

Part	Appraiser A 1	Appraiser A 2	Appraiser B 1	Appraiser B 2	Appraiser C 1	Appraiser C 2	$\bar{x}$ of part, all appraisers
1	6,029	6,030	6,033	6,032	6,031	6,030	6,0308
2	6,019	6,020	6,020	6,019	6,020	6,020	6,0197
3	6,004	6,003	6,007	6,007	6,010	6,006	6,0062
4	5,982	5,982	5,985	5,986	5,984	5,984	5,9838
5	6,009	6,009	6,014	6,014	6,015	6,014	6,0125
6	5,971	5,972	5,973	5,972	5,975	5,974	5,9728
7	5,995	5,997	5,997	5,996	5,995	5,994	5,9957
8	6,014	6,018	6,019	6,015	6,016	6,015	6,0162
9	5,985	5,987	5,987	5,986	5,987	5,986	5,9863
10	6,024	6,028	6,029	6,025	6,026	6,025	6,0262

Variance of means $\bar{x}$ of all parts

s^2_{PV}= 0,000381231

- Die Gesamtstreuung setzt sich zusammen aus
  - Part-to-part variation
  - Variation between appraisers
  - Interaction between appraiser and part
  - Measuring equipment variation (“the rest”)

⇨PV Part Variation

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Notes:

Procedure 2 – ANOVA calculation of statistics

Part	Appraiser A 1	Appraiser A 2	Appraiser B 1	Appraiser B 2	Appraiser C 1	Appraiser C 2	$\bar{x}$ des Teils alle Prüfer
1	6,029	6,030	6,033	6,032	6,031	6,030	6,0308
2	6,019	6,020	6,020	6,019	6,020	6,020	6,0197
3	6,004	6,003	6,007	6,007	6,010	6,006	6,0062
4	5,982	5,982	5,985	5,986	5,984	5,984	5,9838
5	6,009	6,009	6,014	6,014	6,015	6,014	6,0125
6	5,971	5,972	5,973	5,972	5,975	5,974	5,9728
7	5,995	5,997	5,997	5,996	5,995	5,994	5,9957
8	6,014	6,018	6,019	6,015	6,016	6,015	6,0162
9	5,985	5,987	5,987	5,986	5,987	5,986	5,9863
10	6,024	6,028	6,029	6,025	6,026	6,025	6,0262
	6,0039		6,0058		6,0054		

$\bar{x}$ of each appraiser

Variance of appraisers s^2_{AV}= 9,86E-07

- Total variation is composed of
  - Part-to-part variation
  - Variation between appraisers
  - Interaction between appraiser and part
  - Measuring equipment variation (“the rest”)

⇨PV Part Variation

⇨AV Appraiser Variation

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Notes:

Procedure 2 – ANOVA calculation of statistics

Part	Appraiser A 1	Appraiser A 2	$\bar{x}$ of part at appraiser A	Appraiser B 1	Appraiser B 2	$\bar{x}$ of part at appraiser B	Appraiser C 1	Appraiser C 2	$\bar{x}$ of part at appraiser C	$\bar{x}$ of part all appraisers	Variance of means $\bar{x}$ of each part	
1	6,029	6,030	6,0295	6,033	6,032	6,0325	6,031	6,030	6,0305	6,0309	s^2_{IA1}=	2,33333E-06
2	6,019	6,020	6,0195	6,020	6,019	6,0195	6,020	6,020	6,0200	6,0196	s^2_{IA2}=	8,33333E-08
3	6,004	6,003	6,0035	6,007	6,007	6,0070	6,010	6,006	6,0080	6,0059	s^2_{IA3}=	5,58333E-06
4	5,982	5,982	5,9820	5,985	5,986	5,9855	5,984	5,984	5,9840	5,9838	s^2_{IA4}=	3,08333E-06
5	6,009	6,009	6,0090	6,014	6,014	6,0140	6,015	6,014	6,0145	6,0123	s^2_{IA5}=	9,25E-06
6	5,971	5,972	5,9715	5,973	5,972	5,9725	5,975	5,974	5,9745	5,9726	s^2_{IA6}=	2,33333E-06
7	5,995	5,997	5,9960	5,997	5,996	5,9965	5,995	5,994	5,9945	5,9958	s^2_{IA7}=	1,08333E-06
8	6,014	6,018	6,0160	6,019	6,015	6,0170	6,016	6,015	6,0155	6,0163	s^2_{IA8}=	5,83333E-07
9	5,985	5,987	5,9860	5,987	5,986	5,9865	5,987	5,986	5,9865	5,9863	s^2_{IA9}=	8,33333E-08
10	6,024	6,028	6,0260	6,029	6,025	6,0270	6,026	6,025	6,0255	6,0263	s^2_{IA10}=	5,83333E-07
	6,0039			6,0058			6,0054				Minus PV and AV	
				$\bar{x}$ of each appraiser							⇒ s^2_{IA}	

- Total variation is composed of
  - Part-to-part variation ⇨ PV Part Variation
  - Variation between appraisers ⇨ AV Appraiser Variation
  - Interaction between appraiser and part ⇨ IA Interaction
  - Measuring equipment variation (“the rest”)

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Notes:

Procedure 2 – ANOVA calculation of statistics

Part	Appraiser A 1	Appraiser A 2	$\bar{x}$ of part at appraiser A	Appraiser B 1	Appraiser B 2	$\bar{x}$ of part at appraiser B	Appraiser C 1	Appraiser C 2	$\bar{x}$ of part at appraiser C	$\bar{x}$ of part all appraisers
1	6,029	6,030	6,0295	6,033	6,032	6,0325	6,031	6,030	6,0305	6,0309
2	6,019	6,020	6,0195	6,020	6,019	6,0195	6,020	6,020	6,0200	6,0196
3	6,004	6,003	6,0035	6,007	6,007	6,0070	6,010	6,006	6,0080	6,0059
4	5,982	5,982	5,9820	5,985	5,986	5,9855	5,984	5,984	5,9840	5,9838
5	6,009	6,009	6,0090	6,014	6,014	6,0140	6,015	6,014	6,0145	6,0123
6	5,971	5,972	5,9715	5,973	5,972	5,9725	5,975	5,974	5,9745	5,9726
7	5,995	5,997	5,9960	5,997	5,996	5,9965	5,995	5,994	5,9945	5,9958
8	6,014	6,018	6,0160	6,019	6,015	6,0170	6,016	6,015	6,0155	6,0163
9	5,985	5,987	5,9860	5,987	5,986	5,9865	5,987	5,986	5,9865	5,9863
10	6,024	6,028	6,0260	6,029	6,025	6,0270	6,026	6,025	6,0255	6,0263
$\bar{x}$ of each appraiser	6,0039			6,0058			6,0054			

Variance of all measurements s^2_{EV} = 0,000352 Minus variation from PV, AV and IA

- Total variation is composed of
  - Part-to-part variation
  - Variation between appraisers
  - Interaction between appraiser and part
  - Measuring equipment variation (“the rest”)

⇨PV Part Variation
⇨AV Appraiser Variation
⇨IA Interaction
⇨EV Equipment Variation

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Notes:

Procedure 2 – ANOVA calculation of statistics

Part	Appraiser A 1	Appraiser A 2	$\bar{x}$ of part at appraiser A	Appraiser B 1	Appraiser B 2	$\bar{x}$ of part at appraiser B	Appraiser C 1	Appraiser C 2	$\bar{x}$ of part at appraiser C	$\bar{x}$ of part all appraisers
1	6,029	6,030	6,0295	6,033	6,032	6,0325	6,031	6,030	6,0305	6,0309
2	6,019	6,020	6,0195	6,020	6,019	6,0195	6,020	6,020	6,0200	6,0196
3	6,004	6,003	6,0035	6,007	6,007	6,0070	6,010	6,006	6,0080	6,0059
4	5,982	5,982	5,9820	5,985	5,986	5,9855	5,984	5,984	5,9840	5,9838
5	6,009	6,009	6,0090	6,014	6,014	6,0140	6,015	6,014	6,0145	6,0123
6	5,971	5,972	5,9715	5,973	5,972	5,9725	5,975	5,974	5,9745	5,9726
7	5,995	5,997	5,9960	5,997	5,996	5,9965	5,995	5,994	5,9945	5,9958
8	6,014	6,018	6,0160	6,019	6,015	6,0170	6,016	6,015	6,0155	6,0163
9	5,985	5,987	5,9860	5,987	5,986	5,9865	5,987	5,986	5,9865	5,9863
10	6,024	6,028	6,0260	6,029	6,025	6,0270	6,026	6,025	6,0255	6,0263
$\bar{x}$ of each appraiser	6,0039			6,0058			6,0054			

- Total variation is composed of
  - AV = $\hat{\sigma}_{AV}$ Appraiser Variation
  - IA = $\hat{\sigma}_{IA}$ Interaction
  - EV = $\hat{\sigma}_{EV}$ Equipment Variation
  - ⇨ GRR = $\hat{\sigma}_{GRR}$ Gage Repeatability & Reproducibility

$$GRR = \sqrt{EV^2 + AV^2 + IA^2}$$

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Notes:

Procedure 2 – ANOVA calculation of statistics

	Variance	Standard dev.	Confidence interval 1-α = 95.000%	
Repeatability	0.0000023556	0.0015348	EV =0.0012799 ≤ **0.0015348** ≤ 0.0019174	%EV = 15.35%
Reproducibility	0.00000086806	0.00093169	AV =0.00035980 ≤ **0.00093169** ≤ 0.006229	%AV = 9.32%
Interaction	[pooling]	[pooling]	IA =	%IA = ---
Repeatability & Reproducib	0.0000032236	0.0017954	GRR =0.0015827 ≤ **0.0017954** ≤ 0.0064169	%GRR = 17.95%
Part Variation	0.00038084	0.019515	PV = 0.012607 ≤ **0.019515** ≤ 0.036405	%PV = 195.15%
Total Variation	0.00038406	0.019598	TV = 0.020	

Design			Reference Figure		
No. of Trials	=	2	Process Variation	=	0
Number of Operators	=	3	Tolerance	=	0.060
Number of Parts	=	10	required Cp value	=	

Resolution	%RE	=	1.67%	0 5
number of distinct categories	ndc	=	15	0 5
Repeatability & Reproducibility	%GRR	=	17.95%	0 10 30
Minimum reference figure for capable measuring system =	$T_{min (\%GRR)}$	=	0.108	
Minimum reference figure for measuring system of limited c=	$T_{min (\%GRR)}$	=	0.0359	

Measurement system marginally capable (%RE,min,%GRR)

BOSCH 2018: Type 2

- Total variation is composed of
  - AV = $\hat{\sigma}_{AV}$ Appraiser Variation
  - IA = $\hat{\sigma}_{IA}$ Interaction
  - EV = $\hat{\sigma}_{EV}$ Equipment Variation
  - ⇨ GRR = $\hat{\sigma}_{GRR}$ Gage Repeatability & Reproducibility

$$GRR = \sqrt{EV^2 + AV^2 + IA^2}$$

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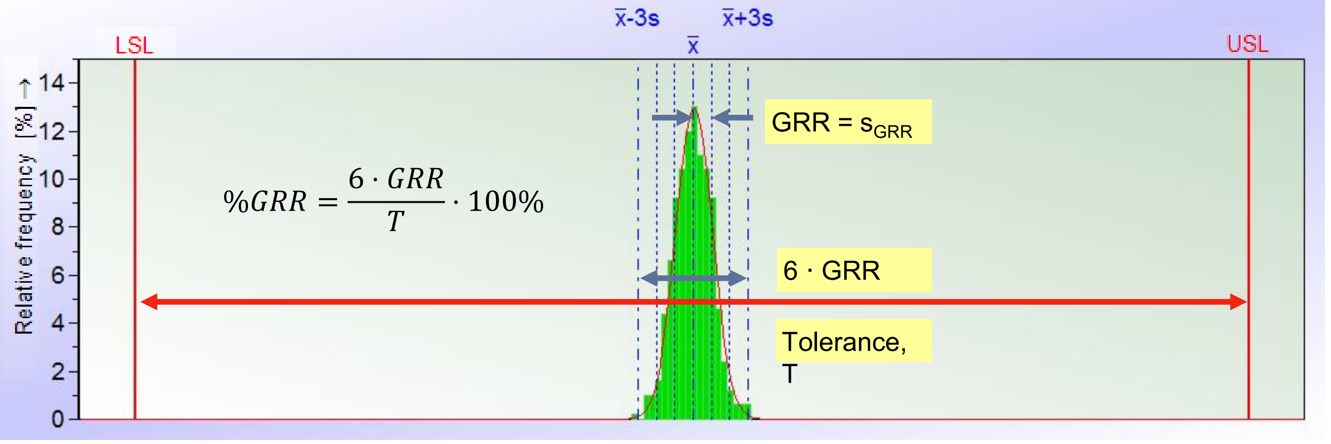
Procedure 2 - Relating GRR

- GRR corresponds to one standard deviation s
- Spread is typically expressed as six standard deviations (cf. procedure 1):
  Spread $= 6 \cdot s = 6 \cdot GRR$
- The tolerance T is used as a reference value



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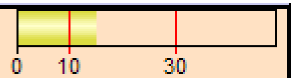
Notes:

Procedure 2 – Requirements for %GRR

- Requirements:
  - %GRR ≤ 10% capable
  - 10% < %GRR ≤ 30% conditionally capable
  - %GRR > 30% not capable

Repeatability & Reproducibility = $\%GRR = 6 \times \frac{GRR \times 100\%}{T}$ = 15.43%



Notes:

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Verfahren 2 – Bericht

- Report solara.MP
- Header data
  - Product, characteristic, tolerance
  - Measuring system, test station, operation
  - Area, group/dept., workshop
- Value Chart Deviations
- Measurement results of the operators
- Key figures and assessment
  - EV, AV, IA, GRR, PV, TV
  - In relation to tolerance (usualy)
  - Assessment %RE, %GRR, (ndc)
  - Minimum reference values
  - Capability Decision

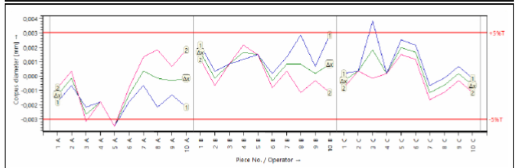
Booklet 10 — Capability of Measurement and Test Processes

BOSCH — Measurement System Analysis Procedure 2 — Sheet 1 / 1

Area	:	MSE3	Operation	:	Mating corpus/needle	Characteristic	:	Corpus diameter
Group/Dptm.	:	MOE7	Machine	:	PAKO 8	Char. No.	:	1
Workshop/sect.	:	W450	Machine No.	:	1004537	Nominal value	:	6.000
Product	:	Injector	Test station	:	JML0583W004	Lower allowance	:	-0.030
Part	:	Hole type nozzle	Gage	:	JML0563W001	Upper allowance	:	0.030
Article number	:	0 433 171 914	Gage No.	:	6702779430001	Tolerance	:	0.060
Change status	:	20.01.2019	Gage Manuf.	:	BaP	Unit	:	mm
			Resolution	:	0.001			

Comment : Manual operation; room temperature 20.2 °C

Standard: Standard No.: Standard/Ref. value:



i	$x_{A;1}$	$x_{A;2}$	$x_{g;j}$	$s_{g;j}$	$x_{B;1}$	$x_{B;2}$	$x_{g;j}$	$s_{g;j}$	$x_{C;1}$	$x_{C;2}$	$x_{g;j}$	$s_{g;j}$
1	6.029	6.030	6.0295	0.0007	6.033	6.032	6.0325	0.0007	6.031	6.030	6.0305	0.0007
2	6.019	6.020	6.0195	0.0007	6.020	6.019	6.0195	0.0007	6.020	6.020	6.0200	0.0000
3	6.004	6.030	6.0035	0.0007	6.007	6.007	6.007	0.0000	6.010	6.006	6.0080	0.0028
4	5.982	5.982	5.9820	0.0000	5.985	5.986	5.9855	0.0007	5.984	5.984	5.9840	0.0000
5	6.009	6.009	6.0090	0.0000	6.014	6.014	6.014	0.0000	6.015	6.014	6.0145	0.0007
6	5.971	5.972	5.9715	0.0007	5.973	5.972	5.9725	0.0007	5.975	5.974	5.9745	0.0007
7	5.995	5.997	5.9960	0,0014	5.997	5.996	5.9965	0.0007	5.995	5.994	5.9945	0.0007
8	6.014	6.018	6.0160	0.0028	6.019	6.015	6.017	0.0028	6.016	6.015	6.0155	0.0007
9	5.985	5.987	5.9860	0,0014	5.987	5.986	5.9865	0.0007	5.987	5.986	5.9865	0.0007
10	6.024	6.028	6.0260	0.0028	6.029	6.025	6.027	0.0028	6.026	6.025	6.0255	0.0007

	Variance	Standard dev.	Confidence level 1 - α = 95%	
Repeatability	0.0000023556	0.0015348	EV: 0.0012799 ≤ 0.0015348 ≤ 0.0019174	%EV = 15.35%
Reproducibility	0,00000086806	0.00093169	AV: 0.00035980 ≤ 0.00093169 ≤ 0.006229	%AV = 9.32%
Interaction	pooling	pooling	IA: ≤ ≤	%IA = ---
R&R	0.0000032236	0.0017954	GRR: 0.0015827 ≤ 0.0017954 ≤ 0.0064169	%GRR = 17.95%
Part variation	0.00038084	0.019515	PV: 0.0126070 ≤ 0.019515 ≤ 0.036405	%PV = 195.15%
Total variation	0.00038406	0.019598	TV: 0.020	

Test design			Reference quantity		
Number of trials	=	2	Process variation	=	0
Number of appraisers	=	3	Tolerance	=	0.060
Number of parts	=	10	Required Cp value	=	

Resolution	%RE	=	1.67%	0 5
Number of distinct categories (ndc)	ndc	=	15	0 5
Repeatability & Reproducibility	%GRR	=	17.95%	0 10 30
Minimum reference figure f. capable measurem. system	$T_{min\ (\%GRR)}$	=	0.108	
Min. ref. fig. f. conditionally capable measurem. system	$T'_{min\ (\%GRR)}$	=	0.0359	

Measurement system is conditionally capable (RE, %GRR)

Bosch 2018 — Procedure 2

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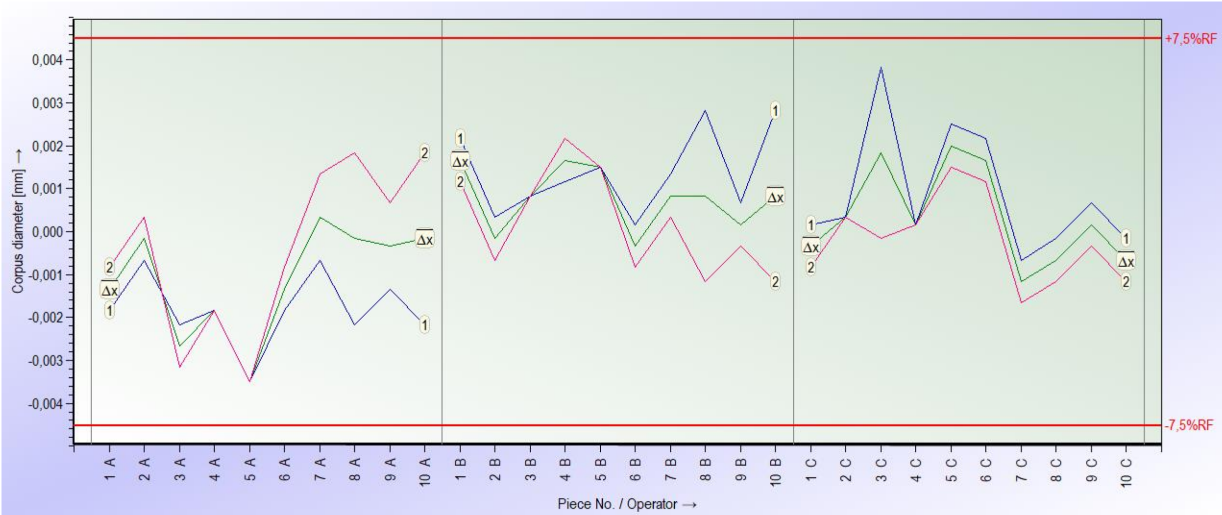
Notes:

Procedure 2 – Report

- Value Chart Deviations



- Line 1 and 2: Deviations of the individual measurements …
- Line $\Delta\bar{x}$: Mean deviation of the appraiser …
- … to the mean value of all measurements of the respective part
- Graphical representation of the variation values EV, AV and IA

Notes:

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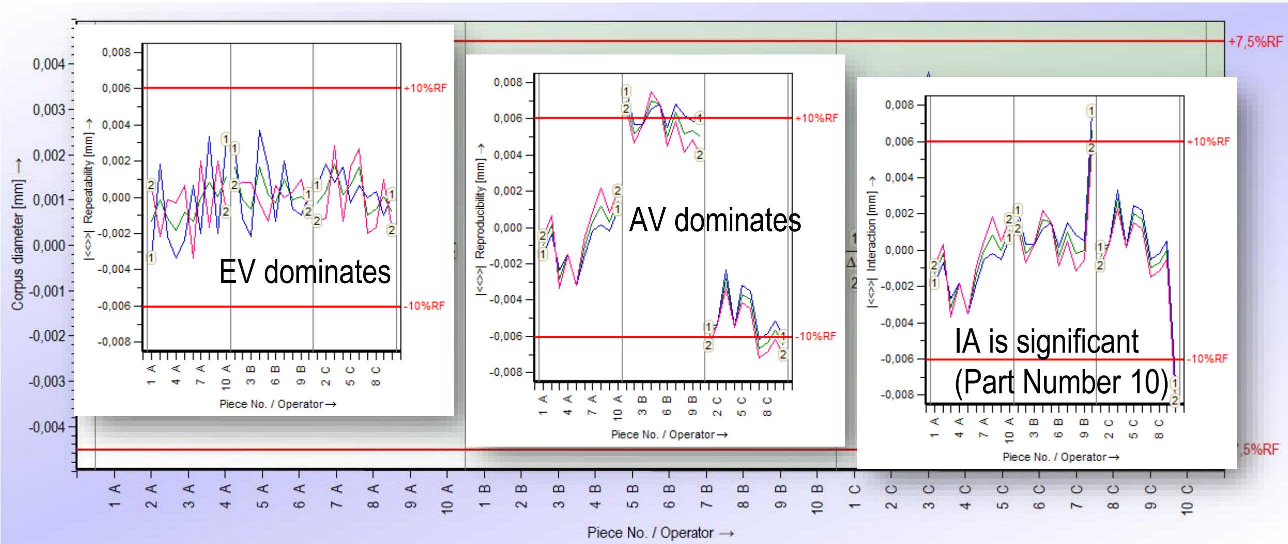
Notes:

Procedure 2 – Detect dominant dispersion influences

- Value Chart Deviations



- Deviations of the individual measurements from the mean value of all measurements of the respective part
- Graphical representation of the variation values EV, AV and IA

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Notes:

Procedure 2 – Report

- Characteristic values

	Variance	Standard dev.	Confidence level 1 - α = 95%								
Repeatability	0.0000023556	0.0015348	EV:	0.0012799	≤	0.0015348	≤	0.0019174	%EV	=	15.35%
Reproducibility	0,00000086806	0.00093169	AV:	0.00035980	≤	0.00093169	≤	0.006229	%AV	=	9.32%
Interaction	pooling	pooling	IA:		≤		≤		%IA	=	---
R&R	0.0000032236	0.0017954	GRR:	0.0015827	≤	0.0017954	≤	0.0064169	%GRR	=	17.95%
Part variation	0.00038084	0.019515	PV:	0.0126070	≤	0.019515	≤	0.036405	%PV	=	195.15%
Total variation	0.00038406	0.019598	TV:			0.020					

Test design			Reference quantity		
Number of trials	=	2	Process variation	=	0
Number of appraisers	=	3	Tolerance	=	0.060
Number of parts	=	10	Required Cp value	=	

Resolution	%RE	=	1.67%	0 5
Number of distinct categories (ndc)	ndc	=	15	0 5
Repeatability & Reproducibility	%GRR	=	17.95%	0 10 30
Minimum reference figure f. capable measurem. system	$T_{min\ (\%GRR)}$	=	0.108	
Min. ref. fig. f. conditionally capable measurem. system	$T_{min\ (\%GRR)}$	=	0.0359	
Measurement system is conditionally capable (RE, %GRR)				
Bosch 2018 — Procedure 2				

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Notes:

Procedure 2 – Report

- Characteristic values
-

	Variance	Standard dev.	Confidence level 1 - α = 95%								
Repeatability	0.0000023556	0.0015348	EV:	0.0012799	≤	0.0015348	≤	0.0019174	%EV	=	15.35%
Reproducibility	0,00000086806	0.00093169	AV:	0.00035980	≤	0.00093169	≤	0.006229	%AV	=	9.32%
Interaction	pooling	pooling	IA:		≤		≤		%IA	=	---
R&R	0.0000032236	0.0017954	GRR:	0.0015827	≤	0.0017954	≤	0.0064169	%GRR	=	17.95%
Part variation	0.00038084	0.019515	PV:	0.0126070	≤	0.019515	≤	0.036405	%PV	=	195.15%
Total variation	0.00038406	0.019598	TV:			0.020					

Test design			Reference quantity		
Number of trials	=	2	Process variation	=	0
Number of appraisers	=	3	Tolerance	=	0.060
Number of parts	=	10	Required Cp value	=	

Resolution	%RE	=	1.67%	0 … 5
Number of distinct categories (ndc)	ndc	=	15	0 … 5
Repeatability & Reproducibility	%GRR	=	17.95%	0 … 10 … 30
Minimum reference figure f. capable measurem. system	$T_{min\ (\%GRR)}$	=	0.108	
Min. ref. fig. f. conditionally capable measurem. system	$T_{min\ (\%GRR)}$	=	0.0359	
Measurement system is conditionally capable (RE, %GRR)				
Bosch 2018 — Procedure 2				

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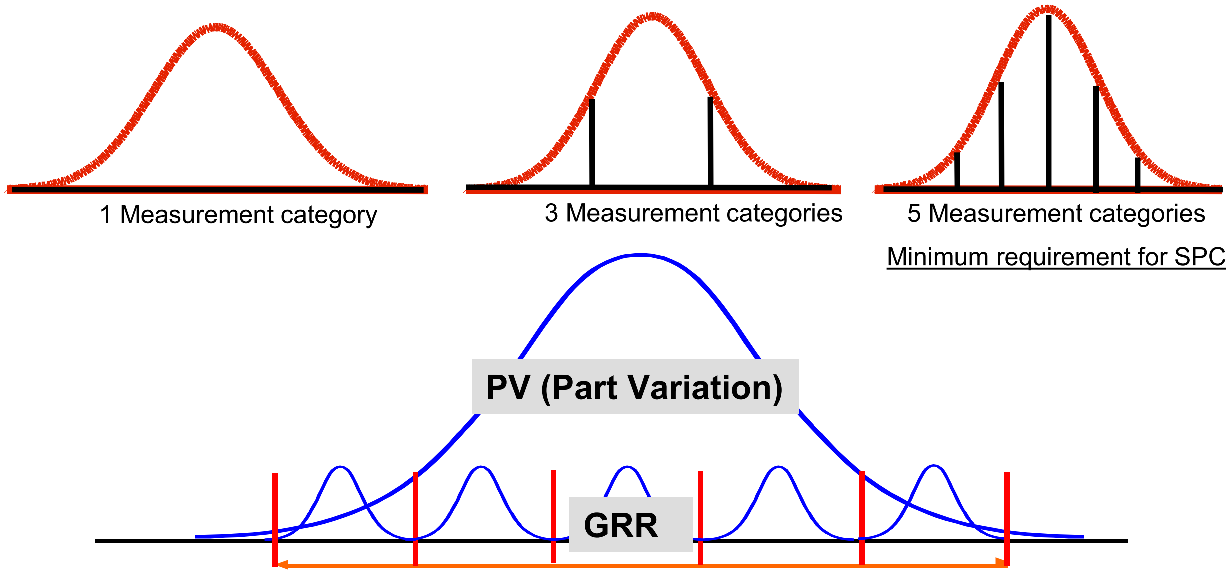
Procedure 2 - Number of Distinct Categories ndc

- Number of Distinct Categories
- $ndc = 1{,}41 \cdot \frac{PV}{GRR} \geq 5$



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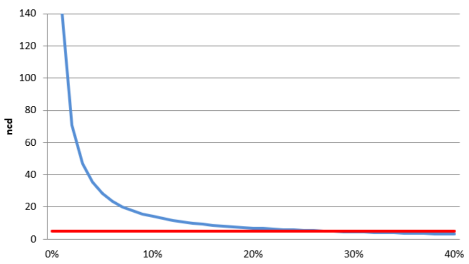
Notes:

Procedure 2 - Criticism of the characteristic value ndc

- Calculation usually referred to PV from the 10 parts of the test, but according to AIAG MSA PV is calculated from the reference TV for $\%GRR$: $PV = \sqrt{TV^2 - GRR^2}$. With reference to tolerance (Bosch Booklet 10) $TV = T$ and

$$PV = \sqrt{T^2 - GRR^2}$$

- But then applies:
- ndc can be derived from $\%GRR$: $ndc = \sqrt{2 \cdot \left(\frac{1}{\%GRR^2} - 1\right)}$ and is therefore not independent



- Limit values do not match the limit values of $\%GRR$:
  - $ndc \approx 14$ at $\%GRR = 10\%$, $ndc \approx 4$ at $\%GRR = 30\%$

- Statement on ndc by Donald J. Wheeler, originally named as author

The number of distinct categories value from ratio 13 does not represent anything that can be expressed in practical terms. So even though I may be the author of this ratio, it is useless in practice. I personally quit using it back in the 1980s. I suggest that you do the same, starting immediately.

  - http://www.qualitydigest.com/inside/quality-insider-column/problems-gauge-rr-studies.html
  - Quality Digest, Januar 2011

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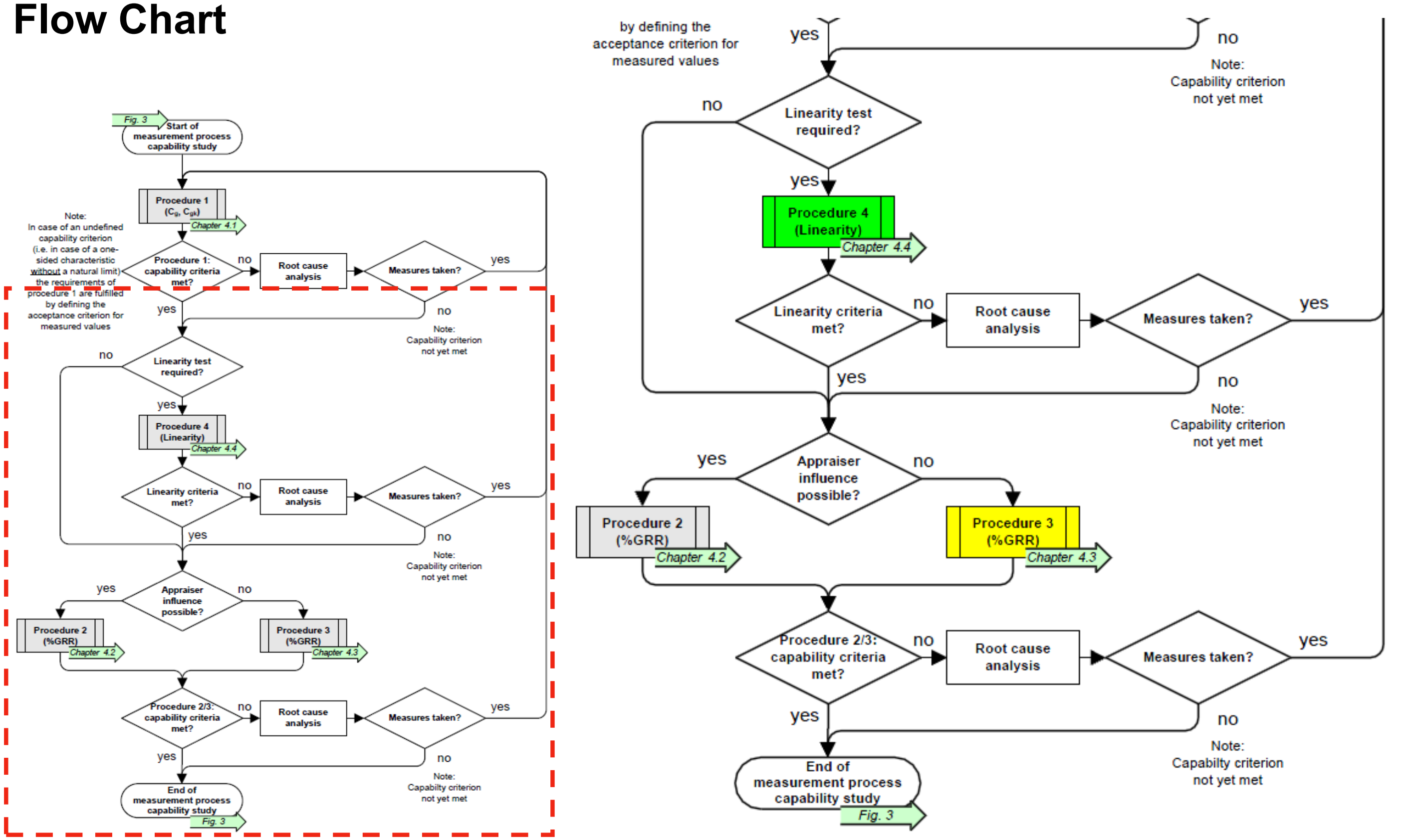
Notes:

Flow Chart



Notes:

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Procedure 3 – Repeatability and reproducibility without appraiser

- Objective
  To demonstrate the capability of a measurement process (as a test process for a defined characteristic) in terms of its variability, using measurements of production parts, without appraiser influence.

- Requirements
  Before conducting procedure 3, a careful check has to be performed to verify that appraiser influence on measured values can be excluded.
  This being a special case of procedure 2, the same requirements apply.

Notes:

Procedure 3 – Repeatability and reproducibility without appraiser

- Conducting the study
  - Performed under operating conditions which correspond to the later operational conditions of the measuring equipment.
  - Measure ...
    - … at least 25 series production parts that are randomly selected and repeatably measurable
    - … in random sequence
    - … using at least 2 measurement series
    - … under repeatability conditions and at defined measurement points.
- Analysis
  - Per procedure 2 using ANOVA
  - ARM analysis “out of date and no longer recommended”

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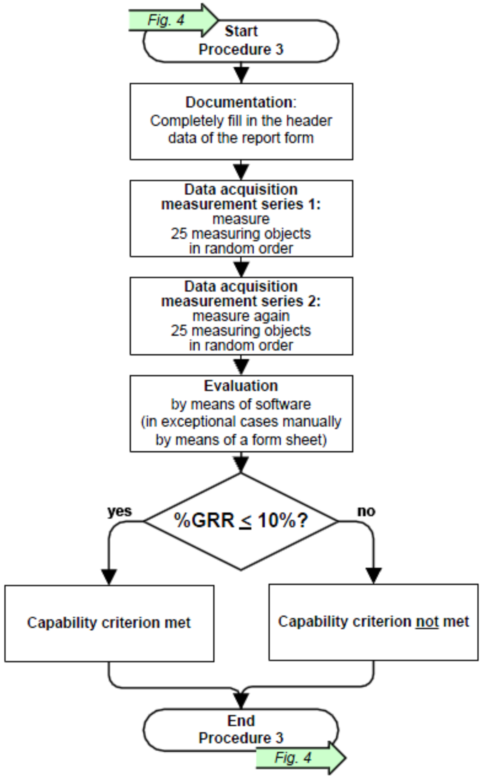
Notes:

Procedure 3 – Sequence

- Documentation
- Measurement series 1
  Measure 25 parts in random order
- Measurement series 2
  Measure the 25 parts again in random order
- Analysis
- Capability assessment



Notes:

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Procedure 3 – ANOVA calculation of statistics

	Appraiser A			Appraiser B			Appraiser C			
n	$x_{A;1}$	$x_{A;2}$	$\bar{x}_{g\,j}$	$x_{B;1}$	$x_{B;2}$	$\bar{x}_{g\,j}$	$x_{C;1}$	$x_{C;2}$	$\bar{x}_{g\,j}$	$\bar{x}_{g\,n}$
1	6,029	6,030	6,0295	6,033	6,032	6,0325	6,031	6,030	6,0305	6,03083
2	6,019	6,020	6,0195	6,020	6,019	6,0195	6,020	6,020	6,0200	6,01967
3	6,004	6,003	6,0035	6,007	6,007	6,0070	6,010	6,006	6,0080	6,00617
4	5,982	5,982	5,9820	5,985	5,986	5,9855	5,984	5,984	5,9840	5,98383
5	6,009	6,009	6,0090	6,014	6,014	6,0140	6,015	6,014	6,0145	6,01250
6	5,971	5,972	5,9715	5,973	5,972	5,9725	5,975	5,974	5,9745	5,97283
7	5,995	5,997	5,9960	5,997	5,996	5,9965	5,995	5,994	5,9945	5,99567
8	6,014	6,018	6,0160	6,019	6,015	6,0170	6,016	6,015	6,0155	6,01617
9	5,985	5,987	5,9860	5,987	5,986	5,9865	5,987	5,986	5,9865	5,98633
10	6,024	6,028	6,0260	6,029	6,025	6,0270	6,026	6,025	6,0255	6,02617

↓ **25**

- Total variation is composed of
  - Part-to-part variation ⇨PV Part Variation
  - ~~Variation between appraisers ⇨AV Appraiser Variation~~
  - ~~Interaction between appraiser and part ⇨IA Interaction~~
  - Measuring equipment variation (“the rest”) ⇨EV Equipment Variation

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Notes:

Procedure 3 – Report

- Report solara.MP

- Header data
  - Product, characteristic, tolerance
  - Measuring system, test station, operation
  - Area, group/dept., workshop

- Measurement results
- Value Chart of the repeated measurements
- Value Chart of the range per part

- Key figures and assessment
  - EV, GRR, PV, TV
  - In relation to tolerance (usualy)
  - Assessment %RE, %GRR, (ndc)
  - Minimum reference values
  - Capability Decision

Booklet 10 — Capability of Measurement and Test Processes

BOSCH — Measurement System Analysis Procedure 3 — Sheet 1 / 1

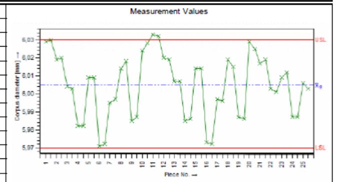
Area	: MSE3	Operation	: Mating corpus/needle	Characteristic	: Corpus diameter
Group/Dptm.	: MOE7	Machine	: PAKO 9	Char. No.	: 1
Workshop/sect.	: W450	Machine No.	: 1003521	Nominal value	: 6.000
Product	: Injector	Test station	: JML0583W001	Lower allowance	: -0.030
Part	: Hole type nozzle	Gage	: JML0563W003	Upper allowance	: 0.030
Article number	: 0 433 171 914	Gage No.	: 6702779430004	Tolerance	: 0.060
Change status	: 20.01.2019	Gage Manuf.	: BaP	Unit	: mm
		Resolution	: 0.001		

Comment :

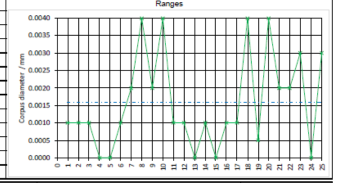
Standard: Standard No.: Standard/Ref. value:

i	$x_{A;1}$	$x_{A;2}$	$x_{g,j}$	$s_{g,j}$
1	6.029	6.030	6.0295	0.0007
2	6.019	6.020	6.0195	0.0007
3	6.004	6.003	6.0035	0.0007
4	5.982	5.982	5.9820	0.0000
5	6.009	6.009	6.0090	0.0000
6	5.971	5.972	5.9715	0.0007
7	5.995	5.997	5.9960	0.0014
8	6.014	6.018	6.0160	0.0028
9	5.985	5.987	5.9860	0.0014
10	6.024	6.028	6.0260	0.0028
11	6.033	6.032	6.0325	0.0007
12	6.020	6.019	6.0195	0.0007
13	6.007	6.007	6.0070	0.0000
14	5.985	5.986	5.9855	0.0007
15	6.014	6.014	6.0140	0.0000
16	5.973	5.972	5.9725	0.0007
17	5.997	5.996	5.9965	0.0007
18	6.019	6.015	6.0170	0.0028
19	5.987	5.9865	5.9865	0.0007
20	6.029	6.025	6.0270	0.0028
21	6.017	6.019	6.0180	0.0014
22	6.003	6.001	6.0020	0.0014
23	6.009	6.012	6.0105	0.0021
24	5.987	5.987	5.9870	0.0000
25	6.006	6.003	6.0045	0.0021

Measurement Values



Ranges



	Variance	Standard dev.	Confidence level 1 - α = 95%	
Repeatability	0.0000021600	0.0014697	EV: 0.0011526 ≤ 0.0014697 ≤ 0.0020288	%EV = 14.70%
R&R	0.0000021600	0.0014697	GRR: 0.0011526 ≤ 0.0014697 ≤ 0.0020288	%GRR = 14.70%
Part variation	0.0003133200	0.017701	PV: 0.0126070 ≤ 0.0177010 ≤ 0.0266200	%PV = 177.01%
Total variation	0.0003840600	0.017762	TV: 0,018	

Versuchsplan			Reference quantity		
Number of trials	=	2	Process variation	=	0
Number of parts	=	25	Tolerance	=	0.060
			Required Cp value	=	

Resolution	%RE	=	0.0167
Number of distinct categories (ndc)	ndc	=	17
Repeatability & Reproducibility	%GRR	=	14.7%
Minimum reference figure f. capable measurem. system	$T_{min\ (\%GRR)}$	=	0.0882
Min. ref. fig. f. conditionally capable measurem. system	$T_{min\ (\%GRR)}$	=	0.0294

Measurement system is conditionally capable (%RE, %GRR)

Bosch 2018 — Procedure 3

Notes:

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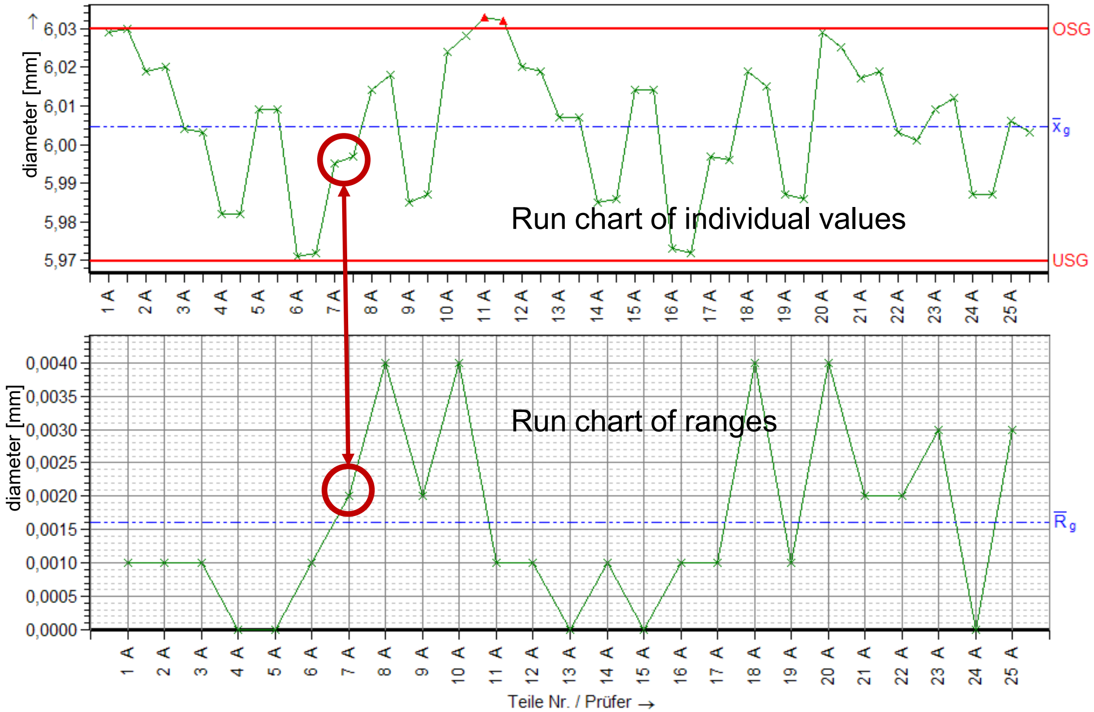
Notes:

Procedure 3 – Report

- Werteverläufe der Wiederholmessungen und der Spannweiten



Procedure 3 – Characteristic values

- Important characteristic values Procedure 3

	Variance	Standard dev.	Confidence level 1 - α = 95%	
Repeatability	0.0000021600	0.0014697	EV: 0.0011526 ≤ 0.0014697 ≤ 0.0020288	%EV = 14.70%
R&R	0.0000021600	0.0014697	GRR: 0.0011526 ≤ 0.0014697 ≤ 0.0020288	%GRR = 14.70%
Part variation	0.0003133200	0.017701	PV: 0.0126070 ≤ 0.0177010 ≤ 0.0266200	%PV = 177.01%
Total variation	0.0003840600	0.017762	TV: 0,018	

Versuchsplan			Reference quantity		
Number of trials	=	2	Process variation	=	0
Number of parts	=	25	Tolerance	=	0.060
			Required Cp value	=	

Resolution	%RE	=	0.0167	0 … 5
Number of distinct categories (ndc)	ndc	=	17	0 … 5
Repeatability & Reproducibility	%GRR	=	14.7%	0 … 10 … 30
Minimum reference figure f. capable measurem. system	$T_{min\ (\%GRR)}$	=	0.0882	
Min. ref. fig. f. conditionally capable measurem. system	$T_{min\ (\%GRR)}$	=	0.0294	
Measurement system is conditionally capable (%RE, %GRR)				
Bosch 2018 — Procedure 3				

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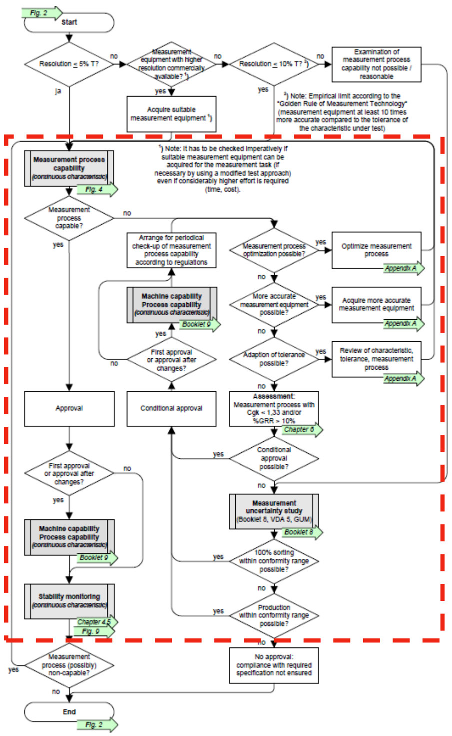
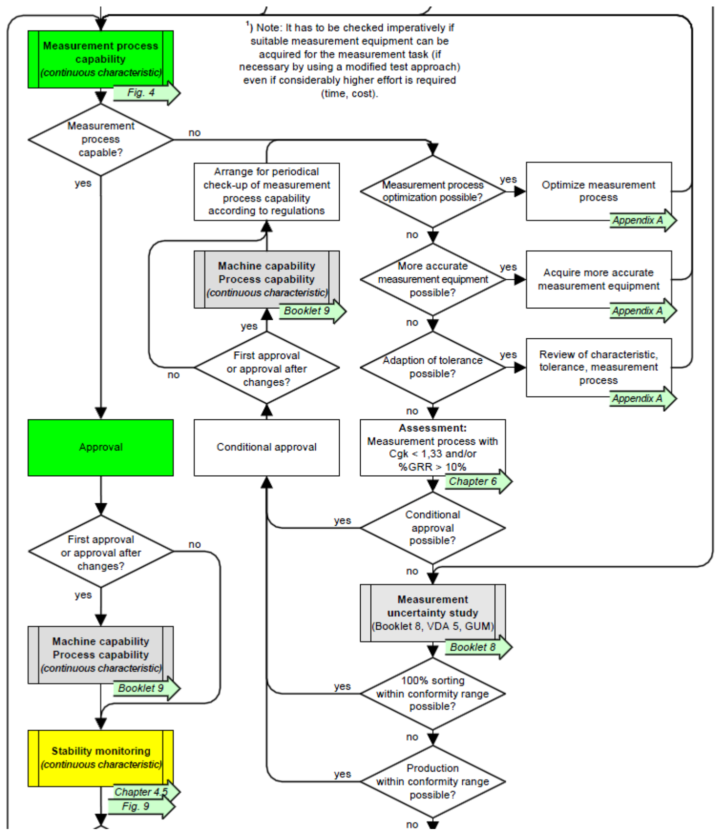
Notes:

Flow Chart





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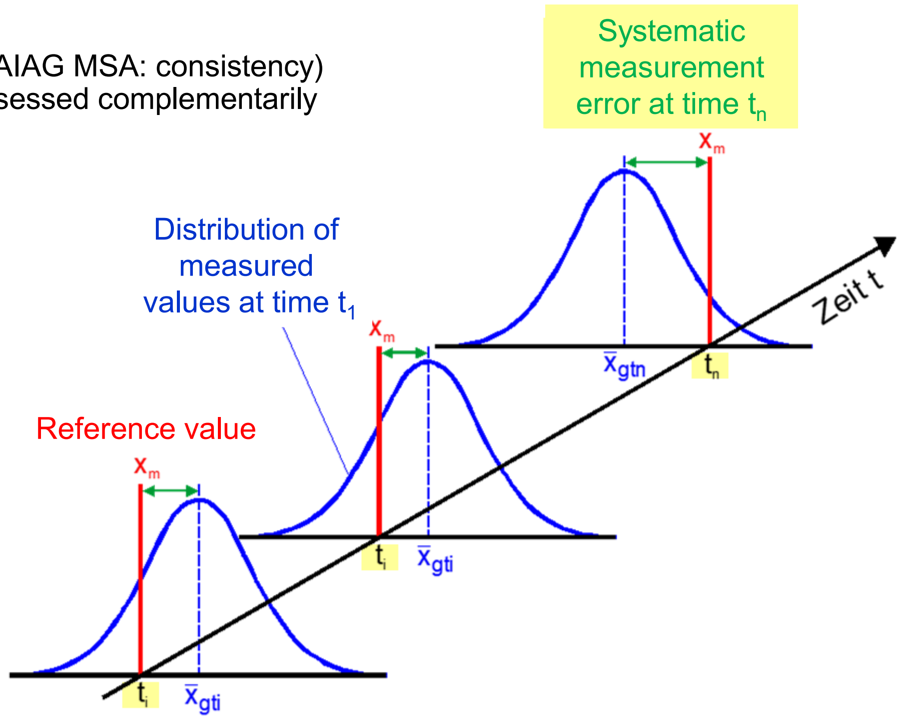
Notes:

Procedure 5 – Stability

- Stability is the variability of the bias over time
- Variability of dispersion (AIAG MSA: consistency) is often observed and assessed complementarily
- Constant dispersion (homoskedasticity) is usually assumed.



Notes:

Procedure 5 – Stability

- Objective
  - Verification of consistently correct measurement results by monitoring the long-term behaviour of a measurement process and corresponding …
  - … assessment of the stability (measurement stability) of the measuring device
  - Application of a measurement stability map (mathematically analogous to the $\bar{x} - s$ – SPC control chart)
  - Avoid the term "control chart", because this triggers further actions from various Bosch-internal rules and regulations.

- Requirements
  - Stable long-term performance cannot be safely assumed
  - A reference part (measurement standard, or a stable, possibly modified production part) is available (see also requirements for the measurement standard used in procedure 1)

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Notes:

Procedure 5 - Stability Implementation

- Reference part (stability part)
  - at process-specific fixed time intervals (Inspection intervals, sampling intervals)
  - measure at least three times each (n ≥ 3).
- The measured values are documented in tabular form on the stability map (measurement stability chart)
- Mean and standard deviation of each sample calculated and plotted in temporal order on the $\bar{x}$- or s- chart.
- The $\bar{x}$ -chart can be kept absolute or relative to the reference value x_m, i.e., the differences of the measured values to the reference value (residuals) are recorded.

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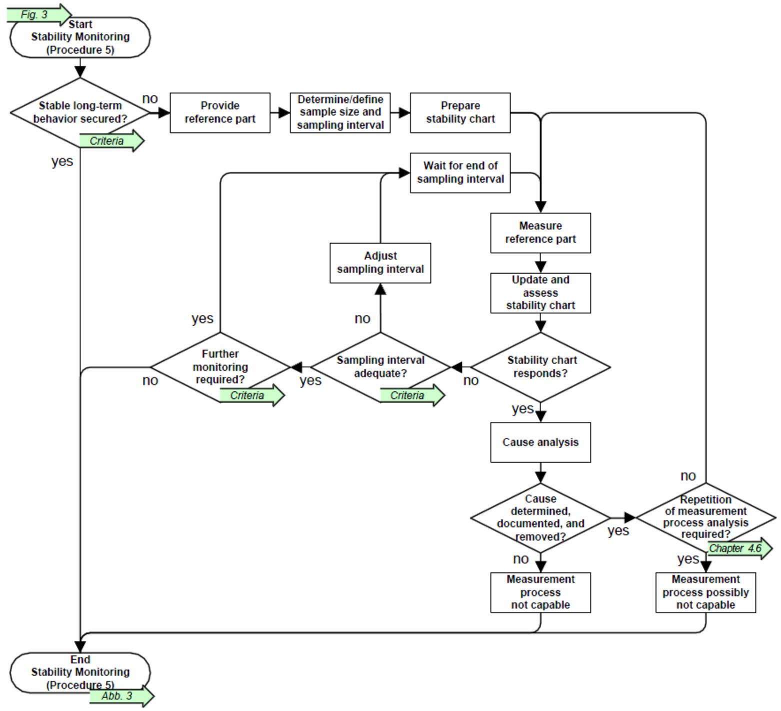
Notes:

Procedure 5 – Stability

- Conducting the study



Notes:

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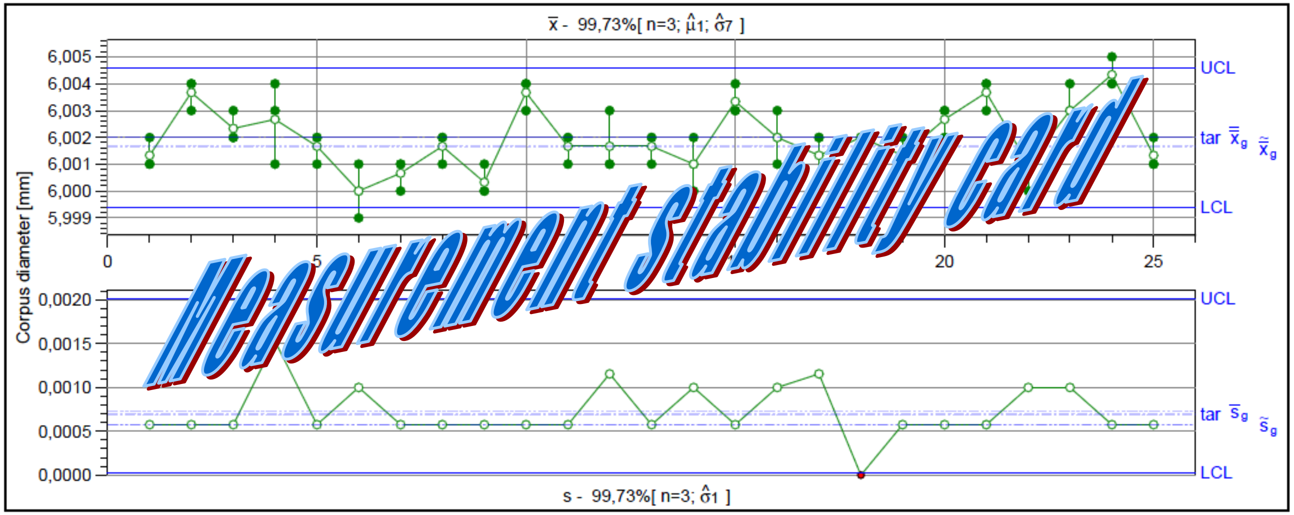
Procedure 5 – Stability – Measurement stability chart



- Is calculated analogously to the $\bar{x}$- or s- quality control chart (see Bosch booklet 7 - SPC)
- For details on the general calculation of the intervention limits see Bosch booklet 10
  - Chapter 4.5.1
  - Appendix F
- Calculated automatically by solara.MP

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Notes:

Notes:

Procedure 5 – Stability Chart

- For details on the general calculation of the intervention limits, see Bosch Booklet 10 Chapter 4.5.1

Control limits for stability charts

	Lower **c**ontrol **l**imit (LCL)	**U**pper **c**ontrol **l**imit (UCL)
$\overline{x}$-chart (mean values):	$LCL = x_m - u_p \cdot \frac{s}{\sqrt{n}}$	$UCL = x_m + u_p \cdot \frac{s}{\sqrt{n}}$
s-chart (standard deviations):	$LCL_s = B'_{Eun} \cdot s$	$UCL_s = B'_{Eob} \cdot s$
Individual value chart:	$LCL = x_m - E'_E \cdot s$	$UCL = x_m + E'_E \cdot s$

For x_m the following values can be used:
- the reference value of the reference part (stability part) or
- the mean value of a previous test run (see [AIAG MSA], chapter 3, paragraph B).

For s the following values can be used:
- 2.5% of the characteristic tolerance T (=T/40) or
- the standard deviation from a previous test run (see [AIAG MSA], chapter 3, paragraph B) or
- the standard deviation from procedure 1 (not recommended because of short-term study).

The sample size is used for n, i.e. the number of measurements per sample.

u_p, B'_{Eun}, B'_{Eob} and E'_E corresponding to the sample size n are taken from the following table for confidence level 99%. For individual value charts, it must be decided how many measured values are combined in one group of size n (pseudo-sample). n = 3 is well-established.

n	u_p	B'_{Eun}	B'_{Eob}	E'_E
3	2.58	0.071	2.302	2.935
4	2.58	0.155	2.069	3.023
5	2.58	0.227	1.927	3.090

Values for further sample sizes and confidence levels can be calculated according to Appendix F.

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Procedure 5 – Inspection interval

- No fixed rule, depends on the measurement process and its behavior over time
- General principle: begin with short intervals, then lengthen
- Examples of typical criteria for using short intervals:
  - Unstable measurement process
  - Capability indices are close to the limit
  - Characteristic is critical to function or to correct process operation
  - New measurement / test methods
  - No empirical values available
  - High statistical confidence required
  - Timely corrective action must be assured in the event of errors

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Notes:

Procedure 5 – Inspection intervals are …

- … appropriate, if
  - All averages are within the control limits
  - There are visible random changes from value to value
  - ⇨ One control measurement per shift is usually enough
  - ⇨ If there is long-term stability, the interval may be lengthened
- … too short, if there are no or only minimal changes from value to value
  - ⇨ However, one control measurement per shift is a must!
- … too long, if there are values beyond the control limits
- Special case: If the equipment is recalibrated or adjusted before each measurement, stability monitoring is not required

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Notes:

Procedure 5 – Stability criteria

- Stable measurement process
  - All values within the control limits
  - Random variation without special causes

- Unstable measurement process
  - Values beyond the control limits
  - Large random variation over time
  - Signs of special causes
    - Run
    - Trend
    - Middle Third

- If the measurement process is unstable:
  - Identify causes; risk analysis: improvement and re-approval

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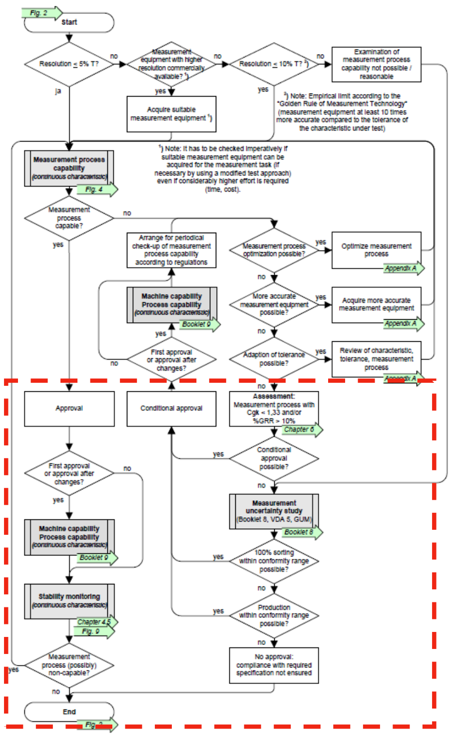
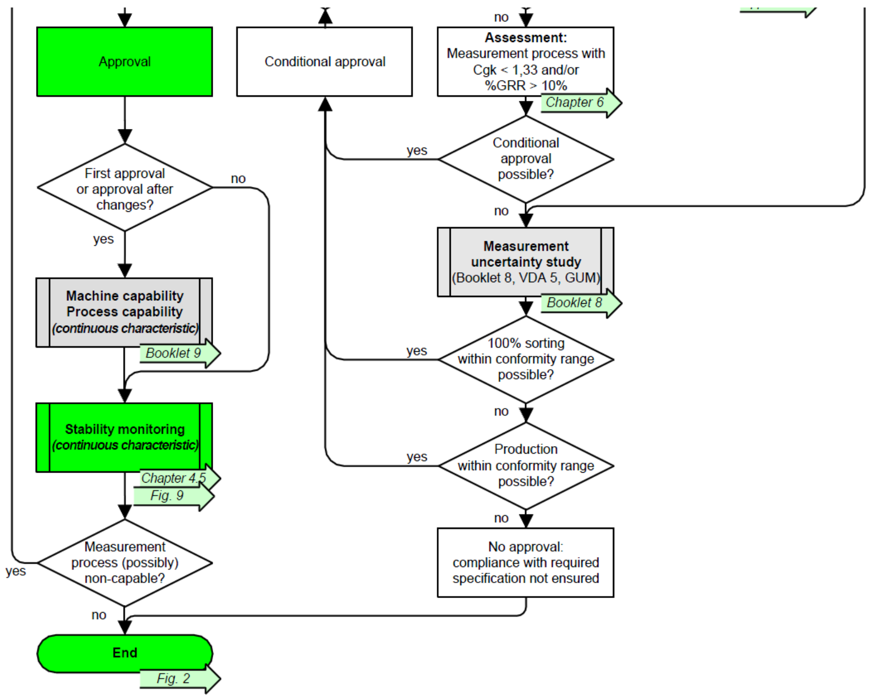
Notes:

Flow Chart





Notes:

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Repeat demonstration of capability

- No defined requirements as for control of inspection, measurement and test equipment!
- “During application in production, the capability of the measurement process must be ensured at all times (preferably using procedure 5).”
- Examples of criteria for re-approval:
  - Significant changes in the stability chart after an intervention
  - Recommissioning after maintenance or repair work etc.
  - Technical changes, significant parameter changes
  - Changes in conditions, environment, staff etc.
  - Before/after relocation
  - Suspected equipment errors
  - …

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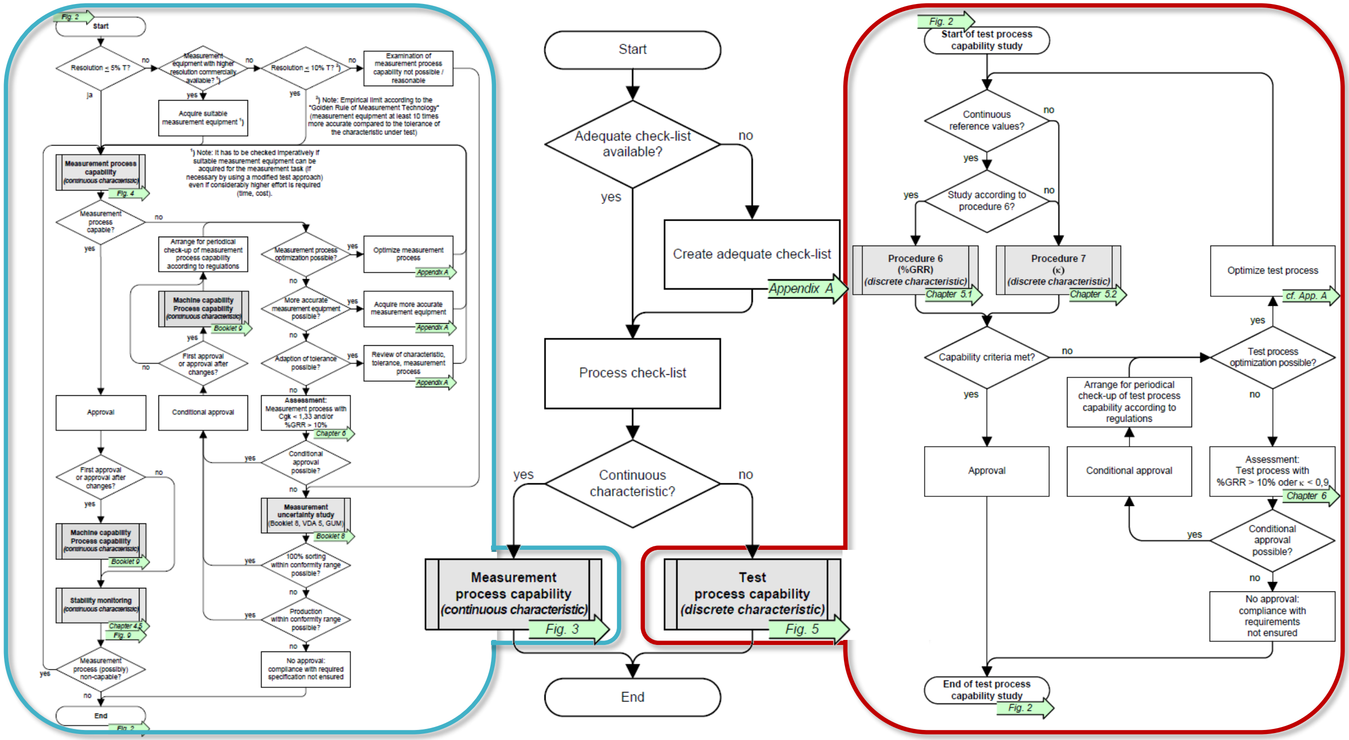
Notes:

Methods according to Booklet 10



Notes:

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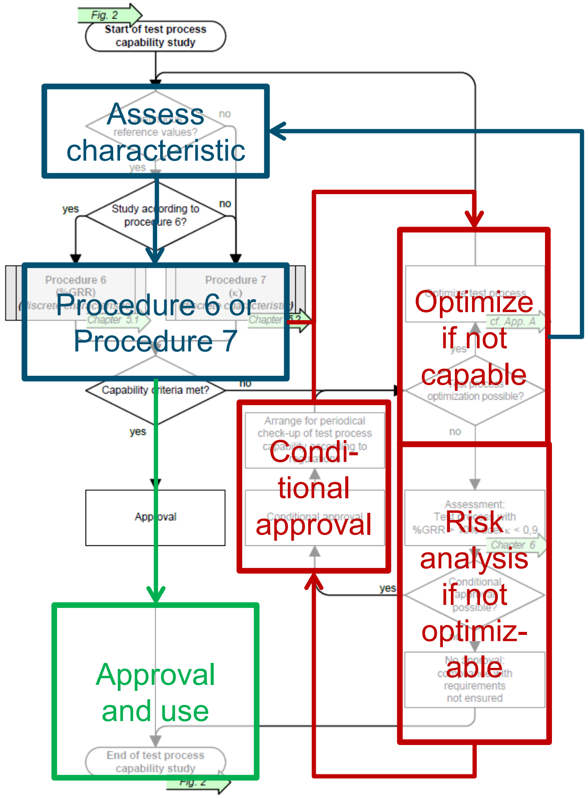
Notes:

Flow chart – Test processes

- Assess characteristic and define study type
- Perform capability analyses
- If capable: use
- If not capable:
  - Optimize
  - Risk analysis
  - Conditional approval and re-qualification



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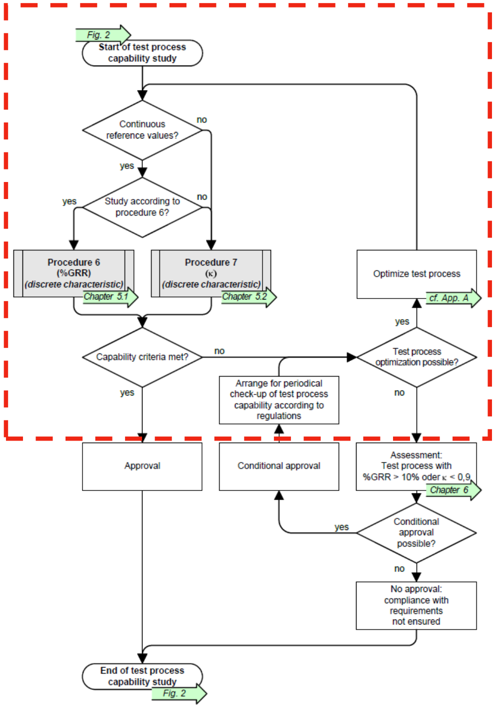
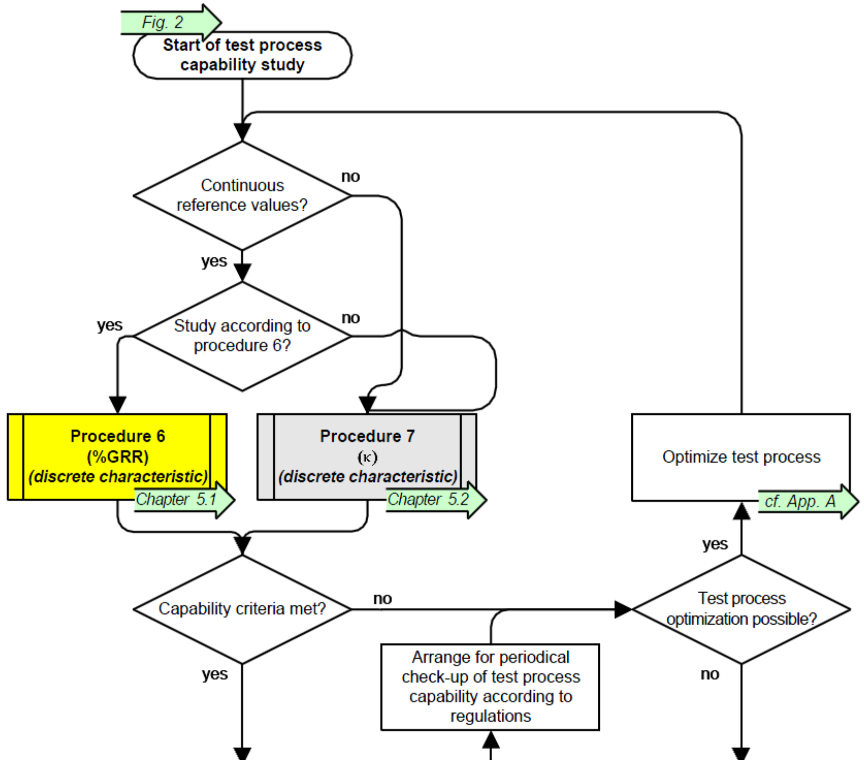
Flow chart





Notes:

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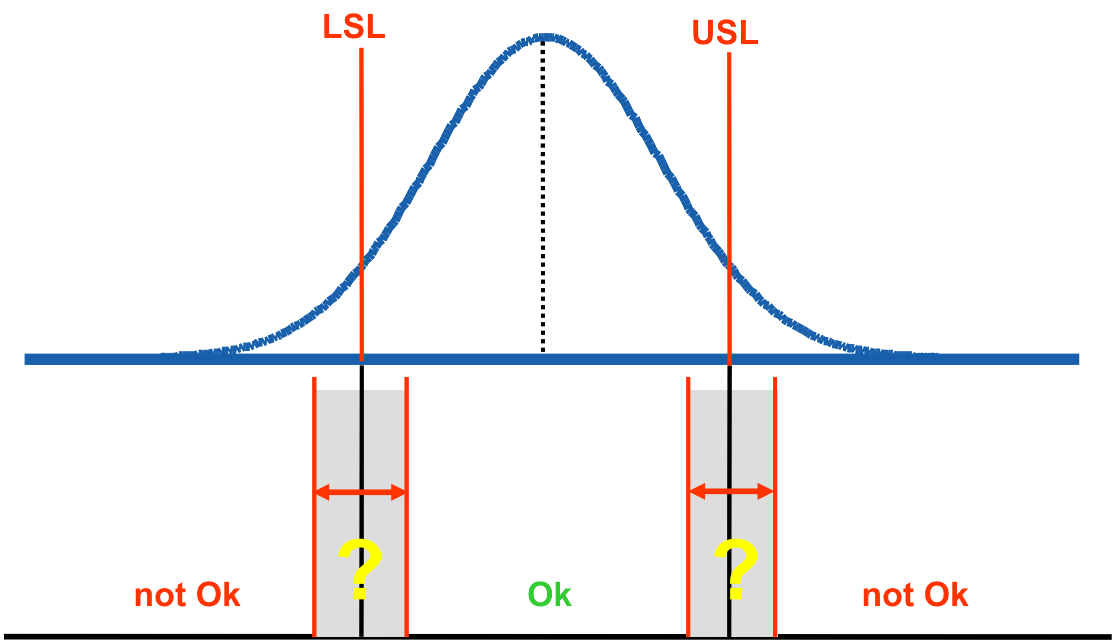
Procedure 6 – Discretized continuous characteristics

- We're looking for the average width of the grey area near USL and LSL



Notes:

Procedure 6 – Discretized continuous characteristics

- Objective
  To demonstrate the capability of a test process in terms of its ability to deliver unambiguous decisions when testing discretized characteristics.

- Requirements
  - A reference lot of 50 reference parts from production (series parts)
  - Reference values for each reference part are determined and documented before the start of the test
  - The expanded measurement uncertainty U assigned to the measured values must be known.
  - Characteristic values of the reference parts cover the tolerance range +/- the measurement uncertainty range of the reference measurements
    - That means, reference parts cover the range from
      - less than $LSL - U$ to
      - more than $USL + U$.

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Notes:

Notes:

Procedure 6 - Implementation

- Corresponds to the "Signal Detection" procedure

- Find for …
  - … each characteristic to be gauged …
  - … 50 parts distributed over the tolerance (+/- U).

- Determine a reference value in the precision measurement room
  - …for each part and …
  - … each characteristic to be inspected
    (for gauges with several inspection characteristics)

- Let the parts be checked …
  - … by 2 appraisers …
  - … 2 times each …
  - … in random order.

- Enter the results in a table.

n	Ref. 1	$x_{A;1}$	$x_{A;2}$	$x_{B;1}$	$x_{B;2}$	
1	3,6320	−	−	+	+	☹
2	3,6490	−	−	−	−	☺
3	3,5870	+	+	+	+	☺
4	3,5520	+	−	−	−	☹
5	3,6210	+	+	+	+	☺
6	3,6450	−	−	−	−	☺
7	3,6520	−	−	−	−	☺
8	3,5990	+	+	+	+	☺
9	3,6340	−	−	−	+	☹
10	3,6250	+	+	+	+	☺
11	3,5720	+	+	+	+	☺
12	3,5520	+	−	−	−	☹
13	3,5950	+	+	+	+	☺
14	3,5610	+	+	−	+	☹
15	3,6170	+	+	+	+	☺
16	3,5850	+	+	+	+	☺
17	3,5310	−	−	−	−	☺
18	3,5820	+	+	+	+	☺
19	3,5440	−	−	−	−	☺
20	3,5740	+	+	+	+	☺
21	3,5950	+	+	+	+	☺
22	3,6420	−	−	−	−	☺
23	3,6210	+	+	+	+	☺
24	3,5650	+	+	−	−	☹
25	3,5930	+	+	+	+	☺
26	3,6220	+	+	+	+	☺
27	3,6320	−	−	+	+	☹
28	3,6640	−	−	−	−	☺
29	3,5460	−	−	−	−	☺
30	3,6520	−	−	−	−	☺
31	3,5860	+	+	+	+	☺
32	3,6410	−	−	+	−	☹
33	3,6140	+	+	+	+	☺
34	3,6000	+	+	+	+	☺
35	3,5910	+	+	+	+	☺
36	3,6320	−	−	+	+	☹
37	3,5700	+	+	+	+	☺
38	3,6030	+	+	+	+	☺
39	3,5780	+	+	+	+	☺
40	3,5970	+	+	+	+	☺
41	3,5870	+	+	+	+	☺
42	3,6140	+	+	+	+	☺
43	3,6130	+	+	+	+	☺
44	3,5920	+	+	+	+	☺
45	3,5600	+	+	−	−	☹
46	3,6260	+	+	+	+	☺
47	3,6320	−	−	+	+	☹
48	3,5730	+	+	+	+	☺
49	3,5590	+	+	−	−	☹
50	3,6090	+	+	+	+	☺

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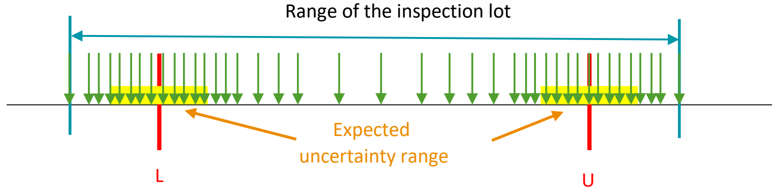
Procedure 6 – Discretized continuous characteristics

- Signal Detection" procedure according to AIAG MSA and VDA Volume 5

- Please note
  - The selection of parts should overlap the expected uncertainty range
  - Largest and smallest part outside the tolerance must each be clearly recognized as “NOK” to identify the end of the uncertainty range
  - The uncertainty cannot become smaller than the dimensional distance of the parts with non-agreements
  - Use "salted samples". According to AIAG MSA, 25% of the parts should be around each tolerance limit.



n	Ref. 1	$x_{A;1}$	$x_{A;2}$	$x_{B;1}$	$x_{B;2}$	
1	3,6320	−	−	+	+	☹
2	3,6490	−	−	−	−	☺
3	3,5870	+	+	+	+	☺
4	3,5520	+	−	−	−	☹
5	3,6210	+	+	+	+	☺
6	3,6450	−	−	−	−	☺
7	3,6520	−	−	−	−	☺
8	3,5990	+	+	+	+	☺
9	3,6340	−	−	−	+	☹
10	3,6250	+	+	+	+	☺
11	3,5720	+	+	+	+	☺
12	3,5520	+	−	−	−	☹
13	3,5950	+	+	+	+	☺
14	3,5610	+	+	−	+	☹
15	3,6170	+	+	+	+	☺
16	3,5850	+	+	+	+	☺
17	3,5310	−	−	−	−	☺
18	3,5820	+	+	+	+	☺
19	3,5440	−	−	−	−	☺
20	3,5740	+	+	+	+	☺
21	3,5950	+	+	+	+	☺
22	3,6420	−	−	−	−	☺
23	3,6210	+	+	+	+	☺
24	3,5650	+	+	−	−	☹
25	3,5930	+	+	+	+	☺
26	3,6220	+	+	+	+	☺
27	3,6320	−	−	+	+	☹
28	3,6640	−	−	−	−	☺
29	3,5460	−	−	−	−	☺
30	3,6520	−	−	−	−	☺
31	3,5860	+	+	+	+	☺
32	3,6410	−	−	+	−	☹
33	3,6140	+	+	+	+	☺
34	3,6000	+	+	+	+	☺
35	3,5910	+	+	+	+	☺
36	3,6320	−	−	+	+	☹
37	3,5700	+	+	+	+	☺
38	3,6030	+	+	+	+	☺
39	3,5780	+	+	+	+	☺
40	3,5970	+	+	+	+	☺
41	3,5870	+	+	+	+	☺
42	3,6140	+	+	+	+	☺
43	3,6130	+	+	+	+	☺
44	3,5920	+	+	+	+	☺
45	3,5600	+	+	−	−	☹
46	3,6260	+	+	+	+	☺
47	3,6320	−	−	+	+	☹
48	3,5730	+	+	+	+	☺
49	3,5590	+	+	−	−	☹
50	3,6090	+	+	+	+	☺

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Notes:

Notes:

Procedure 6 – Discretized continuous characteristics

- Check in random order, sort afterwards

n	Ref. 1	$x_{A;1}$	$x_{A;2}$	$x_{B;1}$	$x_{B;2}$	
1	3,6320	−	−	+	+	☹
2	3,6490	−	−	−	−	☺
3	3,5870	+	+	+	+	☺
4	3,5520	+	−	−	−	☹
5	3,6210	+	+	+	+	☺
6	3,6450	−	−	−	−	☺
7	3,6520	−	−	−	−	☺
8	3,5990	+	+	+	+	☺
9	3,6340	−	−	−	+	☹
10	3,6250	+	+	+	+	☺
11	3,5720	+	+	+	+	☺
12	3,5520	+	−	−	−	☹
13	3,5950	+	+	+	+	☺
14	3,5610	+	+	−	+	☹
15	3,6170	+	+	+	+	☺
16	3,5850	+	+	+	+	☺
17	3,5310	−	−	−	−	☺
18	3,5820	+	+	+	+	☺
19	3,5440	−	−	−	−	☺
20	3,5740	+	+	+	+	☺
21	3,5950	+	+	+	+	☺
22	3,6420	−	−	−	−	☺
23	3,6210	+	+	+	+	☺
24	3,5650	+	+	−	−	☹
25	3,5930	+	+	+	+	☺
26	3,6220	+	+	+	+	☺
27	3,6320	−	−	+	+	☹
28	3,6640	−	−	−	−	☺
29	3,5460	−	−	−	−	☺
30	3,6520	−	−	−	−	☺
31	3,5860	+	+	+	+	☺
32	3,6410	−	−	+	−	☹
33	3,6140	+	+	+	+	☺
34	3,6000	+	+	+	+	☺
35	3,5910	+	+	+	+	☺
36	3,6320	−	−	+	+	☹
37	3,5700	+	+	+	+	☺
38	3,6030	+	+	+	+	☺
39	3,5780	+	+	+	+	☺
40	3,5970	+	+	+	+	☺
41	3,5870	+	+	+	+	☺
42	3,6140	+	+	+	+	☺
43	3,6130	+	+	+	+	☺
44	3,5920	+	+	+	+	☺
45	3,5600	+	+	−	−	☹
46	3,6260	+	+	+	+	☺
47	3,6320	−	−	+	+	☹
48	3,5730	+	+	+	+	☺
49	3,5590	+	+	−	−	☹
50	3,6090	+	+	+	+	☺

Sort the results in ascending order according to the reference value

n	Ref. 1	$x_{A;1}$	$x_{A;2}$	$x_{B;1}$	$x_{B;2}$	
28	3,6640	−	−	−	−	☺
7	3,6520	−	−	−	−	☺
30	3,6520	−	−	−	−	☺
2	3,6490	−	−	−	−	☺
6	3,6450	−	−	−	−	☺
22	3,6420	−	−	−	−	☺
32	3,6410	−	−	+	−	☹
9	3,6340	−	−	−	+	☹
27	3,6320	−	−	+	+	☹
36	3,6320	−	−	+	+	☹
1	3,6320	−	−	+	+	☹
47	3,6320	−	−	+	+	☹
46	3,6260	+	+	+	+	☺
10	3,6250	+	+	+	+	☺
26	3,6220	+	+	+	+	☺
23	3,6210	+	+	+	+	☺
5	3,6210	+	+	+	+	☺
15	3,6170	+	+	+	+	☺
33	3,6140	+	+	+	+	☺
42	3,6140	+	+	+	+	☺
43	3,6130	+	+	+	+	☺
50	3,6090	+	+	+	+	☺
38	3,6030	+	+	+	+	☺
34	3,6000	+	+	+	+	☺
8	3,5990	+	+	+	+	☺
40	3,5970	+	+	+	+	☺
13	3,5950	+	+	+	+	☺
21	3,5950	+	+	+	+	☺
25	3,5930	+	+	+	+	☺
44	3,5920	+	+	+	+	☺
35	3,5910	+	+	+	+	☺
41	3,5870	+	+	+	+	☺
3	3,5870	+	+	+	+	☺
31	3,5860	+	+	+	+	☺
16	3,5850	+	+	+	+	☺
18	3,5820	+	+	+	+	☺
39	3,5780	+	+	+	+	☺
20	3,5740	+	+	+	+	☺
48	3,5730	+	+	+	+	☺
11	3,5720	+	+	+	+	☺
37	3,5700	+	+	+	+	☺
24	3,5650	+	+	−	−	☹
14	3,5610	+	+	−	+	☹
45	3,5600	+	+	−	−	☹
49	3,5590	+	+	−	−	☹
4	3,5520	+	−	−	−	☹
12	3,5520	+	−	−	−	☹
29	3,5460	−	−	−	−	☺
19	3,5440	−	−	−	−	☺
17	3,5310	−	−	−	−	☺

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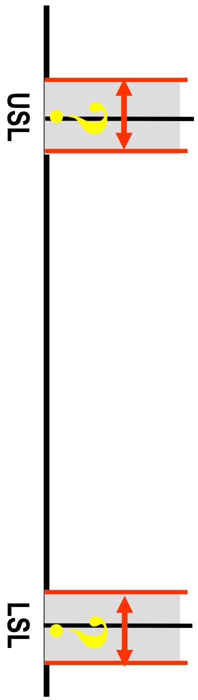
Procedure 6 – Discretized continuous characteristics



n	Ref. 1	$x_{A;1}$	$x_{A;2}$	$x_{B;1}$	$x_{B;2}$	
28	3,6640	–	–	–	–	☺
7	3,6520	–	–	–	–	☺
30	3,6520	–	–	–	–	☺
2	3,6490	–	–	–	–	☺
6	3,6450	–	–	–	–	☺
22	3,6420	–	–	–	–	☺
32	3,6410	–	–	+	–	☹
9	3,6340	–	–	–	+	☹
27	3,6320	–	–	+	+	☹
36	3,6320	–	–	+	+	☹
1	3,6320	–	–	+	+	☹
47	3,6320	–	–	+	+	☹
46	3,6260	+	+	+	+	☺
10	3,6250	+	+	+	+	☺
26	3,6220	+	+	+	+	☺
23	3,6210	+	+	+	+	☺
5	3,6210	+	+	+	+	☺
15	3,6170	+	+	+	+	☺
33	3,6140	+	+	+	+	☺
42	3,6140	+	+	+	+	☺
43	3,6130	+	+	+	+	☺
50	3,6090	+	+	+	+	☺
38	3,6030	+	+	+	+	☺
34	3,6000	+	+	+	+	☺
8	3,5990	+	+	+	+	☺
40	3,5970	+	+	+	+	☺
13	3,5950	+	+	+	+	☺
21	3,5950	+	+	+	+	☺
25	3,5930	+	+	+	+	☺
44	3,5920	+	+	+	+	☺
35	3,5910	+	+	+	+	☺
41	3,5870	+	+	+	+	☺
3	3,5870	+	+	+	+	☺
31	3,5860	+	+	+	+	☺
16	3,5850	+	+	+	+	☺
18	3,5820	+	+	+	+	☺
39	3,5780	+	+	+	+	☺
20	3,5740	+	+	+	+	☺
48	3,5730	+	+	+	+	☺
11	3,5720	+	+	+	+	☺
37	3,5700	+	+	+	+	☺
24	3,5650	+	+	–	–	☹
14	3,5610	+	+	–	+	☹
45	3,5600	+	+	–	–	☹
49	3,5590	+	+	–	–	☹
4	3,5520	+	–	–	–	☹
12	3,5520	+	–	–	–	☹
29	3,5460	–	–	–	–	☺
19	3,5440	–	–	–	–	☺
17	3,5310	–	–	–	–	☺

d_{USL}

$$\bar{d} = \frac{d_{USL} + d_{LSL}}{2} = GRR$$

d_{LSL}

$$\%GRR = \frac{\bar{d}}{T} \cdot 100\%$$

Assessment as per procedure 2 :

$\%GRR \leq 10\%$	capable
$10\% < \%GRR \leq 30\%$	conditionally capable
$\%GRR > 30\%$	not capable

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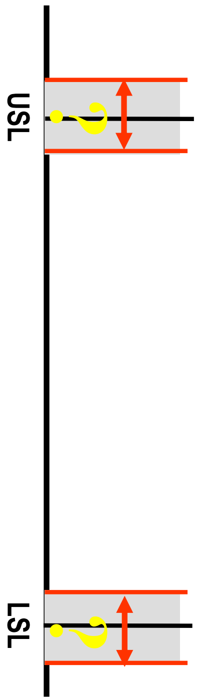
Notes:

Notes:

Procedure 6 – Report



n	Ref. 1	$x_{A;1}$	$x_{A;2}$	$x_{B;1}$	$x_{B;2}$	
28	3,6640	−	−	−	−	☺
7	3,6520	−	−	−	−	☺
30	3,6520	−	−	−	−	☺
2	3,6490	−	−	−	−	☺
6	3,6450	−	−	−	−	☺
22	3,6420	−	−	−	−	☺
32	3,6410	−	−	+	−	☹
9	3,6340	−	−	−	+	☹
27	3,6320	−	−	+	+	☹
36	3,6320	−	−	+	+	☹
1	3,6320	−	−	+	+	☹
47	3,6320	−	−	+	+	☹
46	3,6260	+	+	+	+	☺
10	3,6250	+	+	+	+	☺
26	3,6220	+	+	+	+	☺
23	3,6210	+	+	+	+	☺
5	3,6210	+	+	+	+	☺
15	3,6170	+	+	+	+	☺
33	3,6140	+	+	+	+	☺
42	3,6140	+	+	+	+	☺
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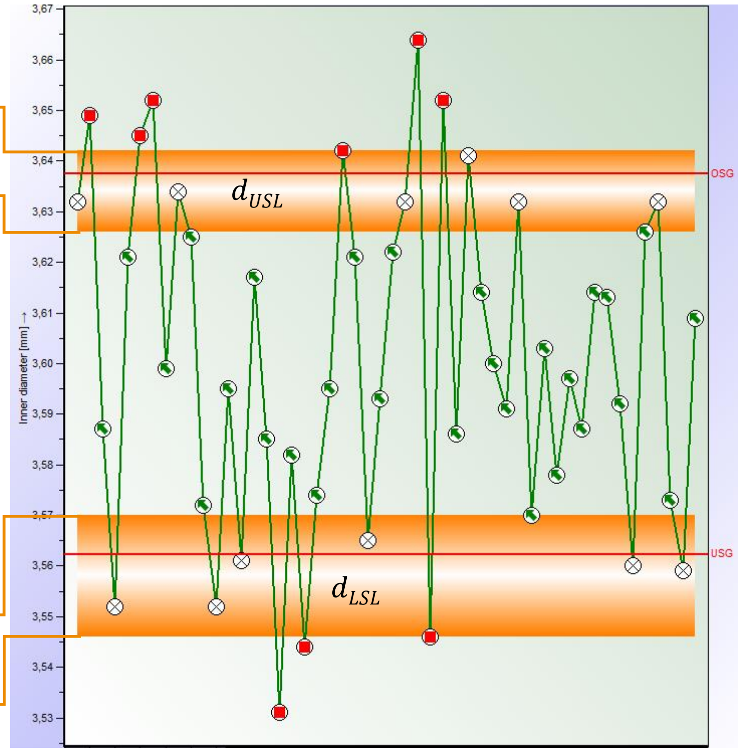
38	3,6030	+	+	+	+	☺
34	3,6000	+	+	+	+	☺
8	3,5990	+	+	+	+	☺
40	3,5970	+	+	+	+	☺
13	3,5950	+	+	+	+	☺
21	3,5950	+	+	+	+	☺
25	3,5930	+	+	+	+	☺
44	3,5920	+	+	+	+	☺
35	3,5910	+	+	+	+	☺
41	3,5870	+	+	+	+	☺
3	3,5870	+	+	+	+	☺
31	3,5860	+	+	+	+	☺
16	3,5850	+	+	+	+	☺
18	3,5820	+	+	+	+	☺
39	3,5780	+	+	+	+	☺
20	3,5740	+	+	+	+	☺
48	3,5730	+	+	+	+	☺
11	3,5720	+	+	+	+	☺
37	3,5700	+	+	+	+	☺
24	3,5650	+	+	−	−	☹
14	3,5610	+	+	−	+	☹
45	3,5600	+	+	−	−	☹
49	3,5590	+	+	−	−	☹
4	3,5520	+	−	−	−	☹
12	3,5520	+	−	−	−	☹
29	3,5460	−	−	−	−	☺
19	3,5440	−	−	−	−	☺
17	3,5310	−	−	−	−	☺



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Notes:

Procedure 6 – Report

- Results

Booklet 10 — Capability of Measurement and Test Processes

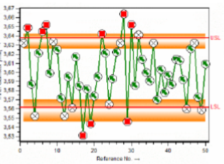
BOSCH	Measurement System Analysis Procedure 6 (Discrete Char.)	Sheet 1 / 1

Area	: MSE3	Operation	:	Grinding inner diam.	Characteristic	:	Inner diameter
Group/Dptm.	: MOE7	Machine	:	BOKO 3	Char. No.	:	1
Workshop/sect.	: W450	Machine No.	:	1003954	Nominal value	:	3.600
Product	: Injector	Test station	:	JML0782W001	Lower allowance	:	-0.0375
Part	: Needle	Gage	:	LG_4H7N1	Upper allowance	:	0.0375
Article number	: 0 433 392 425	Gage No.	:	67027025840013	Tolerance	:	0.075
Change status	: 20.01.2019	Gage Manuf.	:	BaP	Unit	:	mm
		Resolution	:	0.002			

Comment :

Standard: Standard No.: Standard/Ref. value:

n	Ref. 1	$x_{A;1}$	$x_{A;2}$	$x_{A;3}$	$x_{B;1}$	$x_{B;2}$	$x_{B;3}$	
1	3,6320	−	−	+	+	+	−	☹
2	3,6490	−	−	−	−	−	−	☺
3	3,5870	+	+	+	+	+	+	☺
4	3,5520	+	−	−	−	−	−	☹
5	3,6210	+	+	+	+	+	+	☺
6	3,6450	−	−	−	−	−	−	☺
7	3,6520	−	−	−	−	−	−	☺
8	3,5990	+	+	+	+	+	+	☺
9	3,6340	−	−	+	−	+	−	☹
10	3,6250	+	+	+	+	+	+	☺
11	3,5720	+	+	+	+	+	+	☺
12	3,5520	+	−	+	−	−	+	☹
13	3,5950	+	+	+	+	+	+	☺
14	3,5610	+	+	+	−	+	+	☹
15	3,6170	+	+	+	+	+	+	☺
16	3,5850	+	+	+	+	+	+	☺
17	3,5310	−	−	−	−	−	−	☺
18	3,5820	+	+	+	+	+	+	☺
19	3,5440	−	−	−	−	−	−	☺
20	3,5740	+	+	+	+	+	+	☺
21	3,5950	+	+	+	+	+	+	☺
22	3,6420	−	−	−	−	−	−	☺
23	3,6210	+	+	+	+	+	+	☺
24	3,5650	+	+	−	−	−	+	☹
25	3,5930	+	+	+	+	+	+	☺
26	3,6220	+	+	+	+	+	+	☺
27	3,6320	−	−	−	+	+	+	☹
28	3,6640	−	−	−	−	−	−	☺
29	3,5460	−	−	−	−	−	−	☺
30	3,6520	−	−	−	−	−	−	☺
31	3,5860	+	+	+	+	+	+	☺
32	3,6410	−	−	−	+	−	+	☹
33	3,6140	+	+	+	+	+	+	☺
34	3,6000	+	+	+	+	+	+	☺
35	3,5910	+	+	+	+	+	+	☺
36	3,6320	−	−	−	+	+	−	☹
37	3,5700	+	+	+	+	+	+	☺
38	3,6030	+	+	+	+	+	+	☺
39	3,5780	+	+	+	+	+	+	☺
40	3,5970	+	+	+	+	+	+	☺
41	3,5870	+	+	+	+	+	+	☺
42	3,6140	+	+	+	+	+	+	☺
43	3,6130	+	+	+	+	+	+	☺
44	3,5920	+	+	+	+	+	+	☺
45	3,5600	+	+	+	−	−	+	☹
46	3,6260	+	+	+	+	+	+	☺
47	3,6320	−	−	−	+	+	−	☹
48	3,5730	+	+	+	+	+	+	☺
49	3,5590	+	+	−	−	−	−	☹
50	3,6090	+	+	+	+	+	+	☺



Drawing Values			
	USL	=	3,63750
	LSL	=	3,56250
	T	=	0,07500
Number of reference measurements		=	1
Number of reference parts		=	50
Number of appraisers		=	2
Number of trials per appraiser		=	3

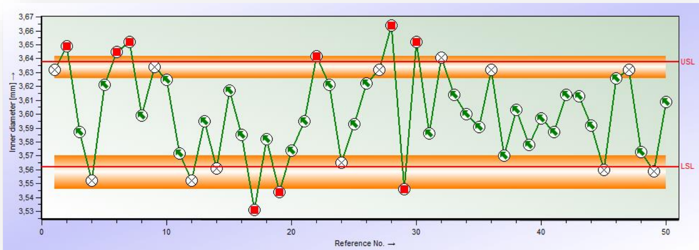
Analysis of Non-Conformancies			
Number of non-conformancies	$n_{<>}$	=	12
	$n_{max<>}$	=	0
	$n'_{max<>}$	=	1

Signal Detection Approach			
Non-conformance range	d_{OSG}	=	0.01600
Non-conformance range	d_{USG}	=	0.02400
Average non-conformance range	d	=	0.02000
Repeatability & Reproducibility	%GRR	=	26.67%

0 10 30

Hypothesis Tests			
$Kappa_{Fl}$	K'_{Fl}	=	0.6060
$Kappa_{Co}$	K'_{Co}	=	0.6063
$Kappa_{min}$	K'_{min}	=	—

Bosch 2018 — Procedure 6, Discrete Characteristics



Number of trials per operator	=	2

Attribute Agreement Analysis						
No. of Non-conformancies	$n_{<>}$	=	12	$n_{max<>}$	=	0
				$n'_{max<>}$	=	1

Signal detection approach			
Non-conformance range (USL)	d_{USL}	=	0.016000
Non-conformance range (LSL)	d_{LSL}	=	0.024000
Average non-conformance range	d	=	0.020000
Repeatability & Reproducibility	%GRR	=	26.67%

0 10 30

Hypothesis testing								
$Kappa_{Fl}$	K'_{Fl}	= 0.5781	$Kappa_{Co}$	K'_{Co}	= 0.5784	$Kappa_{min}$	K'_{min}	= ---

The requirements were not met (min,GRR) ☹

BOSCH 2018: Type 6

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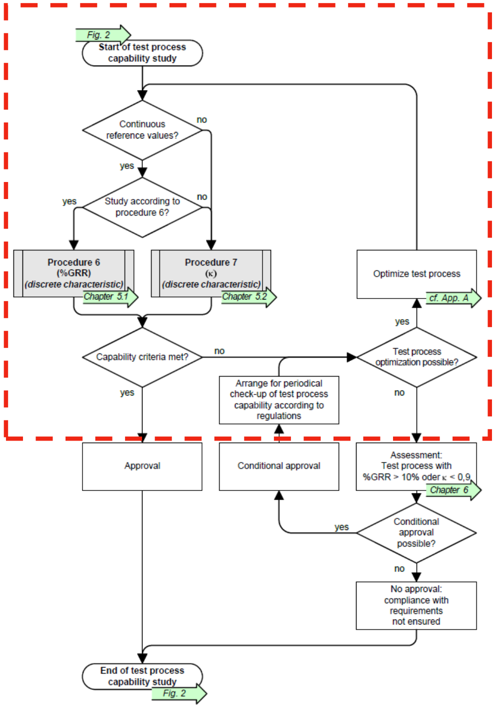
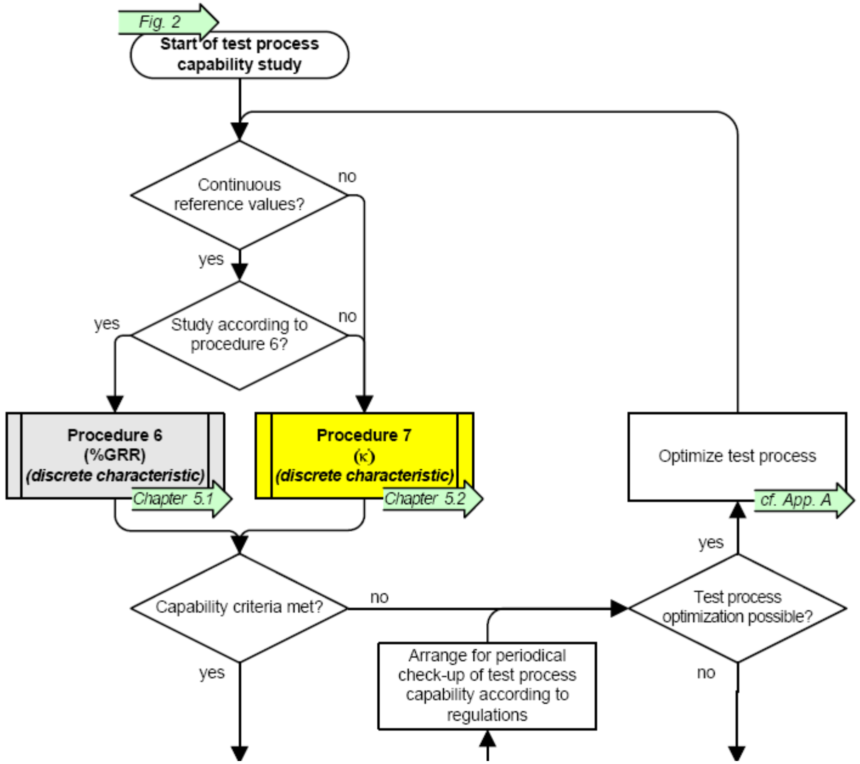
Flow chart





Notes:

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Procedure 7 – Discrete characteristics

- Objective
  - Evaluation of the capability of an inspection process with regard to unambiguous inspection decisions for discrete or discretised continuous characteristics.

- Requirements for **reference parts with continuous characteristic values**
  - Analogous to procedure 6

- Requirements for **reference parts with discrete characteristic values**
  - Provide standards for comparison (catalogue of limiting samples)
  - Classification in categories (OK/NOK)
  - Several categories are possible (grades, reject/good/rework)

- Requirements for **reference lot (Master)**
  - 100-200 parts recommended, according to AIAG MSA at least 50
  - All properties relevant for the test must be represented in a typical ratio to each other
  - All parts clearly identifiable (not recognisable for tester!)

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Notes:

Procedure 7 - Discrete Characteristics - Implementation

- Analogous to procedure 6, assign the test objects
  - in random order
  - under series conditions and
  - to a category
- If operator influence is to be expected: At least three testers and at least three passes.
- No operator influence to be expected: At least six test runs.
- The test sequence shall be randomly selected for each run.

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Notes:

Notes:

Procedure 7 - Discrete Characteristics - Fleiss' Kappa

- The pairwise agreement of the individual test results are evaluated
- A kappa value (κ) is formed from the observed (P_{Obs}), expected (P_{Exp}) and total possible (100%) percentages of the matches in each case
- Valuation factor Kappa κ

$$\kappa = \frac{P_{Obs} - P_{Exp}}{1 - P_{Exp}} = \frac{\text{observed non ramdom agreements}}{\text{possible non ramdom agreements}}$$

  - Ratio of observed non-random agreements to possible non-random agreements
    - The difference between the observed agreements P_{Obs} and the expected (random) agreements P_{Exp} gives the proportion of "observed non-random agreements " $P_{Obs} - P_{Exp}$
    - The difference between the expected (random) agreements P_{Exp} and the total possible agreements $(100\% = 1)$ gives the proportion of "possible non-random agreements" $1 - P_{Exp}$

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Procedure 7 - Discrete Characteristics - Fleiss' Kappa - Evaluation

- Kappa values are calculated for the following comparisons:
  - A x A Repeatability - Agreement of appraiser A with himself
  - B x B Repeatability - Agreement of appraiser B with himself
  - C x C Repeatability - Agreement of appraiser C with himself

  - A x B x C Reproducibility - Agreement among all appraiser

  - A x Ref Agreement of appraiser A with reference decision
  - B x Ref Agreement of appraiser B with reference decision
  - C x Ref Agreement of appraiser C with reference decision

  - A x B x C x Ref Common agreement of all appraisers with the reference decision

- I.e., 3 appraisers and one reference decision result in 8 kappa values

- The smallest kappa value is relevant for the capability decision

Notes:

Procedure 7 - Discrete Characteristics - Fleiss' Kappa

- Capability assessment

  Capability is assessed based on the κ statistic ("Kappa"):

  - $\kappa \geq 0.9$: test process capable
  - $0.9 > \kappa \geq 0.7$: test process conditionally capable
  - $\kappa < 0.7$: test process not capable (unsuitable)
  - Use the minimum of all the κ-values for the overall assessment.

Notes:

Notes:

Procedure 7 - Discrete Characteristics - Fleiss' Kappa

- Example Bosch issue 10:
  - 3 inspectors evaluate ...
  - ... 50 parts with reference assessment ...
  - ... 3 times each ...
  - ... with 2 categories (good/bad)

- Results matrix

Seq. No.	Reference value	Appraiser A	Appraiser B	Appraiser C
1		1 2 3	1 2 3	1 2 3
2	…	…	…	…
3		1 2 3	1 2 3	1 2 3
…	…	…	…	…
6		1 2 3	1 2 3	1 2 3
… 50	…	…	…	…

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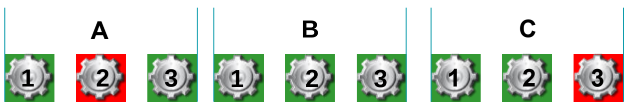
Notes:

Procedure 7 - Discrete Characteristics - Fleiss' Kappa

- Pair combinations per examiner
  - A part is measured three times by an inspector
  - Each measurement is compared with the other two measurements
  - If there is an agreement, it is counted, otherwise not
    - agreement 1-2, 1-3, 2-1, 2-3, 3-1, 3-2 → AxA = 6
    - agreement 1-2, 2-1 → AxA = 2
    - agreement 2-3, 3-2 → AxA = 2
    - agreement 1-2, 1-3, 2-1, 2-3, 3-1, 3-2 → AxA = 6

- Pairwise agreement are counted analogously
  - about all appraisers → AxBxC = 44
  - for each test measurement with the reference value → A1xR = 0 oder 2



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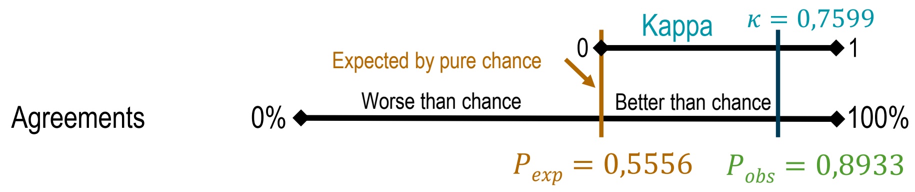
Notes:

Procedure 7 - Discrete Characteristics - Fleiss' Kappa

- Example: Calculate kappa value for A x A
  - Appraiser A evaluates 50 parts 3 times each → Appraiser A makes $N = 150$ decisions
  - $n_+ = 50$ the decision is „OK“ ($P_+ = \frac{1}{3}$), $n_- = 100$ the decision „NOK“ ($P_- = \frac{2}{3}$)
  - $n^* = 268$ of $N^* = 300\ (= 50 \cdot 6)$ possible agreements were found, that means $P_{Obs} = \frac{n^*}{N^*} = 0{,}8933$
  - Assumption: The examiner decides "blindly" without really recognising the defect. Then the probability of making the same decision twice is:
    - 2 x „OK“ $P_{++} = P_+ \cdot P_+ = \frac{1}{3} \cdot \frac{1}{3} = \frac{1}{9}$
    - 2 x „NOK“ $P_{--} = P_- \cdot P_- = \frac{2}{3} \cdot \frac{2}{3} = \frac{4}{9}$
    - Overall probability for agreements $P_{Exp} = P_{++} + P_{--} = \frac{5}{9} = 0{,}5556$
  - Kappa AxA: $\kappa = \frac{P_{Obs} - P_{Exp}}{1 - P_{Exp}} = 0{,}7599$



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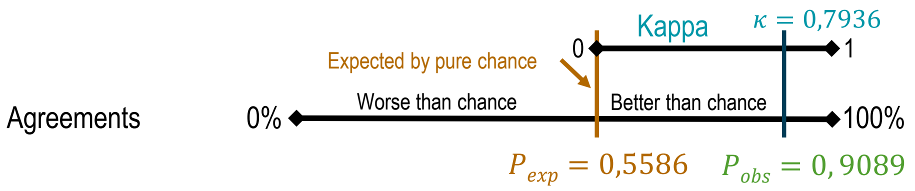
Notes:

Procedure 7 - Discrete Characteristics - Fleiss' Kappa

- Example: Calculate kappa value for A x B x C
  - Three appraisers evaluate 50 parts 3 times each $\rightarrow N = 450$ decisions
  - $n_+ = 148$ times the decision is „OK“ ($P_+ = \frac{148}{450}$), $n_- = 302$ times „NOK“ ($P_- = \frac{302}{450}$)
  - $n^* = 3272$ of $N^* = 3600$ $(= 50 \cdot 72)$ possible agreements were found, that means $P_{Obs} = \frac{n^*}{N^*} = 0{,}9089$
  - Assumption: The examiner decides "blindly" without really recognising the defect. Then the probability of making the same decision twice is:
    - 2 x „i.O.“ $P_{++} = P_+ \cdot P_+ = \frac{148}{450} \cdot \frac{148}{450} = \frac{21904}{202500}$
    - 2 x „n.i.O.“ $P_{--} = P_- \cdot P_- = \frac{302}{450} \cdot \frac{302}{450} = \frac{91204}{202500}$
    - Overall probability for agreements $P_{Exp} = \frac{113108}{202500} = 0{,}5586$
  - Kappa AxBxC: $\kappa = \frac{P_{Obs} - P_{Exp}}{1 - P_{Exp}} = 0{,}7936$



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Notes:

Procedure 7 - Discrete Characteristics - Fleiss' Kappa

BOSCH Quality Management

Test Process Analysis Procedure 7

Record No.: 9911015
Sheet 1 of 2

Product / Test Object
- Product: Housing
- Part: Cover
- Part / Drawing No.: A 111 999 222
- Revision: 05 / 02/29/2009

Characteristic
- Designation: Surface quality
- Characteristic No.: 15
- ☐ Continuous Characteristic
  - Nominal Value: n/a
  - Upper Limit: n/a
  - Lower Limit: n/a
  - Tolerance: n/a
  - Unit: n/a
- ☑ Discrete Characteristic

Measuring & Test Equipment
- Location: XxP/W000999
- Test / Measuring Station: Visual inspection
- Test / Measuring Equipment No.: 123 456 789
- Designation: Boundary samples catalogue
- Calibration Certificate No.: n/a
- Measurement Uncertainty: n/a

Test Method: Visual inspection, manually, room temperature 20.2ºC, light intensity 250 cd (Candela)

Test Scenario
- Number of reference parts N_O = 50
- Number of appraisers N_A = 3
- Number of trials per appraiser N_T = 3
- Number of evaluation categories N_C = 2

Evaluation Categories
- 0 - Not OK
- 1 - OK

Test Data: See sheet 2 ff

Analysis

Appraiser name	Symbol	Within appraiser without reference: κ (Kappa)	κ ≥ 0.90 capable	0.70 ≤ κ < 0.90 conditionally capable	κ < 0.70 not capable	Each appraiser against reference: κ (Kappa)	κ ≥ 0.90 capable	0.70 ≤ κ < 0.90 conditionally capable	κ < 0.70 not capable
Miller	A	0.7600		X		0.8802		X	
Smith	B	0.8451		X		0.9226	X		
King	C	0.7029		X		0.7747		X	
		Between appraisers without reference				All appraisers against reference			
all		0.7936		X		0.8592		X	

Total Result

Minimum of all results: Kappa = 0.7029

- Kappa ≥ 0.90: ☐ capable
- 0.70 ≤ Kappa < 0.90: ☑ conditionally capable
- Kappa < 0.70: ☐ not capable

Comment: none

Date: 02/29/2009 Department: W025 Name: J. Q. Public Signature: J. Q. Public

Procedure 7: Test Results Record No. 9911015, Sheet 2 of 2

Test Object No.	Reference Value (continuous)	Reference Value (discrete or discretized)	Miller A-1	Miller A-2	Miller A-3	Mayer B-1	Mayer B-2	Mayer B-3	Huber C-1	Huber C-2	Huber C-3			
1	n/a	1	1	1	1	1	1	1	1	1	1			
2	n/a	1	1	1	1	1	1	1	1	1	1			
3	n/a	0	0	0	0	0	0	0	0	0	0			
4	n/a	0	0	0	0	0	0	0	0	0	0			
5	n/a	0	0	0	0	0	0	0	0	0	0			
6	n/a	1	1	1	0	1	1	0	1	0	0			
7	n/a	1	1	1	1	1	1	1	1	0	1			
8	n/a	1	1	1	1	1	1	1	1	1	1			
9	n/a	0	0	0	0	0	0	0	0	0	0			
10	n/a	1	1	1	1	1	1	1	1	1	1			
11	n/a	1	1	1	1	1	1	1	1	1	1			
12	n/a	0	0	0	0	0	0	0	0	1	0			
13	n/a	1	1	1	1	1	1	1	1	1	1			
14	n/a	1	1	1	0	1	1	1	1	0	0			
15	n/a	1	1	1	1	1	1	1	1	1	1			
16	n/a	1	1	1	1	1	1	1	1	1	1			
17	n/a	1	1	1	1	1	1	1	1	1	1			
18	n/a	1	1	1	1	1	1	1	1	1	1			
19	n/a	1	1	1	1	1	1	1	1	1	1			
20	n/a	1	1	1	1	1	1	1	1	1	1			
21	n/a	1	1	1	0	1	0	1	0	1	0			
22	n/a	0	0	0	1	0	1	0	1	1	0			
23	n/a	1	1	1	1	1	1	1	1	1	1			
24	n/a	1	1	1	1	1	1	1	1	1	1			
25	n/a	0	0	0	0	0	0	0	0	0	0			
26	n/a	0	0	1	0	0	0	0	0	0	1			
27	n/a	1	1	1	1	1	1	1	1	1	1			
28	n/a	1	1	1	1	1	1	1	1	1	1			
29	n/a	1	1	1	1	1	1	1	1	1	1			
30	n/a	0	0	0	0	0	0	1	0	0	0			
31	n/a	1	1	1	1	1	1	1	1	1	1			
32	n/a	1	1	1	1	1	1	1	1	1	1			
33	n/a	1	1	1	1	1	1	1	1	1	1			
34	n/a	0	0	0	1	0	0	1	0	1	1			
35	n/a	1	1	1	1	1	1	1	1	1	1			
36	n/a	1	1	1	0	1	1	1	1	0	1			
37	n/a	0	0	0	0	0	0	0	0	0	0			
38	n/a	1	1	1	1	1	1	1	1	1	1			
39	n/a	0	0	0	0	0	0	0	0	0	0			
40	n/a	1	1	1	1	1	1	1	1	1	1			
41	n/a	1	1	1	1	1	1	1	1	1	1			
42	n/a	0	0	0	0	0	0	0	0	0	0			
43	n/a	1	1	0	1	1	1	1	1	1	0			
44	n/a	1	1	1	1	1	1	1	1	1	1			
45	n/a	0	0	0	0	0	0	0	0	0	0			
46	n/a	1	1	1	1	1	1	1	1	1	1			
47	n/a	1	1	1	1	1	1	1	1	1	1			
48	n/a	0	0	0	0	0	0	0	0	0	0			
49	n/a	1	1	1	1	1	1	1	1	1	1			
50	n/a	0	0	0	0	0	0	0	0	0	0			

Evaluation categories: 0 - not OK; 1 - OK n/a - not applicable

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Procedure 7 - Discrete Characteristics - Fleiss' Kappa

- The smallest kappa value decides the overall result

Categories: 0 - Not OK, 1 - OK

Number of pair-wise identical combinations per test object i ($i = 1, \ldots N_O$)

	A x A	B x B	C x C	A x B x C	A-1 x Ref	A-2 x Ref	A-3 x Ref	B-1 x Ref	B-2 x Ref	B-3 x Ref	C-1 x Ref	C-2 x Ref	C-3 x Ref
Test object No. / Reference / Appraiser – Trial: A-1, A-2, A-3, B-1, B-2, B-3, C-1, C-2, C-3													
Kappa: $\frac{P_{Obs} - P_{Exp}}{1 - P_{Exp}} = \kappa$	0.7600	0.8451	0.7029	0.7936	1.0000	0.9081	0.7326	1.0000	0.9081	0.8597	0.9081	0.6834	0.7326
Kappa: Each appraiser against reference (mean values)						0.8802			0.9226			0.7747	
Kappa: All appraisers against reference (mean value)									0.8592				

Appraiser name	Symbol	κ (Kappa)	κ ≥ 0.90 capable	0.70 ≤ κ < 0.90 conditionally capable	κ < 0.70 not capable	κ (Kappa)	κ ≥ 0.90 capable	0.70 ≤ κ < 0.90 conditionally capable	κ < 0.70 not capable
Miller	A	0.7600		X		0.8802		X	
Smith	B	0.8451		X		0.9226	X		
King	C	0.7029		X		0.7747		X	
		Between appraisers without reference				All appraisers against reference			
all		0.7936		X		0.8592		X	

Total Result Minimum of all results: Kappa = 0.7029

Kappa ≥ 0.90: ☐ capable 0.70 ≤ Kappa < 0.90: ☑ conditionally capable Kappa < 0.70: ☐ not capable

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Notes:

Procedure 6/7 – Stability or repetition?

- There are no defined requirements for stability checks for test process capability
- An np- or p-chart as used in SPC would be an obvious possibility
- However, these charts typically use sample sizes n ≥ 50
- So stability monitoring would essentially be an ongoing repetition of procedure 7
- Some typical criteria for a repeat test:
  - When commissioning a new, overhauled or repaired test equipment; after maintenance work
  - After technical changes to an test equipment
  - After additions or significant changes to reference standards
  - After a change of test process conditions or appraisers
  - See also criteria for repeating measurement process capability studies

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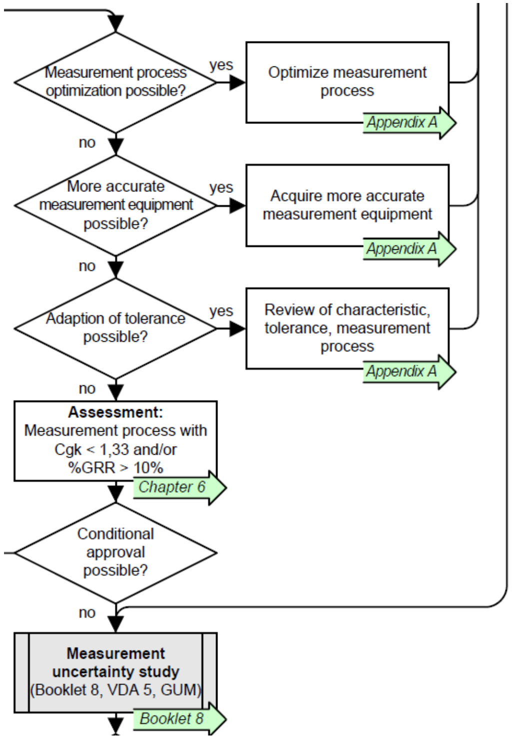
Notes:

Notes:

Non-capable measurement or test processes



- Observe sequence in Booklet 10:
- Optimize measurement processes
  - Measuring equipment, standards
  - Measurement procedure, strategy
  - Environmental conditions
  - Object of measurement
  - Appraisers, instructions
- Purchase more precise measuring system
- Look at characteristic, tolerance, and measurement process

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Notes:

Non-capable measurement or test processes

BOSCH Quality Management

Assessment of Non-capable Measurement & Test Processes

Record No.: 9911015 Sheet 1 of 2

Measuring Equipment | Characteristic | Measurement Standard

1. Capability indices of procedures 1 – 4 and 6 – 7

Check the applicable result for each procedure (n/a – procedure not applicable / not used)

Pro-cedure	n/a	capable	conditionally capable				not capable	
1			$1.20 \le C_{gk} < 1.33$	X	$0.80 \le C_{gk} < 1.20$		$C_{gk} < 0.80$	
2			$10\% < \%GRR \le 20\%$		$20\% < \%GRR \le 30\%$	X	$\%GRR > 30\%$	
3	X		$10\% < \%GRR \le 20\%$		$20\% < \%GRR \le 30\%$		$\%GRR > 30\%$	
4		X	$1.20 \le MIN(C_{gk}) < 1.33$		$0.80 \le MIN(C_{gk}) < 1.20$		$MIN(C_{gk}) < 0.80$	
4 (MSA)	X						Zero line (partly) outside the confidence limits	
5	X							
6	X		$10\% < \%GRR \le 20\%$		$20\% < \%GRR \le 30\%$		$\%GRR > 30\%$	
7	X		$0.8 \le \kappa < 0.9$		$0.7 \le \kappa < 0.8$		$\kappa < 0.7$	
Key figure 1			1		2	X	7	

Highest key figure achieved is relevant

Outer diameter is too large, component group must be scrapped, increased failure costs

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Notes:

Non-capable measurement or test processes

2. External relevance of failures (implication for customer)

Evaluation according to design and process FMEA (see booklet 14; CDQ0305; divisional & plant specific regulations)

Consequences for client	*none*	*insignificant to marginal*	*moderately serious to serious*	*very serious*
B-assessment according to FMEA	*1*	*2 - 4*	*5 - 8*	*9 - 10*
Key figure 2	*1*	*2*	*3* X	*7*

Description of failure implication: *Outer diameter is too large, component group cannot be used in the vehicle; 0 km complaint*

3. Internal relevance of failures (implication for Bosch)

Evaluation according to design and process FMEA (see booklet 14; CDQ0305; divisional & plant specific regulations)

Consequences for Bosch	*none*	*insignificant to marginal*	*moderately serious to serious*	*very serious*
B-assessment according to FMEA	*1*	*2 - 4*	*5 - 8*	*9 - 10*
Key figure 3	*1*	*2*	*3* X	*7*

Description of failure implication: *Outer diameter is too large, component group must be scrapped, increased failure costs*

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Notes:

Non-capable measurement or test processes

BOSCH Quality Management | Assessment of Non-capable Measurement & Test Processes | Record No.: 9911015

4. Result of assessment and measures

Product of key figures: **2** (Key figure 1) x **3** (Key figure 2) x **3** (Key figure 3) = **18** (Key figure of assessment)

Result		Decision	Measures
1 - 2		**Conditional release** Periodical checking for possible improvement of the test process	*Optimize measurement system (prevent from manual influence)* *Repeat MSA according to procedure 1*
3 - 6		**Conditional release** Periodical checking for possible improvement of the test process. Proof of effectiveness of measures in order to avoid failures (customer complaints).	*Optimize measurement system (prevent from manual influence)* *Repeat MSA according to procedure 1* *Safeguard characteristic by additional test XXX ...*
≥ 7	X	**No release** Functioning of the characteristic must be ensured by means of a capable indirect test. If external failure implications cannot be ruled out, regulations are established together with the responsible product development unit. The customer has to be informed.	*Define a new measuring method ...* *Acquire more precise measurement equipment ...* *Wiederholung Messsystemanalyse nach Verfahren ...* *Absicherung des Merkmals über zusätzliche Prüfung XXX ...*

Key figure 3: 1 ☐ 2 ☐ 3 ☒ 7 ☐

Description of failure implication: *Outer diameter is too large, component group must be scrapped, increased failure costs*

HEXAGON

Notes: