DAIMLER

Powertrain Requirement Specifications Part I General Information

Version 2021

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Author	Passenger car planning approval	Truck planning approval
PT/PP4.0, Fleischer	PT/PP, Dr. Messelken	TG/MP, Dr. Juergen Betz

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1. General Information

1.1. Preface

All new procurement projects at Daimler are characterized by highly demanding cost-reduction targets and by extremely high requirements with regard to the productivity of the production equipment.

Here all economic decisions at Daimler are made before the background of Ambition2039 as one of the most important corporate goals. For this reason we ask all suppliers to make their contribution to sustainability. Chapter 2. Energy Efficiency, Environmental Protection and (Work) Safety contains further explanations on *Ambition2039*.

In addition to the manufacturing-related optimization of the workpieces, there is an ongoing detailed revision of the technical standards of the production equipment.

The results are recorded in the following specifications:

➢ **Powertrain Requirement Specifications Part I**	**General Information**
➢ **Powertrain Requirement Specifications Part II**	**Mechanical Components**
➢ **Powertrain Requirement Specifications Part III**	**Electrical Components, Control Technology and Production-Oriented IT Systems**
➢ **Powertrain Requirement Specifications Part IV**	**Production Equipment**
➢ **Powertrain Requirement Specifications Part V**	**Documentation**
➢ **Powertrain Requirement Specifications Part VI**	**IT Security**
➢ **Powertrain Requirement Specifications**	**Workpiece-Specific Scope (created individually by the representative)**

The individual specifications may deviate from the optimum solution, but are considered as an economical measure within the overall system.

As a basic rule, any suggestions from our suppliers to improve the availability of production equipment or provide potential savings will be given careful consideration. Should you have any such suggestions, please do not hesitate to submit these to Daimler.

1.2. Validity and Obligations

These Requirement Specifications define the production equipment specifications "General Information" for all production sites and centers in the divisions

- Mercedes-Benz Cars Powertrain (abbreviated as "MO") of Mercedes-Benz AG and
- Daimler Trucks Powertrain (abbreviated as "Trucks") of Daimler Truck AG

and jointly referred to as "Daimler" in the following.

Compliance with the requirement specifications is binding and shall be confirmed in the bids. The requirement specifications valid at the time of the request for quotation are binding.

The requirements of MBN9666 shall be met. The specifications in these requirement specifications supplement the requirements of MBN9666.

If the vendor feels that deviations are required with regard to the individual points, this shall be indicated in the bid and approved in writing by DAIMLER. This also concerns the energy options requested in Chapter 2.2.1 Energy Checklist, which may conflict with the requirement specifications, however then the deviation must be explicitly pointed out.

The contractor shall ensure that all parties involved in the contract adhere to the latest Daimler regulations.
This tender document may not be disclosed to third parties without the prior consent of Daimler!

1.3. Record of Revisions

Version	Last revised:	Chapter:	Changed by:
2020	07/2020	• 1.2 The requirement specifications valid at the time of the request for quotation are binding • 1.9. Regulation on work safety and environmental protection revised • 2.1 Cost Book – changes to value limit Extended cost book for bids (≥ € 500,000.00) • 2.10 Written documentation with training content and archiving in the documentation • 3.0 Documents for Approval – updated • 5.0 Acceptance – adaptation of terminology/process • 5.1. Standardized Cars acceptance checklist	Participants in work package AP1.1 Fleischer
2021	03/2021	• 1.2 Deviation from standard for energy options – "Ambition 2039" • 2.0 Merging of energy efficiency, environmental protection and (work) safety • 2.2.1 Binding energy options in the energy checklist • PLS Trucks is omitted • 2.7 Taking into account of General Data Protection Regulation (GDPR) during employee briefing • 3.1 Obligatory showing of component prices from product partnership contracts	Participants in work package AP1.1 Fleischer

1.4. Changes from Version 2020 to Version 2021

Any changes in the Function Descriptions and significance from the previous version are indicated as follows:

- Newly added text is underlined (and also displayed in blue in the file).
- Deleted text is ~~crossed out~~.
- In both cases, the lines / paragraphs concerned are marked at the left margin by a vertical line.

Changes made for editorial reasons are not marked.

1.5. Contacts

Direct general or specific comprehension questions about the requirement specifications
to the following address:
LH1-Allgemeines@daimler.com
Support regarding order-specific questions – in accordance with the further processing/data processing-compliant procedure – is provided by the client's designated representative.

1.6. Identifications for Sites and/or Scopes of Validity

Unless otherwise indicated, the chapters/sections are mandatory for all sites and/or scopes of validity.
Examples:

- The chapter on power packs for supply and disposal systems has a limited scope:

...
Power pack for supply and disposal systems | 5
...

- The text passage applies to one site only:

...

In deviation from Appendix 22, a current measurement facility to be agreed upon separately shall be implemented for systems larger than 100 kVA. Y
current measuring setup is to be agreed upon separately, unlike with Appendix 22.
...
- The blank or missing identification field on the right indicates text that applies from here on to all sites and all scopes of validity:

...
2.1.1.1 Machine Connections
...

1.6.1. Sites

If validity is limited, the sites for which the chapter / section is **valid** are indicated as follows:

Code	Meaning
A	Plant 010 (throughout)
E	Plant 040, Berlin (MO/PT)
F	Plant 068, Hamburg (MO/PT)
G	Not assigned
W	Not assigned
X	Plants 030, 034, in Gaggenau, Axle production center/production center for converters, parts, sheet metal/Transmission production center (Trucks)
Y	Plant 069, Kassel, Axle PC (Trucks)
Z	Plant 020, Mannheim, Engine production center, Foundry production center (Trucks)

1.6.2. Scope of Validity

If the scope of validity is limited, the corresponding chapters / sections are identified as follows:

Code	Meaning
1	Mechanical production incl. machine linkages
2	Assembly incl. machine linkages
3	Test stands
4	Handling technology, sorting magazines, stock, shipping
5	Supply and disposal systems
6	Standard production equipment with workpiece-bound equipment and additional automation • Cycle-bound, set up in a concatenated manner, affects availability • Using large and medium standard control panels and control panel interface for connection to MDE/BDE SCADA system
7	Standard production equipment with workpiece-bound equipment and additional automation • Cycle-bound, set up in a concatenated manner, affects availability
8	• Standard production equipment
9	Washing machines

The range of validity of the requested machines has to be taken from the inquiry or requested from Daimler.
Codes 1 to 5 meet the requirements for all special machines as per MBN 9666.

1.7. Daimler Scope of Delivery Interface / Production Equipment Supplier

Interface **Responsible**

- Transport, installation and commissioning — Machine supplier
- Internal shipment — X Y Z

- Extraction of the machines — Daimler
- Connection for extraction at machine — Machine supplier
- Cooling lubricant supply and cleaning up to the machine — Daimler
- Cooling lubricant supply in machine — Machine supplier
- Cooling water up to the machine — Daimler
- Cooling lubricant high pressure and fine filtering — Machine supplier
- Compressed air up to the machine — Daimler
- Connection of the electrical power supply to the terminals in the main switching cabinet — Daimler

• Plinth for central or freestanding switching cabinets	Supplier of machine
• Cable ducts within the machine	Machine supplier
• Busbars (for assembly systems) with branch-off boxes	Machine supplier X Y Z
• and connecting cables including suspension	Daimler
• Chip disposal	See Requirement Specifications for workpiece-specific scopes
• CO_2 central unit	Daimler
• Connection flange for CO_2 system on machine	Machine supplier
• Foundations for machines and control cabinets, preparation of floor on site, floor passages	Daimler
• Hoists for maintenance, loading and unloading	Daimler
• Plinths for factory requirements, steps	Daimler
• Maintenance and repair platforms	Machine supplier
• Floor pans (if required)	Daimler
• Floor pans for cleaning systems	Machine supplier
• Chip conveyor in machine bed (if required)	Machine supplier
• Test benches	Daimler

1.8. Coloring

The paint type and the color shall conform to the specifications of MBN 9666.

1.9. Company Signs

The following conditions apply to machine manufacturer labels that are attached to production equipment:

1. 1 sign per side on the machine
   Exception: for larger systems, a sign is allowed every 50 meters
2. Maximum size: 800x400 mm
3. Attachment of company logos to control cabinets and machine parts is not allowed.

1.10. Special Components

If exemptions are made for the use of components, it should be ensured that these components or 100% compatible components can still be procured for a period of up to 10 years as of the absence of defects.
If this cannot be ensured, for each of these critical component parts a replacement part shall be supplied.
If components are subject to customer protection at the manufacturer, they shall be replaced by standard components. If this is not possible for technical reasons, such protection shall be lifted to allow us to procure replacement parts. Affected components shall be separately listed and submitted for approval...."
In the case of the demonstrable failure to provide such delivery, Daimler reserves the right, even after such a period has elapsed, to charge the machine supplier the conversion costs which become necessary owing to the non-availability of replacement parts.
If the subsequent machining of purchased and standard parts cannot be avoided, then the component in question shall be correspondingly identified in the parts list and the production/modification drawing shall be supplied.

1.11.

2. Energy Efficiency, Environmental Protection and (Work) Safety:

2.1. Energy Efficiency

For Daimler, economic, ecological and social responsibility belong together, i.e. along the entire value chain. Until 2039 Daimler will strive for CO_2-neutral production at all plants and in all divisions worldwide.
In order to also structure the manufacturing of our vehicles as environmentally friendly as possible, Daimler is banking on the responsible use of resources – from water to energy to the raw materials used – in the entire production process. Here the Sustainable Development Goals of the United Nations and the ten principles of the UN Global Compact, with which Daimler as a founding member is especially connected, serve as guidelines.
Daimler's production equipment suppliers have a very important and direct leverage on the two goals 'climate protection and air pollution control' and 'resource conservation'. Only together is it possible to meet the demands of producing with the most modern and resource-saving equipment. Therefore, when designing the means of production and submitting bids, the goal is to focus on resource conservation.

The following applies for Mercedes-Benz Cars & Vans: A E F
With regard to the reduction, Mercedes-Benz Cars & Vans has set the intermediate goal of reducing the absolute CO_2 emissions by 50 percent by 2030 compared to 2018.
Specific goals of Mercedes-Benz passenger car and van plants until 2030 are:

- Reduction of the energy consumption per vehicle by 43%
- Reduction of the water consumption per vehicle by 33%
- Reduction of the waste quantity for disposal per vehicle by 43%

These goals apply to the newly industrialized facilities to be built. Therefore, when designing the means of production and submitting bids, the goal is to focus on resource conservation.

~~2.1.~~2.2. Specifications for Energy Saving and Increasing Energy Efficiency

Energy saving and increasing energy efficiency are important objectives in the design and optimization of production at Daimler.

In this regard, the design and execution of our production equipment also make a significant contribution. To ensure optimum implementation and optimization, the scopes relevant for energy consumption are defined as standard in the corresponding chapters of the Requirement Specifications.

In addition, vendors are requested to confirm the adherence to and if necessary the concrete implementation of energy-relevant topics as part of bid creation using the attached

"Energy Checklist for Production Equipment"

The filled-out energy checklist is to be sent to the respective responsible representative/planner. This person then has the collected energy checklists of an order for scopes from the Car area MO/PT plants
010 (Untertürkheim),
040 (Berlin-Marienfelde),
068 (Hamburg),
516 (Kölleda)

shall be sent to the e-mail address energieeffizienz.powertrain@daimler.com

or

for scopes from the Truck area TG/MP plants
020 (Mannheim),
030 (Gaggenau),

034 (Gaggenau, Rastatt plant section),
069 (Kassel)

to the e-mail address energie-checkliste-trucks@daimler.com

Without submitting the complete energy checklist, a vendor cannot be taken into consideration in the procurement process. The consumption figures are relevant to decision making.

In compliance with VDMA standard sheet 34179, the supplier undertakes to measure the consumption values through the time of acceptance on Daimler's premises ("on campus"). They shall likewise be documented in the energy checklist under "measurement value" and shall be sent to the representative/planner and to the aforementioned respective email address. If the consumption specifications are exceeded by the measurement values, Daimler reserves the right to take additional steps.
In measuring and proceeding with the energy data determination, we recommend employing the VDMA standard sheet with "Measuring Instructions for Determining the Energy and Substance Requirements of Machine Tools in Series Production".
Version VDMA 34719:2019-04 was published in the DIN communications.

To achieve this goal, energy savings need to be realized in the procurement process for new systems and equipment.

The energy requirement can be reduced across all energy carriers (electrical energy, natural gas, operating heat, etc.) and consumed substances (compressed air, coolants, cooling lubricants, process exhaust air).
All options for increasing energy efficiency are to be offered. In principle, the options are to be listed separately and with the relevant potential savings in the bid/cost book.
The energy efficiency of the scope of delivery is included as one of several decision criteria and plays a role in the selection of the supplier.

Besides the genera requirements, the following also applies to Mercedes-Benz Cars:
The objective is to reduce the energy consumption per vehicle by **43%** in production by 2030 (reference point = average value from 2013/2014).
Insofar as Daimler specifies targets in the energy checklist form, the objective is that the planned levels and measurement values match these targets. If the target is not attained, the supplier shall explain why this attainment is not possible.
Should no targets be available, the supplier is nevertheless required to offer all possible ways to increase energy efficiency in order to make a due contribution to achieving the overall goal (-43%).
The options listed in the bid / cost book (potential savings) shall moreover be entered in the energy checklist.

In addition to the scope in the Requirement Specifications, Part III, Chapter 3.5.2.3, the following shall be kept in mind when determining energy consumption and energy efficiency in plants:

- All natural gas consumers shall be measured
- To be measured are the energy consumption levels of all facilities of tax-relevant systems irrespective of the substances and methods employed. - Example: processes for metal treatment, heating and melting (hardening facilities, tempering facilities, metal melting, die-casting facilities, galvanic processes, electrically heated industrial washing facilities, etc.). In this case, only those consumptions may be measured which are used for machining the parts, e.g. the electricity for Automation/Daisy Chain/Control may not be measured with them.
  Applies only to the German plants!

Site-specific specifications shall be considered in linking to the overriding energy data management system.
The contractor shall make sure that all those involved in the contract comply with the current requirements of Daimler.

~~2.1.1.~~2.2.1. Production Equipment Energy Checklist (Form 7)

Within the context of the quotation, the energy and media consumption shall be specified within the energy checklist (as a measurement result, empirical value or expert estimate).

In addition, binding additional energy saving option shall be offered in this energy checklist (see Energy option 1-3 in the energy checklist). Should no further technically possible energy options exist, please specify this in the list.
There is no binding to the requirement specifications for the submission of energy options. If the options do not meet the specification requirements, this must be noted accordingly. The optional commissioning of the additional energy options is reviewed internally and is subject to approval by the client.

Further information to be included in the energy checklist is found in the form under the "Definitions" tab.
For bids > EUR 200,000 (including for reuse measures) the submission of/request for an energy checklist is essential.
For reuse measures for predominantly mechanical scopes (>70%), the energy checklist can be omitted.

A E F

~~2.1.2.~~2.2.2. Contact at Mercedes-Benz Cars Plants

mailto: energieeffizienz.powertrain@daimler.com

X Y Z

~~2.1.3.~~2.2.3. Contact at Daimler Trucks

mailto: energie-checkliste-trucks@daimler.com
Fax: +49 (0)711-17-7906-1440

~~2.2.~~2.3. Environmental Protection

Machines and systems are to be designed and configured in compliance with German environmental regulations.

Systems for handling substances detrimental to water quality (systems as defined in WHG § 62) are to be constructed according to the specifications set forth in the WHG and the AwSV. Such systems may be operated only by specialist WHG enterprises. The manufacturer must send the specialist enterprise certificate to the ordering department when the order is placed, at the latest. (A site-specific process applies to UT).
Before setup, the water protection measures (e.g. secondary protection) are to be agreed in good time with the representative.
The amount of waste water is to be reduced and verified by means of calculation (e.g. by circuit systems, cascade flushes, multiple use, etc.) at all systems according to the specifications of the Water Resources Act (in particular §7 WHG) and the Waste Water Ordinance (AbwV) – in this case Appendix 40 in particular.
Systems in which waste water containing oil may accumulate shall be equipped with an oil separator of sufficient size. If a central technical device (e.g. ultra filtration system) exits, provisions should be made to connect it to the industrial water network.
Drainage of the waste water is to be coordinated with the representative . If a connection to an existing industrial water network is not possible, connections for the extraction of the waste water shall be provided at easily accessible, secured points.
The supplier shall specify the expected waste water volumes and content materials.

Machines and systems shall meet the requirements of the federal law concerning immission protection (BImSchG) and shall be planned and set up in accordance with state of the art.
Any harmful environmental influences or considerable disturbance of the public or the neighborhood due to air pollution, vibrations or noise are to be avoided largely. The site-specific requirements (in particular with regard to noise emissions) are to be taken into account here.
Furthermore, the requirements of the respective ordinances on the implementation of the federal law concerning immission protection (BImSchG) and the technical instructions for the prevention of air pollution (German Clean Air Act) and for noise abatement apply.
When selecting exhaust air filters, it should be made sure that they are regenerative as far as possible to minimize the accumulation of waste.
The system manufacturer or supplier should take these measurements independently at a legally approved measuring point.
The system manufacturer should create the required measurement sections and measuring stations in the current version in line with the respective measurement task according to DIN EN 15259.
Systems causing noise emissions shall be assessed in terms of sound prior to commissioning.

The principle of the German Resource Cycle and Waste Management Act (KrW) for the extensive avoidance of waste should be adhered to. The machine/system should be designed in such a manner to allow any accumulated waste, such as chips, process baths, cooling lubricant, sludge, etc. to be simply removed from the machine, segregated for recycling. Low-waste system (e.g. renewable or backflushable filters) should be used when using filter systems.
The supplier is required to provide information about the type, condition and composition of the waste and system parts that occur (e.g. filter materials, insulation, seals). Furthermore, the system manufacturer is requested to contact the representative in good time in order to agree upon the disposal concept (e.g. type/size of waste receptacles, collection/recording systems, collection frequency).

~~2.3.~~2.4. Work Safety

When executing the order, the contractor shall, in accordance with the Product Safety Act, observe all laws and legal regulations as well as technical and other standards, including Daimler-specific work safety rules, that apply at the time of market placement, insofar as they concern the scope of delivery.
In this regard, the applicable chapters of the **Work Safety Guideline** are to be taken into account.

For systems that are interlinked in terms of production and safety, a CE mark and the EC/EU Declaration of Conformity shall be issued by the general contractor for the entire system. If no general contractor is required after prior agreement between the client and the representative, the contractor shall prepare a CE mark and EC/EU Declaration of Conformity for each machine that can be used independently.
If the contractor realizes that an overall conformity is required, this must be communicated to the client immediately.
When submitting the CE/EU Declaration of Conformity for an entire system (several machines, automation, labeling devices, etc.), a statement shall be supplied specifying which individual machines and systems belong to the entire system (if there are several machines, the identification of the individual machines shall be specified in the statement; list with specification of the MB inventory no.).
Daimler shall be accorded an inspection, on demand, of the risk assessment performed by the contractor for the machine/system (as per ISO 12100), in particular also for interfaces to loading and unloading systems as per the Machinery Directive. It shall also include the risk assessments of the sub-suppliers of a manufacturer.

Conversion of production equipment:
Before any conversion work on a machine, the changes must be evaluated by the contractor. The result of the evaluation is a classification into significant or insignificant changes. This must be certified in accordance with the form (Conversion Declaration, Form 11).
In the case of an insignificant change, the scope of change must comply with the relevant applicable European Directives and/or the German Product Safety Act incl. DGUV (German Statutory Accident Insurance) Regulation 3. Following any significant change to a system as part of a conversion, the system is regarded as being placed on the market for the first time and must comply with current directives in full. The technical documentation in the appendix shall be revised (declarations of installation for partly completed machinery, etc.)

Safety functions of machines and systems in accordance with DIN EN ISO 13849-1 "Safety of machinery - Safety-related parts of control systems":
An overview shall be provided in the technical documentation of the implemented safety functions of the control system to DIN EN 13849, including the achieved Performance Level (PL) ($PL_{Nominal}$ - PL_{Actual} incl. block diagram). A detailed determination of the PL shall be submitted upon request (e.g. using the Sistema documentation). This shall also include the defined fault exclusions.

Systems in need of monitoring and requiring checking:
The manufacturer shall provide a general list of all system and system components in need of monitoring and requiring checking (pursuant to the Ordinance on Industrial Safety), such as pressure devices, ATEX devices, contactless safety systems, lifting gear and load-carrying devices.
The listing is to be attached to the technical documentation.

~~2.3.1.~~2.4.1. Noise and Vibration

MBN 9666-1, 5.6 Noise specifies that the workplace-related emission value and the measuring surface sound-pressure level at 1 m measuring distance be below 75 dB(A).

The workstation-related emission value and the 1 m measuring surface sound pressure level are determined according to DIN EN ISO 3740 "Acoustics - Determination of sound power levels of noise sources" and the respective applicable subsequent parts.
Peak sound pressure levels Lp, Cpeak of 137 dB(C) shall not be reached at any time.

~~2.3.2.~~2.4.2. Sound Pressure Level Measurement upon Acceptance of Production Equipment

1. Set the measuring device to LAeq and F (fast)
2. A minimum of 4 measuring points shall be placed on a virtual enveloping surface at a distance of 1 m from the production equipment. Additional measurement points may need to be selected, e.g. with larger production equipment, across from a processing station in each case. Here, it shall be ensured that each measuring point is representative of an approximately equal sub-area. With relevant sound radiation upwards, (at least) one measuring point above the production equipment shall also be considered. In addition, measurements at the workstation/operating station of the production equipment shall be performed.
3. At each measuring point the total sound pressure level and if applicable also the external noise level (with production equipment fully turned off) shall be measured. Each measurement extends at least over one complete machine cycle/machining cycle; generally several complete cycles should be recorded, however.
4. Specification of the total sound pressure level and if applicable specification of the external noise level and external noise correction. Calculation of the mean measuring area sound pressure level of the examined production equipment and workstation-related emission level.
5. Determination of the environmental correction k2. For the sake of simplification, the following values may be assumed here: no spatial reflections ("green meadow": 0 dB; low machine density: 1 dB, "normal" machine density: 2 dB, near reflecting surfaces (other machines, spatial boundaries): 3 dB
6. Calculation of the adjusted levels
7. The sound level measurement log shall be appended to the machine documentation.

~~2.3.3.~~2.4.3. Hand-Arm Vibrations and Whole-Body Vibrations

The production equipment shall generally be constituted in such a way that the tripping values of 2.5 m/s² for hand-arm vibrations and 0.5 m/s² for whole body vibrations are not reached at any time during the scheduled daily dwell time according to § 9 of the noise vibration labor safety regulations. Deviations from this are only permissible in justified exceptional cases and after prior agreement with the representative. The explosion limit values according to §9 of the noise vibration labor safety regulations of 5.0 m/s² for hand/arm vibrations and 0.8 m/s² for whole-body vibrations in a vertical direction and 1.15 m/s² for whole-body vibrations in a horizontal direction may not be exceeded under any circumstances

~~2.4.~~2.5. Workplace Design, Ergonomics

The workplaces within the production area, e.g. machine and assembly workplaces, are to be designed in accordance with DIN-EN 614-1. For work-related physiological reasons, workplaces for seated or standing operation are preferable.

~~2.5.~~2.6. Employee Briefing/Training

Instruction of the operating and maintenance personnel must be included in the machine price.
Briefing shall take place in accordance with the operating manual. It shall include operation of the machine in all operating modes – in particular the use of the mobile operating unit, troubleshooting, etc., as well as notes on environmentally relevant (German Ordinance on Facilities Handling Substances that are Hazardous to Water (AwSV), etc.), safety-related and energy efficiency (use of the energy manager) aspects.
Instruction shall be documented in writing and appended to the documentation. The contents of the instruction, date, instructed employees (with signature), etc., and the instructing person shall be specified.
According to the General Data Protection Regulation (GDPR), the contractor shall ensure that the data are deleted after 15 years at the latest.
The employees to be trained shall be made aware of the documentation of personal data and duration of storage.
Intended use: Accountability for qualification.

The qualification requirements for special processes are to be additionally coordinated with the representative under inclusion of the Material and Process Technology department of the respective Daimler plant.

Training shall be planned and offered accordingly for the following exemplary phases.
1. Setup phase on the manufacturer's premises
2. Commissioning phase on the manufacturer's premises
3. Set-up phase at Daimler
4. Commissioning phase at Daimler

The bid shall specify the cost of training per working day stating the maximum number of participants and the duration of training.

PLS Trucks has been removed. X Y Z

3. Bid Form

Proof of expertise is to be submitted (electroplating systems, cleaning systems, etc.) according to the Water Resources Act. An incomplete bid cannot be considered.
The following documents and information shall be submitted together with the bid.

3.1. Tender Details - Cost Book

Along with the bid, the vendor shall submit:

- The following applies to MB Cars: a completed extended cost book for bids (≥ € 500,000.00) as an Excel file with all column content and with a row structure as specified in the request for quotation.
- The following applies to Daimler Trucks: completed basic cost book (> € 500,000.00) or an extended cost book (> € 2,500,000.00) as an Excel file with all column content and with a row structure as specified in the request for quotation. If need be, an extended cost book may be requested irrespective of the value limit. This is specified in the request for quotation. X Y Z
- The calculated hourly charge rates are to be entered in the headers of the relevant column in the extended cost book.
- In the case of non-linear hourly rates, the individual service types are to be listed separately in the header data tab, e.g. turning, milling, grinding, ...,

Unterschiedliche Stundensätze für Konstruktion, Montage etc., bezogen auf die
Spalten bei "Hauptauftrag/Nachtrag..", können wie folgt angegeben werden:

Konstrukteur 1	*XX €*	*Monteur 1*	*XX €*
Konstrukteur 2	*XX €*	*Monteur 2*	*XX €*
Konstrukteur 3	*XX €*	*Monteur 3*	*XX €*
Dreher	*XX €*	*Programmierer 1*	*XX €*
Fräser	*XX €*	*Programmierer 2*	*XX €*
Schleifer	*XX €*	*Projektierer*	*XX €*
xxxxxxxx	*XX €*	*xxxxxxxx*	*XX €*

- Services per sub-supplier are to be listed in the relevant separate rows with reference to the supplied or installed machine parts and components.
- Hourly rates of sub-suppliers are to be added in the "Header data" tab of the associated matrix in accordance with the service column.

	Konstruktion			Fertigung	Aufbau	Inbetrieb-nahme	Programmierung CNC	Programmierung Roboter/SPS	Programmierung CNC	Programmierung Roboter/SPS	Aufbau	Inbetrieb-nahme
	mechanisch/ hydraulisch/ pneumatisch	elektrisch	Dokumentation	mechanisch/ elektrisch	Beim Lieferanten	Beim Lieferanten	Beim Lieferanten	Beim Lieferanten	Bei Daimler	Bei Daimler	Bei Daimler	Bei Daimler
Unterlieferant A	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €
Unterlieferant B	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €
Unterlieferant C	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €

- Calculated surcharges on purchased parts and services rendered by subcontractors.

Zuschläge auf Kaufteile:	0,00 %
Zuschläge auf Fremdleistungen:	0,00 %

A full cost book is to be supplied with the order confirmation, i.e. an extended cost book with all column and row content as an Excel file. The project total in the cost book must add up to the bid value and, taking the agreed-upon price reduction into account, the net value as ordered. In the case of machine/system conversions, the full cost book must be submitted with the bid for the request.

In the cases of changes, conversions or retrofit measures, the full cost book shall be used as the basis for checking prices.

Minimum level of detail of the detailed schedule of prices:

- Standard/system components, assemblies and relevant components of the systems shall appear with individual costs. Services and hardware from sub-suppliers shall appear in rows accompanied with further details if necessary.
- The general contractor/subcontractor shall provide the client with all components from Daimler product partnership contracts included in the bid, including individual parts (with individual prices and quantities) in tabular form.
  Product partnerships:
  - Truck: Siemens, Fanuc, SEW, Bosch Rexroth, Apex, Atlas Copco
  - Cars: Siemens, Fanuc, SEW, Bosch Rexroth, Apex
- If there is an extended cost book, the degree of detail shall be adopted from it and added to the status of the order. The item numbering of the extended cost book should be applied in the bid.
- If there is no extended cost book, the breakdown, including item structure, shall be taken from the bid in the full cost book. Each detail row shall indicate prices in columns and as item prices.

The representative shall provide a project-specific "extended/full cost book" (based on PP/PT index) as a basis for structure and details.

Changed/Supplementary Bids
All changes to the scope of supply and services ordered in the main job are to be offered in a separate subsequent order based on the detailed offer detailing (full cost book) of the main order and are to be detailed and calculated in an identical manner in the cost book under "Supplements".

Supplements are to be calculated with a detailed verification based on the main bid:

- Checkable price detailing taking the calculation basis of the main bid into account.
- Itemized breakdown with reference to identical or similar scopes to the main bid.
- Reasoning for the change shown if not ordered by Daimler.
- Planned parts and components shall be entered with quantities and quantity units.
- Items removed from the main order are to be included in the supplement with a negative quantity, quantity unit and price.
- Cost totals of the supplements are to be shown with the resulting increased or reduced costs.
- Order designation, type and design are to be stored for purchased parts of suppliers/sub-suppliers.

3.2. Plans and Drawings

3.2.1. Machine Layout with Sequence and Function Description of the System

1. Which substances are required, e.g. emulsion, oil, DI water, compressed air with specification of average requirement.
2. Connected load in kW of the entire machine and energy consumption for an internal availability of 95% in the agreed-upon cycle time and k=0.8 per hour as a measure of heat output.
3. System dimensions in length/width/height

4. Total weight of the system
5. Exhaust requirements of the overall machine
6. Indication of where support checks are planned
7. Indication of whether hydraulic, electrical, mechanical or NC unit (where necessary, indication of whether rod transducer or glass scale)
8. Loading/unloading height or, in the case of manual operations, the working height
9. Position of the workpiece in each station
10. Indication of where a measuring station (pneumatic, electric or mechanical) is employed
11. Indication of "not OK" belts
12. Information on the configuration of test stations also indicating the test location
13. Number and configuration of control cabinets
14. Work description for each unit
15. Is lifting gear to be provided (offer as option)
16. Installation, foundation and floor pan diagram
17. Transport dimensions and weights
18. Indication of hazardous goods and materials used
19. List of systems or system components that must be monitored, particularly pressure devices as per Directive 97/23/EC
20. Function description of:
    a. Straight ahead running
    b. Reworking processes
    c. Special sequences
    d. Station designations
    e. Visualization and operation concept
    f. Control architecture / network overview
    g. Workpiece carrier
    h. Data medium concept
    i. Definition of the Emergency Stop concept
    j. Description of the switching on and off systems (local and remote)
    k. Definition of workpiece type spectrum for PRISMA
    l. Communication/interfaces with superordinate IT (derived from the function description, points a - f)
    m. Quality data overview (station-related)
    n. Description of the software structure with reference to the project book of the respective product partner and description of the OEM components

3.2.2. Tool Plan Drafts, DIN A3, with the Following Information

1. Graphical representation of the points on the workpiece to be machined, also specifying the number of machining points
2. Specification of cutting data
3. Drawings of the tool in engagement (cutting edge, holder, clamping tools, spindle type, distance between bearing and cutting edge (bearing type in case of nonstandard spindles)
4. Indication of the coolant supply (internal cooling, dry machining, etc.)
5. Indication of coolant pressure and quantity in case of internal coolant supply
6. Description of the machining process
7. Indication of machine no. and station, position of units, where appropriate
8. Special machining instructions
9. In case of multi-spindle heads, which spindles are used
10. Direction of rotation of spindle
11. Milling direction
12. Workpiece numbers
13. The tool concept and tool manufacturer are to be coordinated with the client.
14. Written statements are to be submitted on the number of pieces per tool and tool costs per part.
15. Clamping Diagrams of Each Clamping and Diagrams of Initial Clamping, Clamping and Bearing Points

3.3. Cycle Time Determination and Capacity Utilization Diagram Per Machine

- MTM analysis for systems with high proportions of manual activities.
- Timing diagram (transfer, clamping, etc.) for automatic stations.
- For quantity and cycle time calculations, times for "not OK" messages and loading of a station during the automatic cycle, etc. must be taken into consideration. Additionally, the times for machine set up, preventive maintenance and repair must be specified and deducted from the total planning quantity.
- An operating rate diagram is enclosed as a sample in Appendix 3 (each unit shall be presented in detail).

3.4. Simulation - Availability

For all concatenated production systems, simulations must be drawn up e.g. to certify the feasibility of the agreed-upon EE/OEE and the number of units/cycle time.
These simulations are to be drawn up in accordance with "Powertrain Material Flow and Process Simulation Requirement Specifications Version_4.0".

Further details will be specified in agreement with the representative, e.g. the requirements for partial scopes of the production system (if the contract is awarded without GC), the degree of detail of the simulation and the schedule for the presentation of the results and handing over of the model. These details will be specified by the representative in the "Powertrain Material Flow and Process Simulation Requirement Specifications, Project-specific Requirements Version_4.0".
For the performance of the simulation runs, the representative shall provide the planned shift model, the planned number of employees, the interference range and other input data for the simulation which cannot be influenced by the order placement.
The supplier bears responsibility for availabilities (e.g. of the EE/OEE number), cycle and setup times as well as the quantity of tools and changeover times that are required to satisfy requirements.
The parameterized simulation model is to be handed over to the representative after completion of the simulation studies, including the documentation.

X Y Z

3.5. Service Agreement (Trucks)

The Service Agreement (in general section under Forms/Sample Service Agreement) shall be complied with and signed and submitted to the respective representative prior to contract award. No sourcing shall be undertaken without a signed service agreement.

3.6. Visualization of the Machining Function

For machine tools, the processing of which cannot be seen, video monitoring of the working compartment shall be provided for assistance. Both a stationary solution for continuous use and a portable solution, which can be used on different units, depending on the case, shall be provided.
For interlinked systems, a bid shall be submitted for a completely executable NC simulation. Individual OPs (e.g. transfer units) may be excluded after consultation.
After the contract award, the simulation scenarios shall be submitted in SIEMENS PLM TECNOMATIX format (for eM-RealNC). The simulation scenarios shall be available no later than one week prior to release for dispatch along with the NC programs.

3.7. Price Structure of Bid

All prices shall be stated individually for all machines/equipment as follows:

- Structure corresponding to the standard template or extended cost book, where the 2nd grouping level of the standard template can/shall be used as price component / price sheet of the bid
- Machines and systems in standard design.
- Additional price for Powertrain Requirement Specifications (for information purposes as total value excluding the quotation total, see standard template)
- All required tools, individual price per tool, 1st set and, if available, 2nd and 3rd sets

- Installation and commissioning
- Employee training with regard to the aforementioned training content and phases (provided for information outside of the bid total, see standard template)
- Options shall be clearly identified as such and shall be listed separately.
- Costs of the proof of machine capability (MFU) for dispatch release.
- Indication of workpiece-specific unit prices in accordance with the requirements as specified in Requirement Specifications "Workpiece-specific Scope"
- Technical ramp-up support at the client's facility (for information purposes, excluding the quotation total, see standard template)
- 40 h production at the contractor
- Service contract

X Y Z

4. Documents for Approval That Must be Submitted by the Supplier after Contract Award

A Daimler-internal processing time of about 4 weeks is anticipated.

1. Detailed manufacturing equipment plans, foundation and floor pan plans, assembly plans including supply and disposal data with transfer points in the first third of the delivery period (no later than 2 months after awarding of contract).
2. Bill of materials with identifier (spare part / wear part / workpiece-adjacent parts) 6 weeks before machine delivery with specification of component manufacturers (acceptance criterion). The Excel format templates for bill of materials and order list are stored in the DocMaster/Daimler Supplier Portal.
3.
4. Project schedule
   The schedule for production equipment (see Form 01) shall be submitted to Daimler via the Daimler Supplier Portal and is mandatory.
5. The progress report as per Form 09 shall be signed, updated and transferred unsolicited every two weeks.
6. Note: Data for the production equipment card must already have been entered in the Daimler Supplier Portal (DiPro App) system. Z
   See also: data exchange between powertrain planning department and external suppliers via the production equipment portal (PEP). Data sheets, stating hazardous goods and working materials
7. System components requiring monitoring, and see Sicherheitseinrichtungen.xlsx Requirement Specifications, Part V, Documentation
8. The contractor is fully responsible for installations started prior to the approval.
9. Type approvals for collecting trays, volume calculations and, possibly, documents for environmental approval/license
10. Electrical circuit diagram with fluid diagram and corresponding parts lists as navigatable pdf file, as well as Excel list as per Requirement Specifications, Part V, Documentation.

4.1. Manufacturing Section Drawings

The supplier shall supply manufacturing cross-section drawings (also called measuring-point diagrams) with the following information:

1. Simple representation of the workpiece
2. Graphic representation of the machining scope of each machine
3. Presentation of the machining scope of each machine for multiple machining of a machining point (tool point TP)
4. Dimensions and tolerances matched to the manufacturing section (the tolerances are derived from the design drawing corresponding to the manufacturing section on the holder in the machine). If necessary, specific requirements shall be observed; see Requirements Specification "Workpiece-specific Scope")
5. Identification of axis directions (X, Y, Z in arrow direction +), consistent within a particular machine
6. Dimensions of machining points, with respect to the respective machining function
7. Designation of the machining points (TP = tool point) with numbering system for the machining point drawings (HBS plans) if available. Subject to amendments by the Daimler test planning team for measuring requirements

8. Presentation of support and holding points for each machining point in tabular format
9. Table list of the nominal sizes of every machining point (WP) according to the following criteria: X/Y/Z-coordinates, diameter, angle 1, angle 2, surface, design- and position tolerance, processing order of every station.
10. Drawings in accordance with Daimler standards
11. Data medium: original drawing as hard copy (max. A0, max. 3 sheets per machine scope) and in digital form as a CAD model in the following format: DWG or IGES or NX
12. Digital form of the production sections, see MBN81022 and Appendix _02_-_Powertrain Requirement Specifications, Cars, Digital Factory_1.0, re Requirement Specifications, Part V.

Organizational sequence of the manufacturing section drawings
1. The manufacturing section drawings are prepared by the machine supplier
2. The point of contact at Daimler is the person who issued the RFQ (representative)
3. Modification and updating of the manufacturing section drawings until the absence of defects in the production machine are carried out by the machine supplier
4. The manufacturing section drawings shall under all circumstances be submitted during the first third of the delivery period to the person who issued the RFQ. Otherwise, delays in acceptance owing to missing measuring programs and therefore delivery/delivery-time delays of the production equipment will occur.
5. The release of the manufacturing section drawing, and in particular of the tolerances, is performed by the test planning team subject to the correctness of the design penetration
   The original manufacturing section drawings shall be taken over by Quality Assurance for further use and administration

4.2. Production Release

In the course of the planning/design discussions, drawings of complex assemblies such as the following shall be explained and submitted for approval prior to the start of construction:
- Electrical and fluid technology
- Workpiece clamping devices
  Including documentation of the clamping concept on the initial plan of the approval drawing:
  - Schematic representation of all clamping positions including the initial clamping with the support, transport and mounting points, index mounts, supports, centering devices, play compensation for index bores, etc. in DIN A3 or DIN A4 format (on more than one sheet if necessary).
  - Identification of the supports, clamping points, etc.:
  - The clamping principle or the workpiece can be shown at a reduced scale (e.g. views from CAD 2D/3D model).
  - Key dimensions, such as the distance of the clamping point to the workpiece center (or index) are to be entered.
  - Description of the machines/stations in which the used device types are installed (in table)
- Slide units
- Working spindles, drives and internal coolant supply
- Work-area design, machine covers
- Workpiece handling, linkage
- Cleaning systems
- Deburring systems
- Marking systems
- Measurement, inspection and monitoring installations
- Component feed

to be defined and submitted for approval.

4.3. Provisions, Approvals

All services the client has to provide for the contractor as stipulated in contractual agreements and according to these Requirement Specifications are to be reported to the client by the contractor in good time to allow the order to be processed as scheduled.

4.4. Documents for Preventive Maintenance

Specifications regarding the scope of supply and the manner of supply are to be found in Part V of the documentation.

5. Acceptance of Production Equipment

During acceptance, the machine is checked to see that the specifications in the order have been implemented. In addition to work safety, the relevant departments are also usually included. This is to ensure that, in addition to the safety-relevant characteristics, the demands of maintenance and production are also fulfilled.
The acceptance process at Daimler is divided into the following main steps, which are explained in more detail in the next chapter:

- Release for dispatch (see Chapter 5.1)
- Operational system + acceptance (production breakpoint) (see Chapter 5.2)
- Confirmation of absence of defects (see Chapter 5.3)

The milestones for operational system + acceptance (production breakpoint) occur at the same time in Powertrain.

The acceptance of tool presetters is described in the Powertrain Requirement Specifications under "Tool Presetters".
The acceptance regarding material- and process-related requirements shall be coordinated with the representative with inclusion of the material and process technology department of the corresponding Daimler plant. This applies both to the quality criteria to be fulfilled (such as impermissible edge zone damage and surface conditions) as well as to the acceptance procedure. X Y Z

5.1. Release for Dispatch by Supplier

5.1.1. Condition for Conducting the Dispatch Release

1. Notification that the production equipment is ready

Trucks: The completed checklist (Form 4) shall be submitted to Daimler by the supplier prior to dispatch release. X Y Z
MB Cars: Unless otherwise agreed, the contractor shall submit the completed "Production equipment acceptance checklist" from the DocMaster system to Daimler at least five working days prior to the dispatch release. A E F
For the assessment, the checklist shall be filtered according to the release for dispatch and the status completed.
The non-confirmability of a status shall be explained/commentated.

2. Before dispatch acceptance, the contractor shall deliver 3 to 5 workpieces machined on the production equipment according to the agreed-upon cycle time and acceptance tolerance (with measurement logs) to Daimler for counter-measurement, if necessary along with the proof of machine capability examination (MFU).
3. The checklists for the MDE/BDE interfaces shall be provided to Daimler.

The production equipment shall be completely assembled, including the required loading and unloading devices as well as protective clothing. It shall be operable in the individual operating modes in functionally appropriate procedures. To produce this state, the supplier shall provide temporary equipment such as supply/discharge belts, workpiece stackers in case of gantries, interlinkages of individual stations for assembly, etc. as needed.

For the dispatch release, the documents shall be available as per the documentation part of the Requirement Specifications, Part V.

5.1.2. Conducting the Dispatch Release:

Inspection of the production equipment for compliance with the contractually agreed-upon properties, functionality, compliance with higher-ranking regulations, cycle time, safety, noise, environmental protection, Requirement Specifications, MDE/BDE interface, etc.
Testing of the accuracy of the production equipment using machined workpieces which have been machined within the offered cycle time.
Proof of quality by means of a Machine Capability Examination (MFU) A E F
The following limiting values are specified for this purpose:

Characteristics limited to two sides: cm $\geq$ 2.00 and cmk $\geq$ 1.67
Characteristics limited to one side: cmk $\geq$ 1.67
D characteristics: cmk > 2.0.

For characteristics that cannot be assessed with the MFU, a 70% tolerance utilization is allowed.
For in-process control, the full tolerance may be utilized.
If, after consulting with the representative, an MFU in connection with dispatch release is dispensed with, a maximum tolerance utilization of 55% is allowed. A 70% tolerance utilization is allowed for characteristics that at the process step of the operational system + acceptance cannot be assessed using MFU for acceptance by Daimler.
The following regulation applies if no form tolerances are specified:

- Roundness at fitted bores and mounting holes: perm. roundness error = diameter tolerance/2 (70% utilization for the process step of operational system + acceptance)
- Roughness criteria: max. 100% tolerance utilization

Power Q applies to the Truck plants. X Y Z
No residual dirt analysis is performed for cleaning equipment in the context of the dispatch release. A E F
In the event of insufficient availability of soiled almost-standard parts, a targeted inspection of soiled components is performed on site. The parts cleaned on the system shall be inspected regarding the cleaning/deburring result through an optical check (e.g. endoscopy).
Mannheim: The procedural instruction applies (procedural instruction for washing machine acceptance procedure). Z
Special processes such as casting, forging, welding, hardening, etc., are excepted from this.
Deviating acceptance procedures shall be agreed on beforehand with Daimler.
The documentation of dispatch release occurs in the production equipment acceptance certificate (dispatch release), which is prepared by Daimler AG and jointly signed by the supplier and Daimler.

In case shipping is not accepted, a "dispatch release" for the production equipment can be initiated by Daimler in exceptional cases for operational or time-related reasons.

Information shipment/installation of production equipment can be found in Form 06.

5.1.3. Retest

Daimler reserves the right to charge the supplier for the costs of dispatch release in the case of unsuccessful dispatch release for which the supplier was responsible.

The expected, individual costs:

- Travel expenses for employees of the client
- Vehicle, flight, rail, taxi
- Overnight accommodation incl. expenses
- Daimler personnel costs (according to Daimler charge rates)
- Measurement work: costs for measurement work in the course of the repeated acceptance at the client's premises

5.2. Operational System + Acceptance (production breakpoint)

The contractor shall report the operational system to the representative in writing.
MB Cars: Unless otherwise agreed, the contractor shall submit the completed "Production equipment acceptance checklist" from the DocMaster system to Daimler at least five working days prior to the notification of the operational system + acceptance.

A E F

For the assessment, the checklist shall be filtered according to the phase of operational system + acceptance and the status completed.
The non-confirmability of a status shall be explained/commentated.

Prerequisite for the operational system:
1. a successful MFU
2. no significant safety-related defects
   safety check by the client prior to commissioning
3. presence of the CE mark.
4. technically flawless and safe functioning of the production equipment
5. The defects listed in the production equipment acceptance certificate (dispatch release) are rectified.
6. The functioning of the sensors and interfaces to fire protection equipment is to be verified and documented by the supplier.
7. The supplier shall perform and document energy consumption measurements. The measurement results must be submitted to Daimler (see Chapter 2.3).

Confirmation of operational system is followed by acceptance.
Daimler shall document the recognized defects and the date of correction in the Production Equipment Acceptance Certificate.
Production equipment acceptance certificate = acceptance and confirmation of service rendered (signature flyleaf) including record of defects.
The contractor is the owner of the production equipment until completed acceptance. The contractor's technicians shall be present up to acceptance at Daimler.

A E F

5.2.1. Proof of Machine Capability (MFU)

Testing of the accuracy of the production equipment using workpieces which have been produced within the specified cycle time. A maximum of only 55% of the allowable tolerance may be utilized. 70% (Truck: 60%) tolerance exploitation is permissible in the case of characteristics not assessed by means of the MFU.
For cleaning equipment, compliance with the required component-specific residual dirt limit values shall be verified by the supplier by means of a residual dirt analysis after integration into the process environment with original washing agent and originally soiled component parts from previous machining.

During this test, at least 50 workpieces are machined in succession with an optimally set machine operating at normal temperature. The workpieces are measured by Daimler and the measured values are evaluated with the qs-STAT program in the respective applicable Daimler configuration.
For the truck plants, Appendix 12 (Process Capability List of Requirements) and Appendix 13 (Transfer of Quality Data to QDA).

X Y Z

A E F

The following limiting values are specified for this purpose:
- Characteristics limited on two sides: cm ≥ 2.00 and cmk ≥ 1.67
- Characteristics limited to one side: cmk ≥ 1.67
- D characteristics: cmk > 2.0

Deviating values shall be defined and documented during the planning phase by the representative with the involvement of the test planning team.
If fewer than 50 workpieces are available, the MFU may be conducted with a lower number of workpieces but with a higher cmk value. These values can be taken from the following table.

Quantity	c_{mk} limit
50	1.67
40	1.78

30	1.96
20	2.36
15	2.81

For machines with in-process or post-process measurement control, machine capability testing shall be carried out with enabled measurement control equipment.
During machine capability testing, the supplier shall document and submit the process parameters, cycle time and used tools.
Detailed execution shall be taken from Daimler guideline LF 1236 "Random Sample and Process Analysis". (Appendix 2)
Power Q applies to the Truck plants.

X Y Z

Repeat investigation (MFU):

A E F

In the event of an unsuccessful MFU caused by the supplier, we reserve the right to invoice the supplier for the costs of the additional investigation.
The expected, individual costs:

- Daimler personnel costs (according to Daimler charge rates)
- Costs for measurement work during the course of retesting at the client's premises

A E F

5.2.2. Verification of Measuring Instrument Capability

Proof of measuring device capability shall be furnished in the case of measuring machines/equipment.
In doing so:

- The cg/cgk value determined according to procedure 1 shall be ≥ 1.33
- The % GRR value determined according to procedure 2 in the event of operator intervention shall be ≤ 20%
- The % GRR = % EV value determined according to procedure 3 without operator intervention shall be ≤ 20%

For dedicated workpiece measuring equipment, the following shall be provided based on the nominal dimensions of the characteristics to be measured together with the associated tolerances and form/position deviations:

- A suitable measurement-taking procedure (static/dynamic measurement)
- An appropriate resolution for the measuring sensor
- A suitable number of measuring points

This shall be done for each characteristic and in consideration of influencing ambient factors, the purpose being to ensure a high degree of comparability to the respective reference measurement for the particular characteristic (normally determined by means of a coordinate measuring machine). The selection/solution shall be coordinated with the representative.
The measurement values shall be evaluated with the Solara program using the valid MBC evaluation configuration.
For the truck plants, Appendix 13 (Transfer of Quality Data to QDA) shall apply.

X Y Z

The results shall be documented as a report with the overview forms of V1 and V2 or V3.

A E F

Detailed information can be taken from Daimler Guideline 5 "Proof of Suitability of Test Processes".
The proof of capability (two-dimensional) of balancing machines is described in LF51 (Appendix 1).
Power Q applies to the Truck plants.

X Y Z

A E F

5.2.3. Proof of Availability

The proof of availability is carried out after a successful MFU.
With this proof of availability, internal availability of the individual machine of at least 95% shall be proven over a period of at least ten shifts. With complex, interlinked systems such as assembly systems, proof shall be furnished of 95% availability for the individual stations as well as the contractually agreed output (number of workpieces) for the entire system. For machining centers (BAZs), an availability of 97% is required.
For the entire duration of the proof run, Daimler employees are present at the machines. The supplier is free to accompany this proof run with its own personnel.
The availability test shall be conducted at the latest after a regular shift pattern has been established, using analysis systems cleared for use in Daimler, e.g. PRISMA. The time frame is specified by Daimler.

Here, the internal availability is calculated using the following formula:

$$IV = \frac{\text{"Operational"}}{\text{"Operational" + malfunction duration without waiting}}$$

Inner availability shows the ratio of malfunctions that occur with repairs
(without waiting time) to the operability of the machine

Truck area: X Y Z

The availability is verified during the production support as far as possible. The date is defined by Daimler.

- Availability shall be certified per operation including automatic loading and unloading
- For turnkey systems, the initial condition shall be established as follows:
- Filled by up to 100%
- Decoupling modules filled by 50%
- There is a machined and finished workpiece in the machining tools, ready for unloading
- Warming up of the systems 30 minutes before each shift starts
- The manufacturer shall ensure that the production equipment is in perfect condition before carrying out the availability certification.

5.2.4. Areas with Automatic Operating Data Acquisition

The automatic recording and documentation of malfunctions is carried out through the connection of the production equipment to Daimler's MDE/BDE control systems, e.g. to the "Production Information System for Machines and Systems" (PRISMA).

5.2.5. Areas without Automatic Production Data Acquisition

Operating times and downtimes are recorded manually and are used to calculate the internal availability.

5.3. Confirmation of Absence of Defects

Confirmation of the absence of defects takes place after all the defects/deficiencies listed in the Production Equipment Acceptance Certificate (Acceptance) have been remedied by the supplier. If, at this time, regular shift operation is in place, fulfillment of the availability requirement is also crucial.

5.4. Warranty

The warranty begins after the documented acceptance.
Defects occurring after the acceptance inspection shall be rectified as part of the warranty scope.

5.5. Warranty Support and Cost Allocation

No contract award shall take place without a signed warranty and cost accounting agreement in the general part (forms/samples).
Damage cases shall be immediately reported to the machine supplier on a form (see form 02).
To promptly coordinate the further procedure, Daimler will telephone the machine supplier parallel to sending written notification.
In coordination with the machine supplier, the repair will be started by the Maintenance department until the machine supplier arrives.
(For the process, see Appendix 09).
In the event of external personnel deployment and procurement of parts from an external source, the production equipment manufacturer will be charged the corresponding costs.
With the deployment of Daimler staff as well as with the manufacture of spare parts by Daimler, costs will be charged at the current Daimler hourly rates.
Repairs that, for the aforementioned reasons, must be carried out by Daimler do not affect the remaining warranty in any way.

5.5.1. Appendix Directory for Part I

- Part I General folder
    - Measuring system proof of capability

- Machine capability examination
- PowerQ – excerpt from process capability manual in Manufacturing and Assembly (Trucks)

- Sub-folder, Appendices for Part I – see chapter 6.1
- Sub-folder, forms – see chapter 6.1
- Sub-folder, work safety
  - Project guidelines for work safety
- Material flow simulation
  - Powertrain Material Flow and Process Simulation Requirement Specifications_4.0

6. Appendix

6.1. Appendices & Forms for Powertrain Requirement Specifications Part 1

Appendix No. of pages

Form No. of pages

6.2. Abbreviations

Abbreviation	Explanation
BQF	Approval of source of supply (Bezugsquellenfreigabe)
BTG	Assembly (Bauteilgruppe)
ETK	Theoretically expected amount for replacement parts during the contractual production period ($T_{prod.tot}$)
FG	Function Group
CMM	Coordinate measuring machine
CIP	Continuous improvement process
LD	Service life (Lebensdauer)
MBN	MB standard (Mercedes-Benz Werknorm)
PS	Purchasing Service
WB	Replacement value (Wiederbeschaffungswert)

6.3. Index of Terms

Proof of Capability of Measurement Processes

Guideline LF 5

Version 2013/1

Mercedes-Benz Plants in Berlin, Hamburg and Untertürkheim

Quality Management

Mercedes-Benz Plants in Berlin, Hamburg and Untertürkheim
Quality Management

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Notes on procurement:	In the Intranet via the DocMaster and in the Measuring Technology Manual Accompanying document of PPA Requirement Specifications (CD-ROM)

Title **LF 5**

Verification of Capability of Measurement Processes

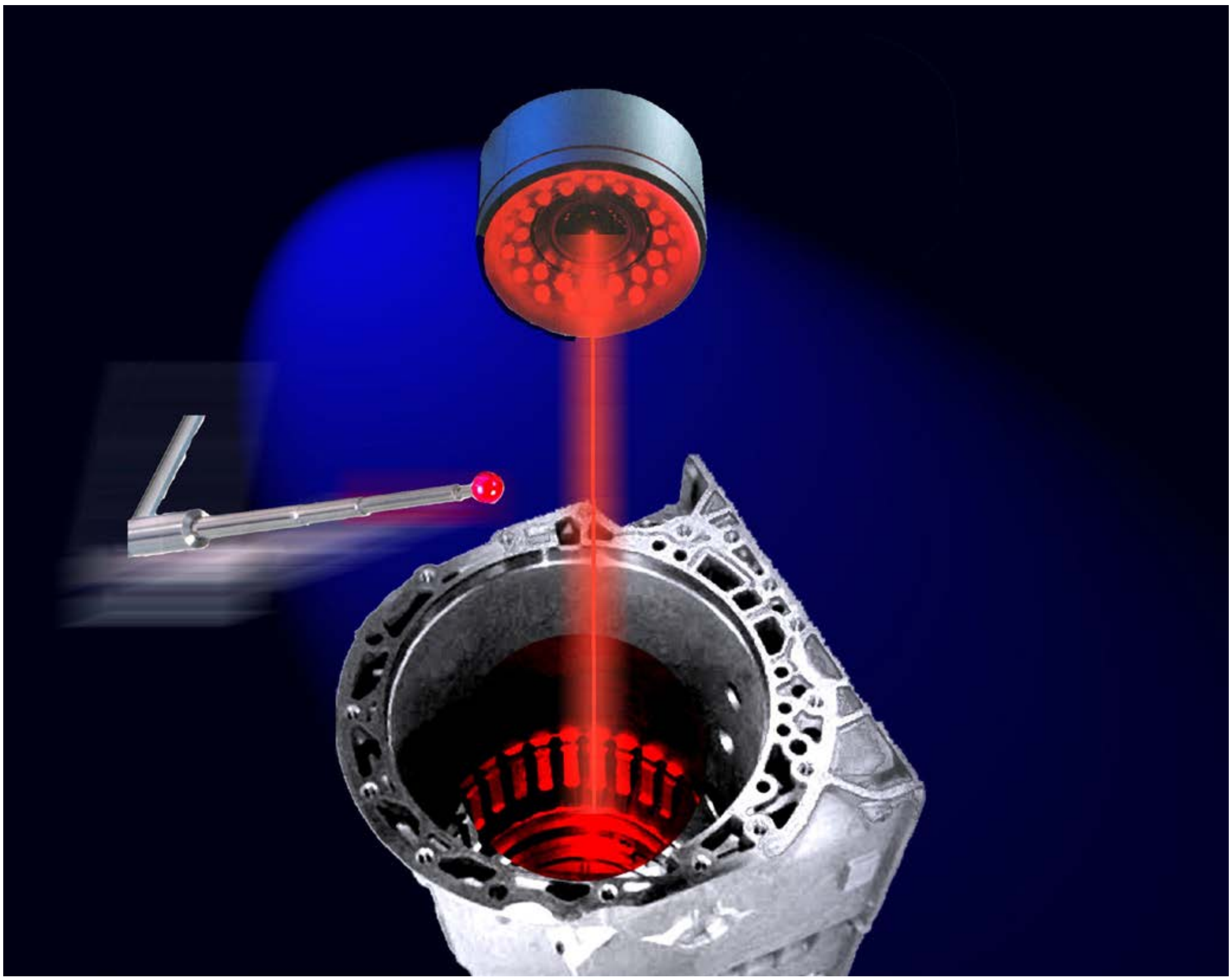


Table of Contents

1 Introduction

1.1 Integration of This Document

This LF5 guideline supplements the existing documents (e.g. procedural instructions) and regulations. It describes the currently valid method for approving measurement processes and supports the user with notes and practical examples.

The requirements regarding the measurement processes in this guideline originate from the following:

- DIN EN 13005: Guide to the Expression of Uncertainty in Measurement (GUM) [2]
- VDA Volume 5: Capability of Measurement Processes [13]
- QS 9000: Measuring Systems Analysis (MSA) Guideline [1]
- DIN EN ISO 14253: Inspection by Measurement of Workpieces and Measuring Equipment [4-5]
- DIN 55319-3: Quality Capability Statistics for Evaluation of Measurement Processes with Multivariate Normally Distributed Measurement Results [8]
- ISO 22514-7: Capability of Measurement Processes [7]
- DIN 1319: Fundamentals of Metrology [3]
- DKD-3: Specification of Uncertainty of Measurement for Calibrations [16]
- DKD-4, Traceability of Measuring and Test Equipment to National Standards [17]
- DIN EN ISO 10012: Quality Assurance Requirements for Measuring Equipment [11]
- DIN EN ISO 9000:-2005: Quality Management Systems [10]
- ISO / TS 16949: Quality Management Systems [9]
- VDA Volume 6 Part1: QM System Audit [14]

Notre:
With the new edition of the VDA 5 Volume "Capability of Measurement Processes" [13] and the publication of ISO 22514-7 "Capability of Measurement Processes" [7], the measuring system analysis (methods1-3) based on the MSA [1], is combined with the measurement uncertainty analysis based on the GUM [2]. As for many measurement process the existing uncertainty components are recorded with the common methods 1/2/3, the MSA-based measuring system analysis is still covered with the LF5 provided here in addition to the measurement uncertainty analysis. A recommendation for selecting the method is described in greater detail in Chapter 1.6. in dependence on the measuring system type.

As a result, the LF5 guideline fulfills the current requirements regarding standardization as well as various guidelines.

Figure 1-1 shows how this document is integrated in the existing documentation structure.

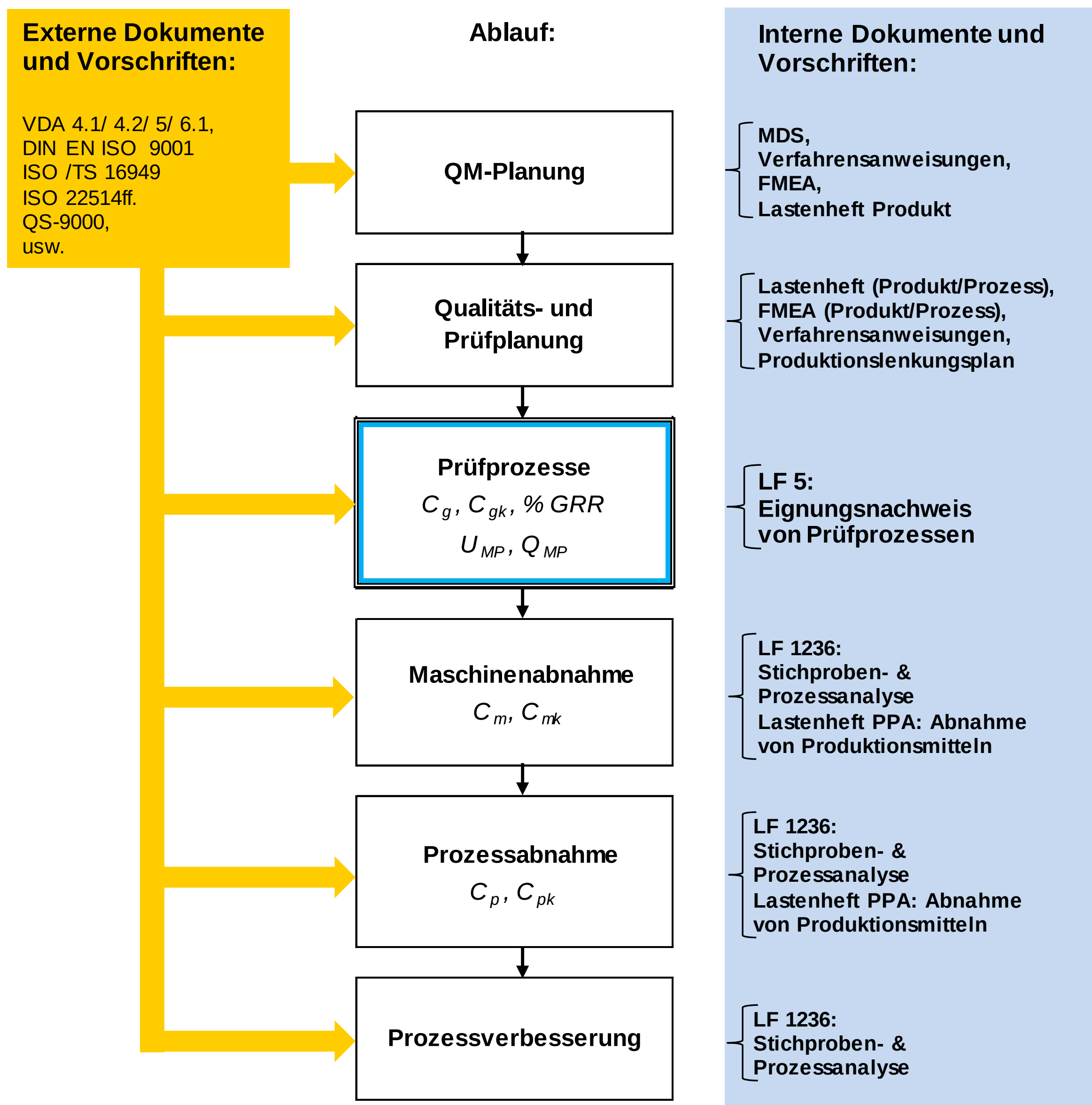


Figure 1-1: LF 5 Guideline in document structure

1.2 Scope

This guideline applies for the Powertrain Plants in Berlin, Hamburg and Stuttgart. It describes the proof of capability of measurement processes with which variable characteristic values are evaluated. This can be carried out either by means of a "capability analysis" or "measurement uncertainty analysis."

1.3 Influence of Measurement Process on Process Capability

The following descriptions are intended to highlight the consequences of using an unsuitable measurement process.

Figure 1-2 gives examples of influencing factors that act within a measurement process. These influences result in measurement errors. The measurement error is the difference between the displayed value and actual value. The aim is to keep the measurement error to a minimum.

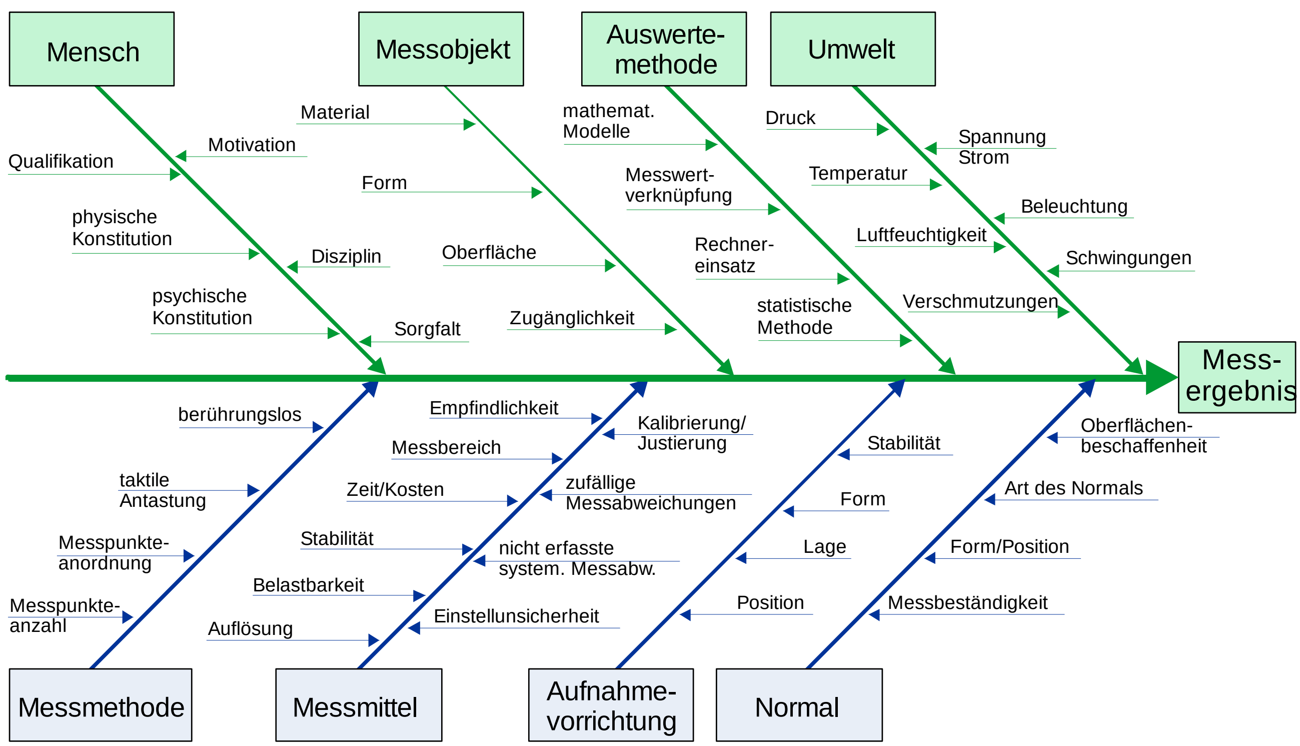


Figure 1-2: Influences on the measurement result
Source: VDA 5 [13]

The following figures show the effects of measurement process variation on the observed process variation.

In Figure 1-3, the measurement process variation is sufficiently small. This means that the actual process variation is virtually identical to the observed process variation.

The measurement process variation in Figure 1-4 is too large. This causes the clear difference between the actual process variation and observed process variation. This difference results in the actual situation being misinterpreted.

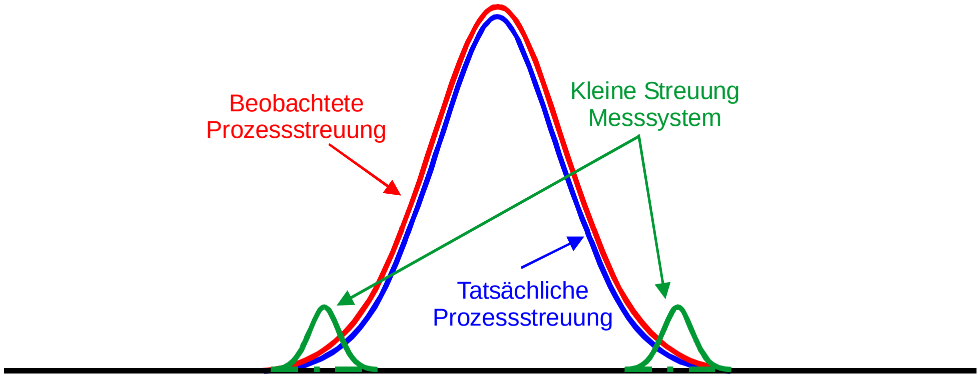


Figure 1-3: Observed process variation not influenced by the measurement process

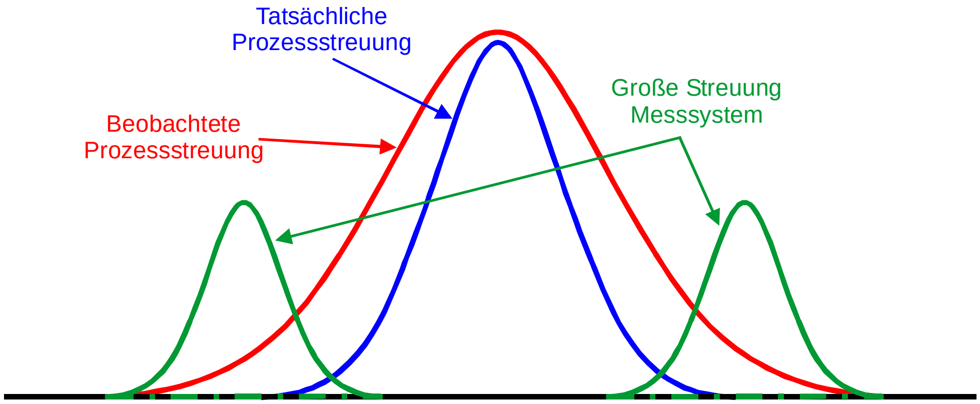


Figure 1-4: Observed process variation influenced by the measurement process

The greater the variation of the measurement process, the less variation the actual production process is entitled to in order to meet capability requirements for the production process.
Example: With a measurement process variation of 40% of the production tolerance, the requirement of C_P > 1.67 cannot be reached; it utilizes the entire available tolerance range.

	Actual C value of the process at...				
Observed C value	**Q_{MP} = 10%**	**Q_{MP} = 20%**	**Q_{MP} = 30%**	**Q_{MP} = 40%**	**Q_{MP} = 50%**
0.67	0.67	0.68	0.70	0.73	0.77
1.00	1.01	1.05	1.12	1.25	1.51
1.33	1.36	1.45	1.66	2.21	18.82
1.67	1.72	1.93	2.53		
2.00	2.10	2.50	4.59		

Figure 1-5: Relationship between $C_{p;real}$ and $C_{p;obs}$ for typical C values

This raises two questions:

1. How is the "variation of a measurement process" determined?
2. How great can the measurement process variation be while keeping the difference between the observed process variation and actual process variation within acceptable limits?

1.4 Effect of Measurement Uncertainty on Manufacturing Tolerance

It must be ensured for series monitoring tests and for conformity tests that the evaluation of the characteristic tolerance "OK" (within the specification limits) or "not OK" (outside the specification limits) is clear and reliably carried out. Variation influences due to the measurement process make the measurement results, and with them the test decision, unreliable. They must be known and may only be accepted up to a reasonable ratio to the tolerance.

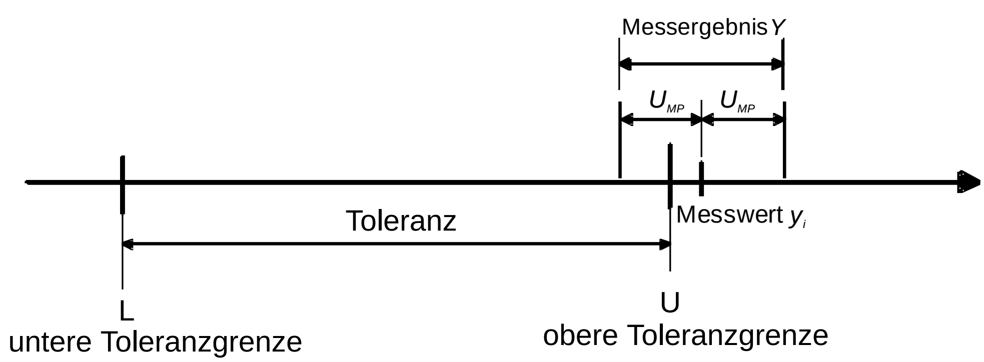


Figure 1-6: Conformance or non-conformance with tolerance cannot be verified

DIN EN ISO 14253-1 [4] defines how, in conjunction with the given specification (tolerance), measurement uncertainty is to be taken into account by the manufacturer and contractor.

It requires the determination of the expanded measurement uncertainty *U* for a measurement process and defines decision-making rules (Figure 1-7):

- **Range of conformance:**
  The specification range is reduced by the expanded measurement uncertainty *U*.
- **Range of non-conformance:**
  The range outside the specification is expanded by the expanded measurement uncertainty *U*.
- **Uncertainty range:**
  Range close to the specification thresholds, for which – under consideration of the measurement uncertainty – neither conformance nor non-conformance can be verified.

The effect of this for the contractor and recipient can be seen in Figure 1-8. The contractor must align manufacturing in such a way that the manufacturing process is always within the range of conformance. This means that the manufacturing leeway is reduced as the measurement uncertainty increases. Conversely, the recipient must accept everything except the range non-conformance.

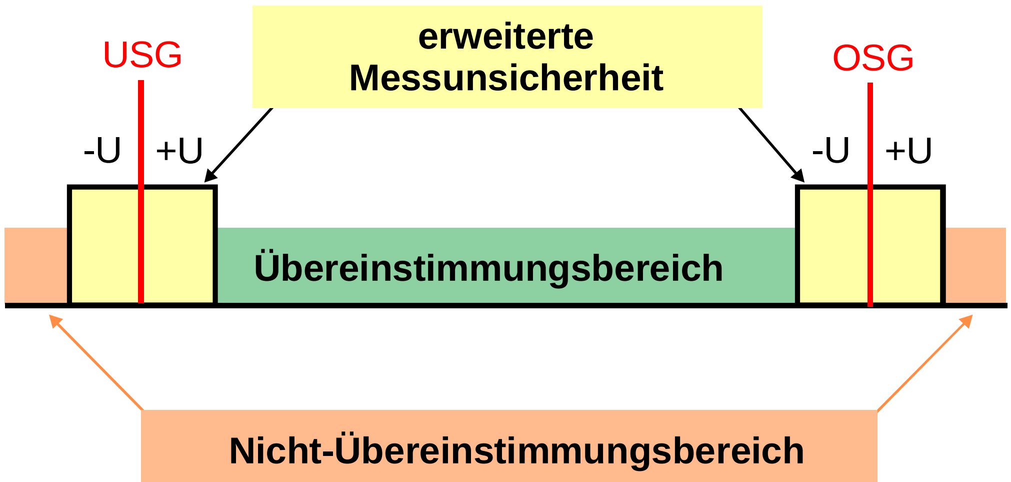


Figure 1-7: Measurement uncertainty at the specification thresholds (requirement of DIN EN ISO 14253 [5])

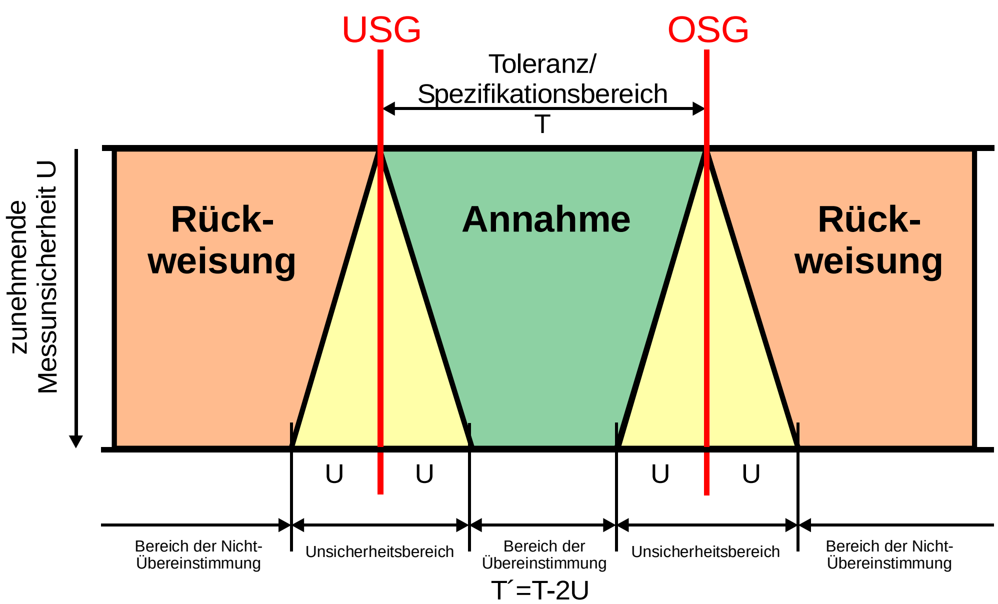


Figure 1-8: Effect of increasing measurement uncertainty on the manufacturing tolerance

1.5 Standard and Special Cases

Regardless of whether the acceptance relates to standard measuring instruments or the capability of a measurement process, a distinction can always be made between "standard cases" and "special cases." For special cases, define and agree upon individual solutions and specification limits. In individual cases, deviations must be made from generally specified specification limits or alternative methods of analysis must be employed. In these cases the process owner must frequently decide if necessary on temporarily usability and the additional measures required in coordination with the quality and/or test scheduling team.

For standard cases, a procedure can be defined on a formulation-by-formulation basis; this procedure is then used for the assessment. In this step-by-step procedure, testing is performed and the measurement results are recorded. On the basis of these, statistical characteristics that are used for verifying capability are calculated. To make a decision regarding the capability of the measurement process, the calculated statistics are compared with predefined specification limits:

- If all of the statistics fulfill the requirements, the measurement process is suitable.
- If certain statistics do not fulfill the requirements, the individual statistics will indicate the causes. Implement appropriate improvements.

These investigations are used in the following cases:

- The acceptance of new measuring systems at the manufacturer’s site (stage 1)
- The acceptance of new measuring systems or modified measurement processes in the plant (stage 2)
- Monitoring the stability of a measurement process in production and in the measuring center (stage 3)
- Test equipment monitoring in accordance with DIN EN ISO 10012 [11] (stage 2).

1.6 Proof of Capability of a Measurement Process

1.6.1 Verification of the Capability of the Test Equipment/Measuring Systems – Stage 1 and Stage 2

The inspection body or cost center representative shall perform initial testing and issue a release for all test equipment and/ or measuring systems (procedural instruction 010 7.6-1).

To verify whether or not the measuring system is suitable for the measurement process, a distinction is made between three application scenarios. For this purpose, the measurement requirements regarding the test equipment and/or measuring system must be defined in dependence of the area of application and the tolerances to be measured.

Case 1 **Workpiece-related measuring systems**:
Perform a capability analysis (method 1) for the agreed characteristics.

Case 2 **Universally used measuring instruments/measuring systems:**
Should the error limit MPE exist, T_{MIN} must be determined. Otherwise T_{MIN} must be determined with method 1 or an uncertainty analysis.

Case 3 **Limit gages** used for inspection by attributes (good/bad) are suitable if the gage tolerances are maintained when the test equipment is monitored.

1.6.2 Verification of Capability of Measurement Process - Stage 3

Following the verification of capability of the measuring system, the capability of the entire measurement process must be examined.

To verify the measurement process capability, a distinction is made between two application scenarios (Figure 1-9):

Case 1 **Workpiece-related measuring systems:**
Perform a method 2 (with user influence) or method 3 (without user influence) capability analysis for the agreed characteristics.

Case 2 **Universally used measuring instruments/measuring systems:**
The measurement uncertainty U_{MP} must be determined for representative or critical test characteristics. This enables the capability characteristic Q_{MP} or the minimum tolerance T_{MIN} to be calculated.

In the case of **limit gages** used for inspection by attributes (good/bad), a capability analysis is not generally performed. They are considered suitable if the gage tolerances are observed. For exceptional situations, VDA 5 explains how to perform the verification of the capability of attribute measurement processes.

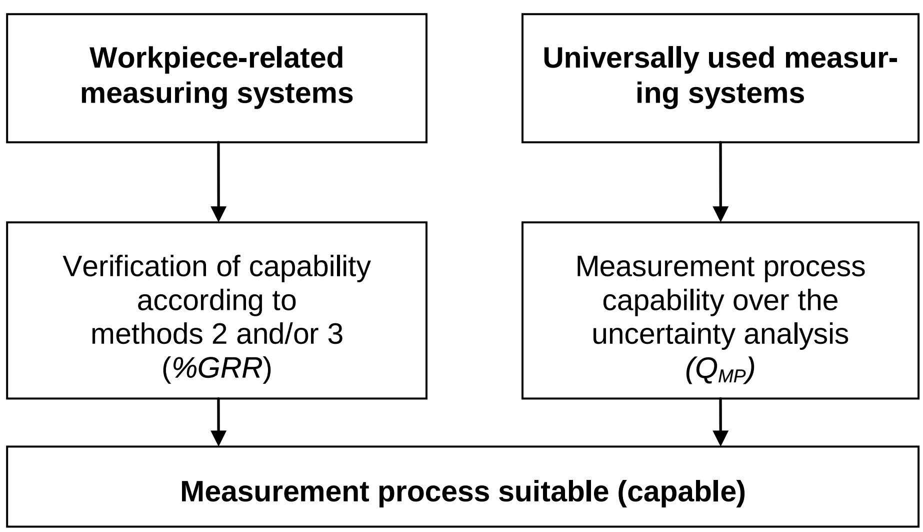


Figure 1-9: Application cases of measurement process capability

Note:
It should be emphasized again here that the two methods described below for verifying the measurement processes capability are not in opposition to each other. Therefore, it is also possible to choose

between the two alternatives or to use the data obtained from one method in the other method.

During the capability analysis (method1/2/3), some uncertainty influences may not always be completely included. If these cannot be ignored, they may have to be recorded in addition and taken into account during the uncertainty analysis. The measurement uncertainty is determined primarily for conformity checks in order to assess the usability of the measurement process or the measured values obtained from it.

For universally used measuring instruments or measuring systems, it would be ideal for users if they could select not only suitable measuring instruments but also measuring systems from a catalog for the relevant measuring task.

2 Terminology and Definitions

Most of the following terms for use in this document have been taken from the following standards, directives and guidelines - DIN ISO 10012 [11], VIM (International Dictionary of Metrology) [12], DIN V EN 13005 (GUM) [2], DIN EN ISO 14253 [4] and DIN 1319 [3], VDA Volume 5 [13].

There are additional explanations for some key definitions below.

2.1 Test Characteristic

Characteristic on the basis of which an inspection is performed.

2.2 Characteristic Value (Measured Value) *yi*

The appearance of the characteristic's assigned value.

2.3 Inspection by Variables (Measurement)

Determination of a special value of a measurand as a multiple or part of a unit or of an agreed upon reference system. During measurement a quantitative comparison of the measurand to the reference variable is carried out by means of a measuring instrument or a measuring system.

2.4 Measurement Result *Y*

A quantity of variable values which are assigned to a measurand, together with any available relevant information.

Note: A measurement result is generally expressed as a single measured value and a measurement uncertainty $Y = y_i \pm U_{MP}$. If the measurement uncertainty is considered to be negligible for some purposes, the measurement result can be expressed as a single measured value.

2.5 Inspection by Attributes (Gaging)

Comparison of the test object with a gage and determination of whether a specified limit is exceeded in the process. The actual existing deviation of the tested variable from the nominal dimension is not determined in the process.

2.6 True Value

The value which matches the definition of a considered special variable.

Note: This value would theoretically be obtained with an ideal measurement.

2.7 Correct Value

A value recognized through agreement which is assigned to a considered special variable and which is subject to an uncertainty suitable for the respective purpose.

2.8 Measurement Standard / Master

A reference part for adjusting the measuring equipment with a reference value. The reference value of the measurement standard must be traceable to the corresponding national or international standard and the measurement uncertainty must be known.

2.9 Calibration

An activity which in a first step under the specified conditions produces a relationship between the variable values provided by standards with their measurement uncertainties and the corresponding displays with their adjunctive measurement uncertainties. In a second step it uses this information to establish a relationship with which a measurement result is obtained from a display.

Note: Calibration should not be confused with adjustment of a measuring system, which is often incorrectly called "self-calibration".

2.10 Adjustment

Elimination of bias from the calibration object determined during calibration. Adjustment comprises all required measures with which the bias is minimized.

Note: Following the adjustment of a measuring system, the measuring system must usually be recalibrated.

2.11 Setting

Setting is the adjustment of measuring systems to a dimension with reference to material measures. If a zero display is targeted here, then a zero setting (zeroing) is referred to.

Note: During setting the calibrated actual value of the adjustment setting standard (material measure) is applied under actual operating conditions to the measuring instrument.

2.12 Uncertainty of the Measurement Standard / Master

The measurement standard or master is extremely important for many measurement processes. It is required for all relative measurement tasks. All measurement standards and masters have a degree of measurement uncertainty due to the way in which they are produced and used. For this reason, the uncertainty contribution from the calibration of the measurement standard must also be taken into account when the capability of a measurement process is being investigated. The measurement standard also ensures the metrological traceability to national and international measurement standards.

Figure 2-1 shows how the measurement uncertainty of a measurement standard increases the further away it is from the national or international measurement standard in the hierarchy level.

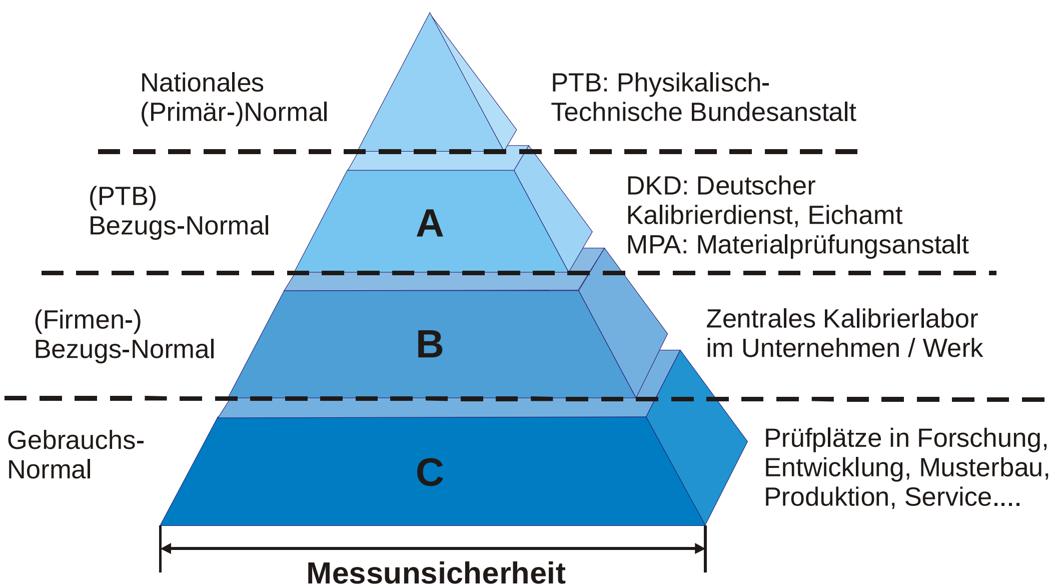


Figure 2-1: Hierarchy of measurement standards

The measurement uncertainty of the reference standard *(U_{CAL})* specified on the calibration certificate is the first factor that influences the assessment of the measurement process. The measurement process is only ever as good as the measurement standard uncertainty. For this reason, the first question to ask is this: How great can the measurement uncertainty U_{CAL} of a measurement standard be so that the measurement standard used is acceptable? $U_{CAL} \leq 5\%$ of the characteristic tolerance is considered an empirical value. If U_{CAL} is within this magnitude, the resulting measurement uncertainty component can generally be ignored when the expanded measurement uncertainty of the measurement process as a whole is being determined.

Often, no uniform measurement standard is available in the industry. In this case, "masters" or "master parts" (hereinafter also referred to as reference parts) can be used. The naming convention is not standardized and therefore differs from company to company. These are usually either workpieces taken from the production process or parts manufactured specially for a measurement process. To be able to use these reference parts for establishing the systematic measurement error, they must fulfill similar conditions as the measurement standards. This means that they must be calibrated and are subject to test equipment monitoring.

A distinction must be made between the following situations:

One calibrated master piece as the measurement standard

If just one calibrated measurement standard is available for the verification of capability, a distinction must be made between two different methods.

1: The master piece used for calibrating the measuring device is used as the measurement standard for the capability analysis. The measuring system is set according to specification. The verification of capability is performed immediately following adjustment.

The systematic measurement error is eliminated with this procedure. Only the repeatability can be determined.

2: The master piece used for calibrating the measuring device is used for the verification of capability. The measuring system is set according to specification. The verification of capability is not performed until shortly before the next planned adjustment.

In this case, systematic measurement error attributable to the stability of or other time-based changes to the measuring system can be recorded and assessed.

Multiple calibrated master pieces as measurement standards

Multiple calibration pieces are often obtained for each measuring procedure. This is the basis for a meaningful verification of capability and offers additional logistical benefits when the master pieces are being monitored. If two or more master pieces are used, it must be ensured that their actual dimensions are distributed across the tolerance range (e.g. close to the upper and lower tolerance limits as well as in the tolerance mean). One master piece is then used for calibrating the measuring system and the other for the verification of capability. If multiple measurement standards distributed across the tolerance range are used, this can also yield information about the linearity.

Calibrated workpiece (master part)

Many areas have a special workpiece (master part) recorded and calibrated accordingly. This calibrated workpiece can be used for monitoring stability and performing a verification of capability of the manufacturing measuring system. Make sure that the individual characteristics have been calibrated with sufficient accuracy.

Non-calibrated characteristics on a master piece

If certain characteristics (e.g. geometrical tolerances) of master pieces have not been calibrated but simply checked for compliance with the manufacturer's specifications, these measurement results may not be used as calibration values for a verification of capability. The measured values obtained while the master piece was being tested in the measuring center may differ significantly from the values of the manufacturing measuring system, for example due to a different measurement point or measurement strategy, which can result in an incorrect assessment of the measuring system. If a verification of capability is nonetheless performed for these characteristics, only the repeatability can be reliably determined. It is impractical to determine the bias.

Measurement standards and masters are used for not only adjusting measurement processes, but also monitoring measuring systems. For example, a calibrated workpiece with several characteristics can serve as a master part, with which three different coordinate measuring machines can be checked weekly. The master part is measured for this purpose. One can obtain a very detailed picture over time of how the different coordinate measuring machines behave with respect to one another. In particular, the change in variation and bias must be observed.

2.13 Measuring Instrument

An instrument used for performing measurements either alone or in conjunction with additional equipment.

Note: A measuring instrument which can be used alone is a measuring system.

2.14 Resolution of the Measuring Instrument

Before any of the investigations mentioned are performed, the resolution of the measuring instrument must be checked. For measured values to be reliably determined and read, the measuring instrument must have a resolution of **%RE ≤ 5%** of the tolerance of the characteristic.

<u>Example</u>**:**

Length dimension 125 ± 0.25 mm

With a tolerance of 0.5 mm, 5% of the tolerance are equal to 0.025 mm. This means the measuring system may have a maximum resolution of 0.025 mm over the entire measuring range. A dial gage with a 0.01 mm scale graduation can be used, for example.

2.15 Measuring Equipment/Test Equipment

All measuring instruments, measurement standards, reference materials, supplementary means and instructions required to perform a measurement. This term encompasses measuring equipment used both for testing and calibration.

2.16 Measuring System

Complete set of measuring instruments and measuring equipment put together for conducting specified measurements for obtaining measured values within certain intervals of variables of certain kinds.

2.17 Measurement Error

2.17.1 Systematic Measurement Error / Bias

The systematic measurement error is the difference between the **average value displayed** on the measuring system when the same characteristic is measured multiple times and the **reference value** of the characteristic. The part to be measured is a measurement standard (reference value), whose value is determined using precision measuring systems (e.g. coordinate measuring machines) and that must be traceable to a national or international measurement standard. A reference value can be determined by conducting several measurements with a high-quality measuring instrument (e.g. measuring center or calibration laboratory).

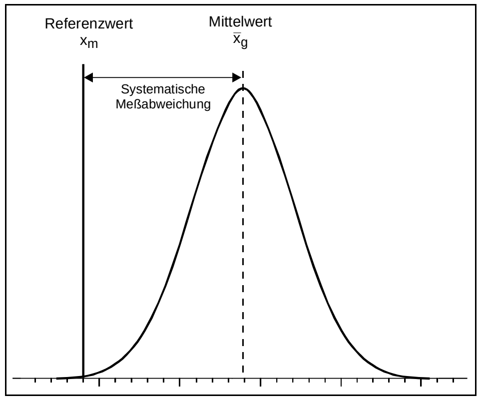


Figure 2-2: Systematic measurement error (bias)

2.17.2 Random Measurement Error

This is the measurement result minus the average value that would result from an infinite number of measurements of the same measurand carried out under repeatability conditions.

2.18 Repeatability

Variation of the measured values obtained during multiple measurements of the same characteristic on the same part performed by the same tester using the same instrument.

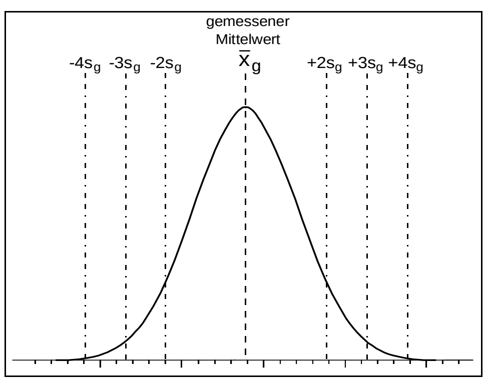


Figure 2-3: Repeatability

2.19 Reproducibility

Variation of the means of measured values, under comparable conditions, e.g. different inspectors, measuring instruments, etc. for an identical characteristic on the same part.

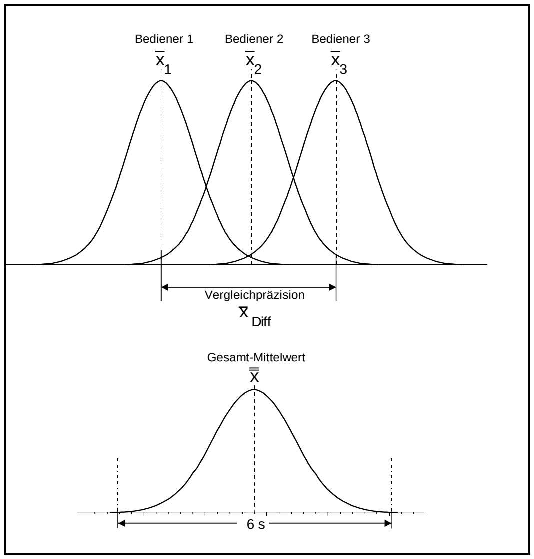


Figure 2-4: Reproducibility

2.20 ANOVA

The ANOVA (Analysis of Variance) is a mathematical method for determining variances based on their standard uncertainties.

2.21 Measuring System Capability

Capability of the measuring system for an intended inspection task while exclusively taking accuracy requirements (capability characteristic value C_g/C_{gk} or capability characteristic value Q_{MS}) into account.

2.22 Maximum Permissible Measurement Error MPE (Error Limit)

The extreme value of a measurement error with regard to a known reference value; approved for a measurement, a measuring instrument or a measuring system with specifications or regulations.

2.23 Linearity

Constant relationship between the output variable and the input variable (measurand) of a measuring system as this changes.

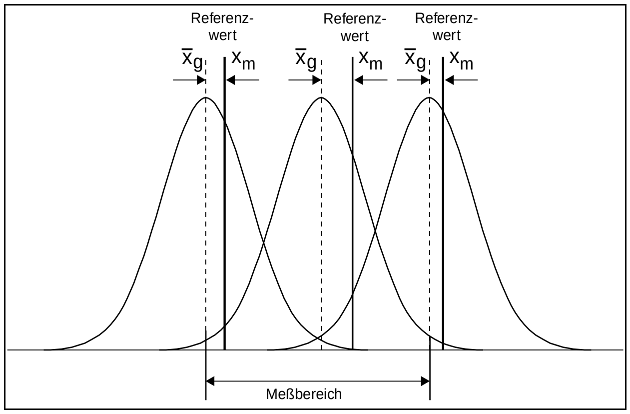


Figure 2-5: Linearity

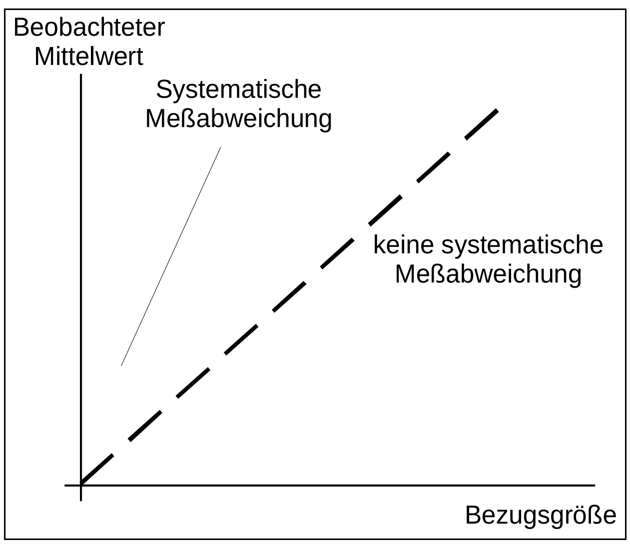


Figure 2-6: Linearity (variable range of variation)

2.24 Measurement Process

The totality of all influencing components for calculating a measured value for a characteristic:
Method, procedure, measuring system, supplementary means, measurement standard, software, operator, etc. used for assigning a value to the characteristic to be measured; in other words, the entire process of recording measured values.

Note: In the MSA (method1-3) and in the LF5 Guideline, Version 2007, the totality of all influencing components were referred to as a measuring system!

2.25 Measurement Process Capability

Capability of the measurement process for a intended inspection task while exclusively taking accuracy requirements (characteristic value *%GRR* or capability characteristic value Q_{MP}) into account

2.26 Stability of a Measuring System / Stability

The capability of a measuring system to maintain the same metrological characteristics over time.

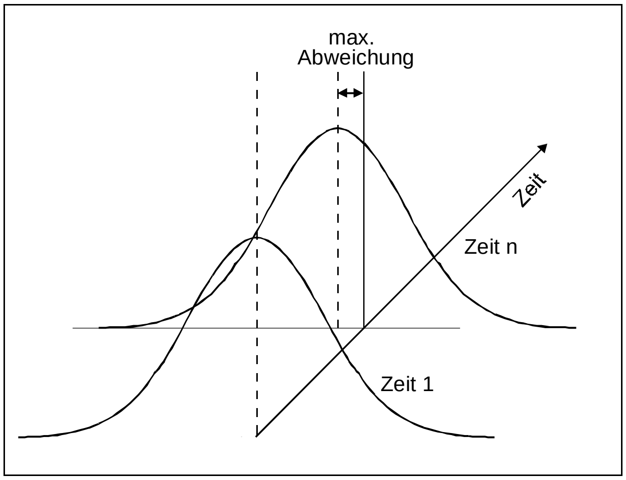


Figure 2-7: Stability of a measuring system

2.27 Measurement Uncertainty

Parameter assigned to the measurement result which identifies the variation of the values, which could reasonably be assigned to the measurand.

2.28 Standard Uncertainty *u(xi)* / (Standard Measurement Uncertainty or Uncertainty Component)

Uncertainty of the results of a measurement expressed as a standard deviation.

2.29 Uncertainty Budget

A table which summarizes the results of the estimations or the statistical evaluations of the uncertainty components which contribute to the uncertainty of a measurement result.

Note: The uncertainty of a measurement result is only clear when the measuring method (including the test item, measurand, measuring method and measuring conditions) is defined.

2.30 Combined Standard Uncertainty *u(y)* (Combined Standard Measurement Uncertainty)

Standard uncertainty of a measurement result when this result is gained from the values of a number of other variables. It is the equal to the positive square root of a sum of links, where the links are variances or covariances of these other variables, weighted according to how the measurement result varies with the change in these variables.

2.31 Coverage Factor *k*

The numeric factor by which the combined standard uncertainty is multiplied to obtain an expanded uncertainty.

$$U_{MS} \text{ bzw. } U_{MP} = k \cdot u(y)$$

2.32 Expanded Measurement Uncertainty (Measurement Uncertainty)

Characteristic value which identifies an area around the measurement result from which it can be expected that it comprises a large percentage of the distribution of the values which could be reasonably assigned to the measurand.

Note: The percentage can be seen as the overlapping probability or confidence level of the area.

2.33 Control Chart

A control chart, also called a quality control chart or QCC for short, is used for statistical process controls. A QCC generally consists of a position and a variation track with specified action limits. In the QCC, the sample means and standard deviations are, for example, entered in the respective track.

3 Execution

With the new edition of VDA 5 Volume "Capability of Measurement Processes" in 2010, the measuring system analysis based on the MSA (methods1-3) were grouped with measurement uncertainty analysis based on the GUM.
As a majority of the uncertainty components is detected for most measurement processes with the common methods 1, 2 or 3, both the MSA-based measurement process analysis and the measurement uncertainty analysis according to the VDA5 Volume are described in the following.

Note: A recommendation for selecting the procedure is described in greater detail in Chapter 1.6. in dependence on the measuring system type.

3.1 Capability Analysis

The capability analysis for verifying the measurement process capability is a practice-oriented assessment of the entire measurement process in which the uncertainty components which mainly affect the measurement process are summarized. The capability analysis essentially involves two methods and is recommended primarily for workpiece-related measuring systems.

On the basis of the capability characteristic values C_g and C_{gk} (method 1), a decision is made, with the help of a measurement standard, regarding whether a measuring system is suitable for the intended application under operating conditions. With the characteristic values %*GRR* (method 2 or 3), a decision is made, under consideration of additional variables, regarding whether or not the measurement process is suitable for the intended measuring task.

3.1.1 Measuring System Analysis Method 1

On the basis of the capability characteristic values C_g and C_{gk}, a decision is made, with the help of a measurement standard, regarding whether a measuring system is suitable for the intended application under operating conditions.

Preparation:

1. The measuring system shall be set up as specified by the manufacturer and made ready for use.
2. A measurement standard/master or master part must be available whose correct value as obtained through calibration is traceable to national or international measurement standards. The calibration uncertainty (measurement uncertainty of the higher-level measuring method), with which the correct value for this measurement standard is determined, must be specified.

   If no measurement standard is available for measuring-related reasons, the calculation of C_{gk} is eliminated. In this case, only the repeatability C_g can be determined using a suitable test part.
3. Prepare the documentation and open a part form. For each characteristic, open a characteristic form and enter the characteristic value and tolerance. Add the measuring instrument, the measuring instrument resolution, measurement standard with calibration value, etc. The corresponding value form is then prepared automatically.

<u>Note</u>:

When a test part (setting master) is used, this can lead to greater variation.

Flow diagram for method 1:

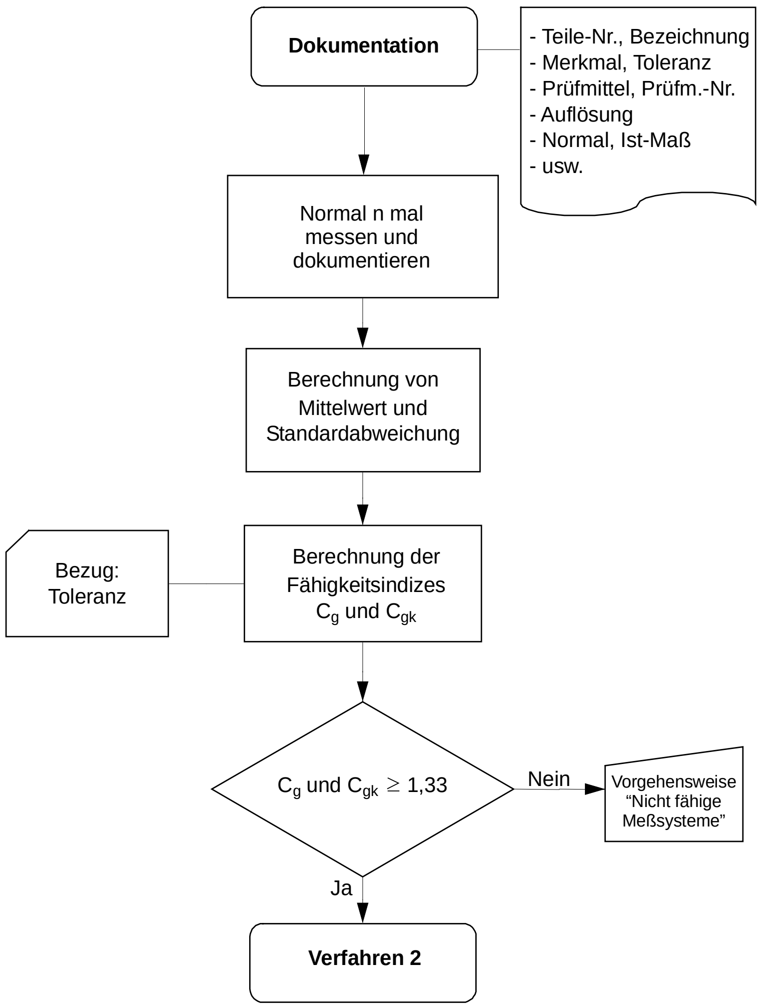


Figure 3-1: Flow diagram for method 1

Measurement and analysis:

Step 1

Assess the resolution (*RE*) of the measuring system (measuring instrument with display) for the reference figure *RF*, usually tolerance T.

$$\%RE = \frac{RE}{RF} \cdot 100\%$$

If %*RE* ≤ 5%, the resolution is suitable; if %*RE* > 5%, the measuring instrument is unsuitable for the intended measuring task due to the inadequate resolution.

Note:

Exceptions must be made on a case-by-case basis (see the procedure for "non-capable measurement processes").

Step 2

Define and select a measurement standard, whose correct value x_m lies within the tolerance field of the test characteristic. On the measurement standard, mark, position or describe the measurement position.

Step 3

Set, align and, if necessary, adjust the measuring system in accordance with the relevant instructions. Changes to the measuring system are not permissible while measurements are being performed.

Step 4

Perform at least 20 repeat measurements in quick succession on the measurement standard in accordance with the applicable test instructions for the subsequent component measurement (repeatability conditions) by the same tester on site. Prior to each measurement, reinsert the measurement standard into the measuring device in the same measurement position.

Step 5

Enter the measured values in the value form. Provided certain conditions have been fulfilled, the values can also be transferred automatically.

Step 6

The average value $\bar{x}_g$, repeatability standard deviation s_g, bias Bi as well as the capability characteristic values C_g and C_{gk} are calculated automatically.

$$Bi = \left|\bar{x}_g - x_m\right|$$

$$C_g = \frac{0,2 \cdot T}{4 \cdot s_g}$$

$$C_{gk} = \frac{0,1 \cdot T - Bi}{2 \cdot s_g}$$

Assessing the results:

I. Case: $C_g \geq 1.33$ and $C_{gk} \geq 1.33$

The measuring system is capable.

A repeatability standard deviation $s_g = 0$ may occur under the following conditions. The characteristic values are not calculated automatically and the case is to be substantiated.

a: The measurement standard is highly uniform in terms of its characteristics.

b: The resolution of the measuring system is not high enough to detect the influences.

c: Error in measuring system (e.g. measuring probe jams).

II. Case: $C_g \geq 1.33$, however $C_{gk} < 1.33$

The measuring system is not capable.

The systematic measurement error must be reduced as appropriate until $C_{gk} \geq 1.33$.

If a working standard was used, it may be that the correct value x_m of the measurement standard was not correctly determined (e.g. different measurement points). Check the correct value x_m and, if necessary, adjust it.

III. Case: $C_{gk} < 1.33$ and $C_g < 1.33$

The measuring system is not capable.

Reduce the variation of the measured values as appropriate until $C_g \geq 1.33$ and $C_{gk} \geq 1.33$.

No sufficient improvement can be achieved only with setting, as the repeatability standard deviation of the measuring system is too great. A different measuring method may have to be employed.

Exceptions must be made on a case-by-case basis (see also "Procedure: Non-Capable Measurement Processes").

Note:

By converting the formula for C_{gk} with $C_{gk} \geq 1.33$, the smallest tolerance as of which the measuring system is suitable according to method 1 can be calculated.

$$T_{min} \geq \frac{2{,}67 \cdot s_g + Bi}{0{,}1} = 26{,}7 \cdot s_g + 10Bi$$

In the SOLARA evaluation software, T_{min} is shown in a large number of reports as standard.

3.1.2 Linearity Test (if Required)

When the measuring system is used, verify its "linearity." When the linearity is tested, a distinction is made between the following situations:

1. The measuring system contains a linear material measure. This is verified in the form of a certificate or test.

   In this case, a separate linearity study is not necessary.

2. The measuring system does not contain a linear material measure.

   In this case, the linearity of the measuring system must be tested in detail.

Definition of "linearity":

DGQ Volume 13-61 [21] defines "linearity" as follows:

"Constant relationship between the output variable and the input variable (measurand) of measuring equipment as it changes."

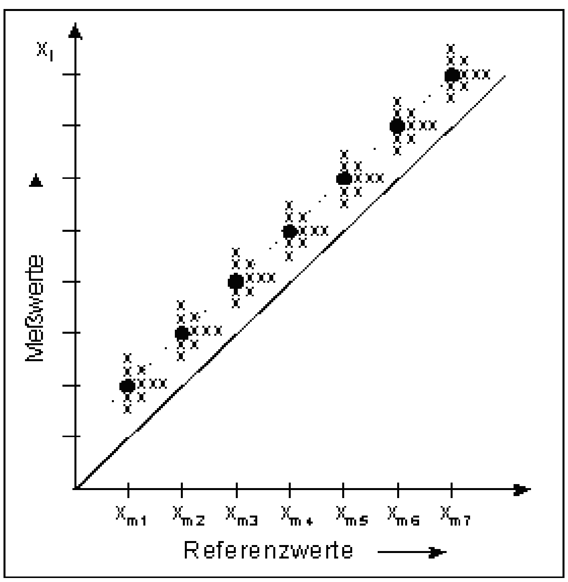
A similar definition can be found in MSA [1]. Neither definition is sufficient for a detailed linearity test.

For this reason, the term "linearity" is initially described as it is to be understood in the context of this guideline.

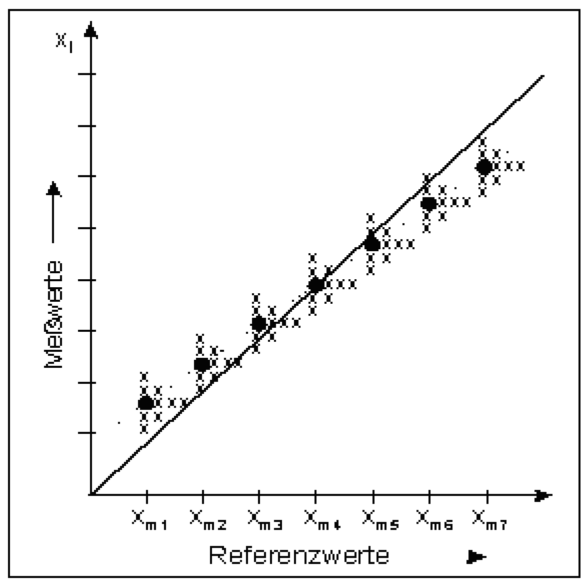
The aim of the linearity test is to determine the "systematic measurement error" of a measuring system across a specified range. The results are used as a basis for assessing whether the systematic measurement error lies within a range in which the measuring system can be considered suitable.

The following diagrams show various situations with deviations from linearity. Key:

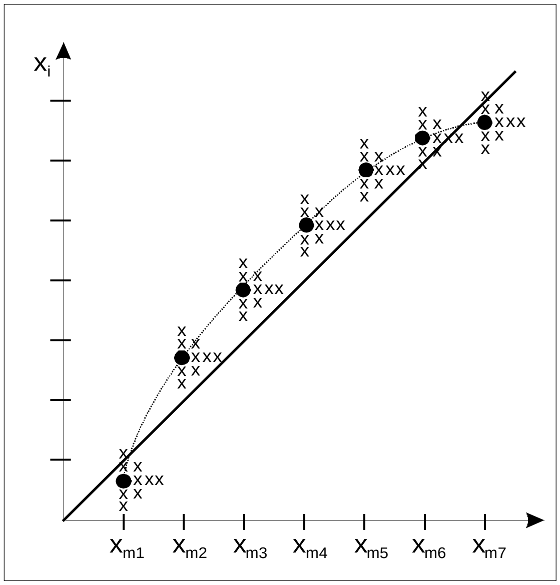
●	Average value of the series of measured values on the measurement standard i
......	Connecting line between the average values
—	Ideal position at which all measured values correspond to the relevant reference value
$(x_m)i$	Reference value for the measurement standard i
x_i	Measured value



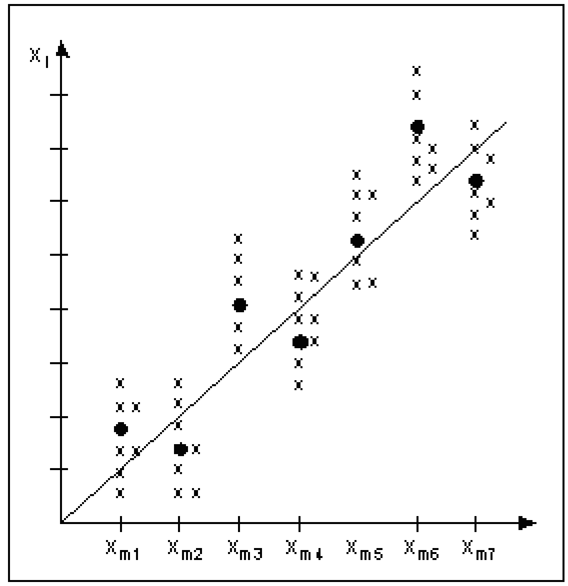
The systematic measurement error is constant, independent of the reference value, across the specified range.



The systematic measurement error changes across the specified range. A linear relationship exists between the reference values and the systematic measurement error.



No linear relationship exists between the reference values and the systematic measurement error.



The variation of the measured values for the individual reference values is significant.

The variation of the measured values on a reference part must be sufficiently small in accordance with method 1.

Testing the linearity:

To assess the linearity in accordance with the definition here, m measurement standards ($m \geq 3$) must be used for each characteristic. The measurement standards should be within the ranges ± 10% at the tolerance limits or the middle of the tolerance.

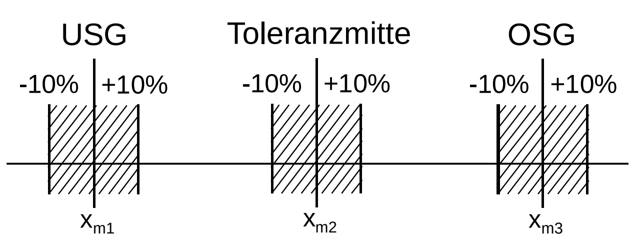


Figure 3-2: Selection of measurement standards for linearity tests

Measurement and analysis:

Step 1

Specification and selection of at least three measurement standards, with correct values x_{mi} which must be within the ranges ± 10% at the tolerance limits or in the middle of the tolerance if possible. On each measurement standard, mark, position or describe the measurement position.

Step 2

Set, align and, if necessary, adjust the measuring system in accordance with the relevant instructions. Changes to the measuring system are not permissible while measurements are being performed.

Step 3

All the measurement standards used are measured ten times under repeatability conditions. The average values ($\bar{x}_g$)$_i$ and the systematic measurement error (*Bi*)$_i$ must then be determined.

Step 4

The measured values and average values for each measurement standard can be shown in the xy plot or as the difference with respect to the relevant reference part in the deviation diagram.

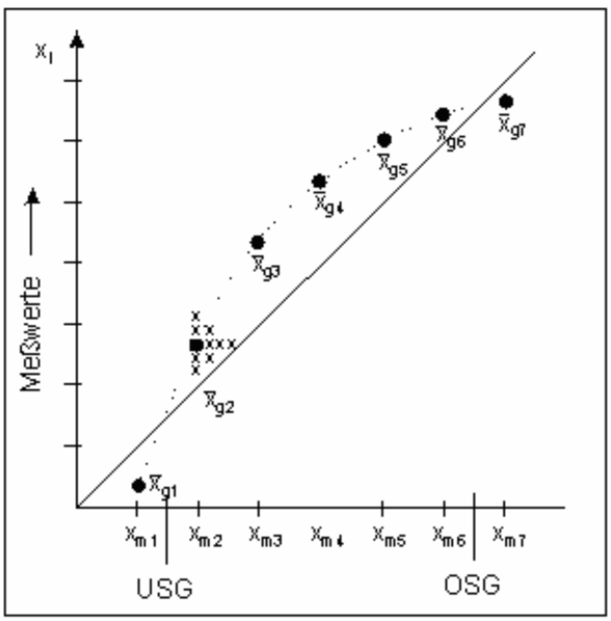


Figure 3-4: Linearity tests (xy plot)

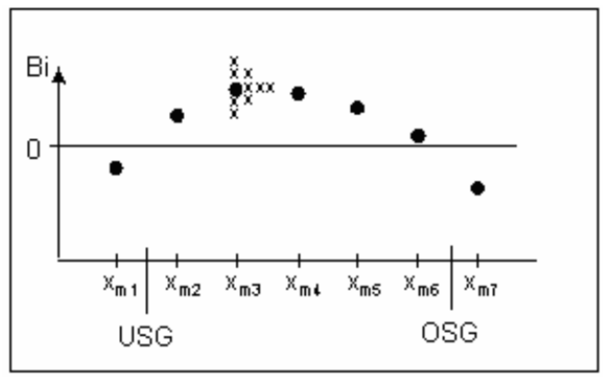


Figure 3-3: Deviation diagram

Assessing the results:

The linearity is assessed on the basis of the systematic measurement error *Bi*. The following applies for each measurement standard:

$$Bi_i = \left(\bar{x}_g\right)_i - \left(x_m\right)_i$$

The systematic measurement error determined on each measurement standard must be smaller than or equal to 5% the tolerance. In this case, the general requirement for *Bi* is:

$$-5\% \cdot T \leq Bi \leq 5\% \cdot T$$

The linearity of the measuring system is verified.

Note:
The variation of the measuring system is not taken into account in this analysis. If this is also to be included in the assessment, a method 1 capability analysis must be performed for each measurement standard.

Plausibility check by means of regression analysis

If a linear relationship exists between the reference value and the measured average values, the linear equation can be determined by means of a regression analysis. The slope of the linear regression lines is estimated on the basis of the correlation coefficient.

The coefficient of determination (R^2) is used as a measure of the goodness of fit obtained by regression. The closer the coefficient of determination is to 100%, the more accurately the line of best fit reflects the situation. R^2 is calculated automatically.

Note regarding tests performed at the specification thresholds only

It is often the case that, for financial reasons, no more than two measurement standards can be provided. This means that testing is performed at the specification thresholds only. For this purpose, one measurement standard must be provided near the lower and another near the upper specification threshold. A method 1 capability analysis must then be performed with each measurement standard. The procedure for measuring and analyzing the values as well as assessing the results is identical to that described in method 1.

3.1.3 Measurement Process Analysis Method 2

With the measurement process analysis method 2, it is evaluated using the characteristic value *%GRR* (measurement process variation) whether the entire measurement process, i.e. the measuring system while taking all additional variables into account, is suitable for the intended measuring task. Variables include dirt, jarring, the time-based and location-based temperature gradient, the operator, the measuring method, the measuring procedure and the condition of the test part, etc.

In principle, an attempt is made with the design of the measuring system to minimize or, if possible, to completely eliminate an operator influence. However, the influence can only be completely excluded if loading with the test part and the measurement process are automated. In this case, method 3 (operator influence not taken into account) can be used.

Preparation:

1. Method 2 may be performed only following successful verification of capability with method 1.
2. The measuring system shall be set up as specified by the manufacturer and made ready for use.
3. Prepare the documentation and open a part form. For each characteristic, open a characteristic form and enter the characteristic value and tolerance. Add the measuring instrument, measuring instrument resolution, measurement standard with calibration value, etc. The corresponding value form is then prepared automatically.

Flow diagram for method 2:

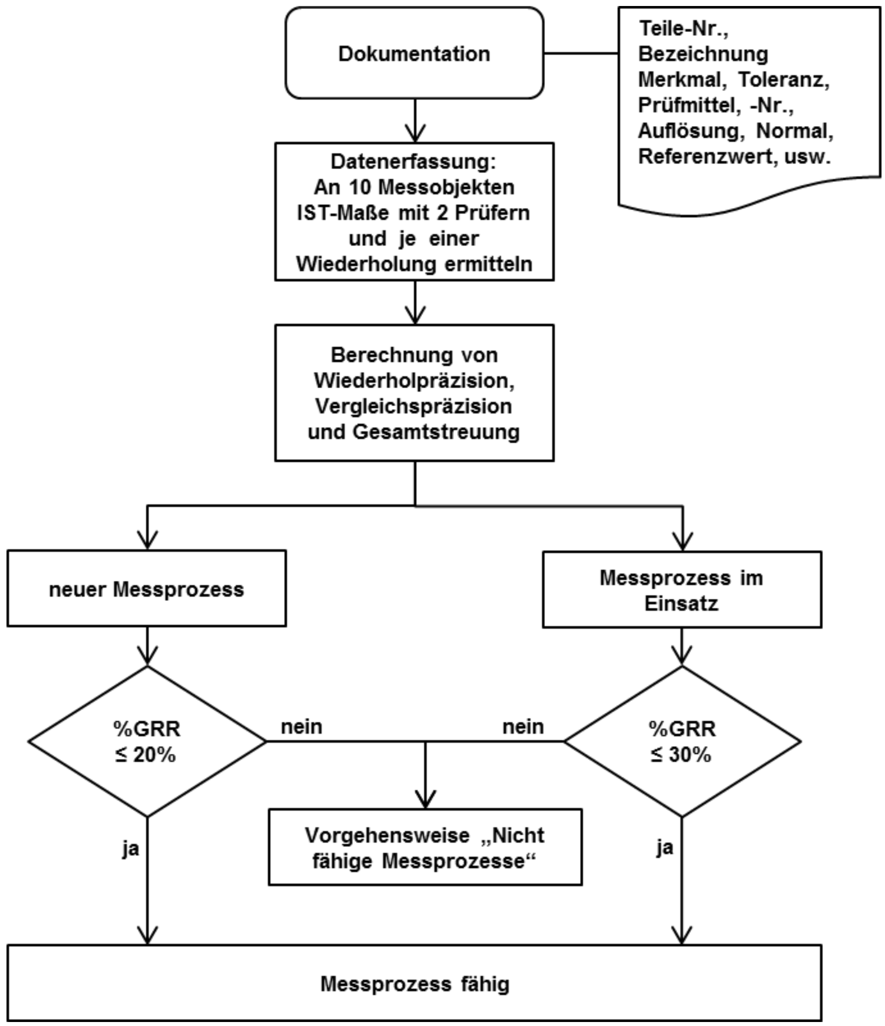


Figure 3-5: Flow diagram for method 2

Measurement and analysis:

Step 1

Define the number of testers ($k \geq 2$). Select 10 test parts ($n \geq 5$), distributed as uniformly as possible across the tolerance range, and the number of measurements for each tester ($r \geq 2$). The product $k \cdot r \cdot n$ must be greater than or equal to 30: $k \cdot r \cdot n \geq 30$.

Standard case: 2 testers, 10 parts with 2 measurement series per tester

Step 2

The parts are numbered. To exclude the influence of the test part (e.g. surface influence), the measurement position is marked or documented. Document the ambient conditions (e.g. temperature, operator, vibrations, etc.).

Step 3

The first device operator adjusts the measuring system and determines the characteristic values of the test parts in the numbered sequence and in accordance with the relevant instructions, taking into account the measurement position. The measured values are documented. The second device operator determines the characteristic values of the test parts a second time, following the same sequence and procedure. The results of the second measurement must not be influenced by the results of the first measurement. Changes to the measuring system are not permissible while the examination is being performed.

Note:

For practical reasons, it is often not possible to follow the measurement sequence recommended here. To identify specific properties of a measuring system or the drift caused by the influence of temperature, it may also be advisable to choose a different sequence.

It is therefore recommended that the measurement sequence be set, depending on the measuring task, individually in consultation between the customer and vendor and documented accordingly.

Step 4

Step 3 is repeated by each of the other testers. While the measurements are being performed, the other testers must not be aware of the various measurement results.

Step 5

Enter the values in the value form. Provided certain conditions have been fulfilled, the values can also be transferred automatically.

Step 6

The average value $\bar{x}_g$, variation R_g and the repeatability *EV, %EV*, reproducibility *AV, %AV*, interdependency *IA, %IA* and measurement process variation *GRR, %GRR* are calculated automatically by SOLARA on the basis of a variance analysis.

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

$$\%GRR = \frac{GRR}{RF} \cdot 100\%$$

Note:
For the "expanded spread", the variation is expanded with the factor 6 (P=99.73%) for the calculation for bilaterally limited characteristics.

Assessing the results:

I. Case: %*GRR* ≤ 20% for new measurement processes

II. Case: %*GRR* ≤ 30% for measurement processes in use

⇨ **The measurement process is suitable.**

If the variation obtained by one or more testers is $s_g = 0$, give reasons for this. This can occur, for example, only under the following conditions:

a: The resolution of the measuring instrument is not high enough to detect the influences.

b: Error in measuring system (e.g. measuring probe jams).

III. Case: %*GRR* > 20% or 30%

⇨ **The measurement process is not suitable.**

The influence of the testers (AV) and/or the repeat variation (EV) must be reduced as appropriate until the requirement is fulfilled. Either a different measuring method must be used or the testers require better instruction (see also "Procedure: Non-Capable Measurement Processes").

Note:

By converting the inequality %*GRR* ≤ 20% or 30%, the smallest permissible tolerance for which the measurement process can be used according to method 2 can be calculated.

$T_{\min} \geq 5 \cdot GRR$ for new measurement processes

$T_{\min} \geq \frac{10}{3} \cdot GRR$ for measurement processes in use

In the SOLARA evaluation software, T_{min} is shown in a large number of reports as standard.

3.1.4 Measurement Process Analysis Method 3 (Special Case for Method 2)

Method 3 is a special case for method 2 and is used for measurement processes that are not subject to operator influence (e.g. mechanized measuring system, automatic testing devices, automatic handling, etc.) or for which the operator influence is negligibly small.

On the basis of the characteristic value *%EV*, a decision is made, with the help of test parts (e.g. production parts) under operating conditions and under consideration of the potential influence of the production parts to be measured (surface influence, dirt, temperature influence, etc.), regarding whether a measuring system is suitable for the intended measuring task.

Preparation:

1. Method 3 may be performed only following successful verification of capability with method 1.
2. The measuring system shall be set up as specified by the manufacturer and made ready for use.
3. Prepare the documentation and open a part form. For each characteristic, open a characteristic form and enter the characteristic value and tolerance. Add the measuring instrument, the measuring instrument resolution, measurement standard with calibration value, etc. The corresponding value form is then prepared automatically.

Measurement and analysis:

Step 1
Select test parts ($n \geq 5$), distributed as uniformly as possible across the tolerance range, and the number of measurements for each test part ($r \geq 2$). The product $n \cdot r$ must be greater than or equal to 20: $n \cdot r \geq 20$.

Standard case: 10 parts with 2 measurements per test part

Step 2
The parts are numbered. To exclude the influence of the test part (e.g. part geometry), the measurement position is marked or documented. Record the variables (e.g. temperature, vibration, etc.).

Step 3
The device operator adjusts the measuring system and determines the measured values of the test parts in the numbered sequence and in accordance with the relevant instructions, taking into account the measurement position. The measured values are documented. The device operator determines the characteristic values of the parts a second time, following the same sequence and procedure. The results of the second measurement must not be influenced by the results of the first measurement. Changes to the measuring system are not permissible while the examination is being performed.

Note:
For practical reasons, it is often not possible to follow the measurement sequence recommended here. To identify specific properties of a measuring system or the drift caused by the influence of temperature, it may be advisable to choose a different sequence.

It is therefore recommended that the measurement sequence be set, depending on the measuring task, individually in consultation between the customer and vendor and documented accordingly.

Step 4

Enter the values in the value form. Provided certain conditions have been fulfilled, the values can also be transferred automatically.

Step 6

The average value $\bar{x}_g$, variation s_g, repeatability *EV, %EV* and measurement process variation *GRR, %GRR* are calculated automatically.

$$GRR = EV$$

$$\%GRR = \frac{GRR}{RF} \cdot 100\%$$

Note:
For the "expanded spread", the variation is expanded by the factor 6 (P=99.73%) for the calculation for bilaterally limited characteristics.

Assessing the results:

I. Case: $\%GRR = \%EV \leq 20\%$ for new measurement processes

II. Case: $\%GRR = \%EV \leq 30\%$ for measurement processes in use

⇨ **The measurement process is suitable**.

If the variation obtained by one or more testers is $s_g = 0$, give reasons for this. This can occur, for example, only under the following conditions:

a: The resolution of the measuring instrument is not high enough to detect the influences.

b: Error in measuring system (e.g. measuring probe jams).

III. Case: $\%GRR = \%EV > 20\%$ or 30%

⇨ **The measurement process is not suitable.**

The measurement variation must be reduced until the requirement is fulfilled (see also "Procedure: Non-Capable Measurement Processes").

Note:

By converting the inequality $\%EV \leq 20\%$ or 30%, the smallest tolerance specification for which the measurement process can be used for measurements performed according to method 3 can be calculated.

$T_{\min} \geq 5 \cdot GRR$ for new measurement processes

$T_{\min} \geq \frac{10}{3} \cdot GRR$ for measurement processes in use

In the SOLARA evaluation software, T_{min} is shown in a large number of reports as standard.

3.2 Measurement Uncertainty Analysis

The measurement uncertainty analysis according to the VDA5 Volume "Capability of Measurement Processes" is a procedure based on GUM [2] "Guide to the Expression of Uncertainty in Measurement" for verifying the capability of a measuring system, measurement process or measurement process (inspection by attributes).

The uncertainties determined with the common methods 1-3 based on the MSA [1] can be supplemented with a large number of additional uncertainty components. Analogous to the method 1-3, a distinction is made between

- Capability of the measuring system with the characteristic value Q_{MS} (comparable to C_{gk})
- Capability of the measurement process with the characteristic value Q_{MP} (comparable to *%GRR*).

To simplify the selection and the expense of the uncertainty components for the user, a table with standard measuring tasks is provided in 3.2.9. These standard measuring tasks categorized in models are simulated in the SOLARA evaluation software and can be used directly for the calculation.

In principle, the measurement uncertainty analysis according to VDA5 can be used for all measurement processes, however is recommended especially for universally used measuring systems/test equipment.

3.2.1 Methods and Procedures for Determining the Measurement Uncertainty

It employs theoretical considerations regarding which factors have an influence. These are then used as a basis for estimating the expanded uncertainty and, in turn, the impact on the measurement process. It involves the creation of a measurement uncertainty budget containing the influencing components to be taken into account.

In the process, a distinction is made between the

- measuring system with the expanded uncertainty U_{MS} or the characteristic value Q_{MS}

  and the

- measurement process with the expanded uncertainty U_{MP} or the characteristic value.

If the measuring system already fails to meet the requirements, the examination of the measurement process can be eliminated.

The influence of uncertainty components on the measurement result is quantified by determining standard uncertainties $u(x_i)$. The standard uncertainties can be determined as follows:

1. statistical evaluation of measurement series/tests → **Method A**

or

2. use of prior information → **Method B**

The standard uncertainties of methods A and B are treated in the same way.

1	Theoretische Analyse des Messystems und des Messprozesses: Unsicherheitskomponenten benennen	1, 2, …, n
2	Ermittlung der Standardunsicherheiten des <u>Messsystems</u> durch Methode A und/oder B	$u_{(x)i}$
3	Berechnung der erweiterten Unsicherheit U_{MS} und des Kennwertes Q_{MS} des <u>Messsystems</u>	U_{MS}; Q_{MS}
4	Ermittlung der Standardunsicherheiten des <u>Messprozesses</u> durch Methode A und/oder B	$u_{(x)i}$
5	Berechnung der erweiterten Unsicherheit U_{MP} und des Kennwertes Q_{MP} des <u>Messprozesses</u>	U_{MP}; Q_{MP}

Figure 3-6: Generally applicable procedure for determining measurement uncertainties

Method A (standard deviation)

From a measurement series with *n* individual measured values calculated under defined test conditions, the empirical standard deviation s_g of the individual measured value is calculated according to:

$$s_g = \sqrt{\frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}{n-1}}$$

It is determined only once during the measurement uncertainty analysis. n = 20 repeat measurements are recommended for this purpose.

The standard deviation is integrated in the measurement uncertainty budget as the standard measurement uncertainty $u(x_i)$ if, as is usual in case of a practical application, the measurement result is determined with only a one-time measurement.

$$u(x_i) = s_g$$

Note:
With conformity tests or series monitoring, n^* = 1 generally applies. A smaller value of $u(x_i)$ is obtained with the sample size is increased to $n^*>1$.

$$u(x_i) = \frac{s_n}{\sqrt{n^*}}$$

Method A (ANOVA)

If several uncertainty components are verified experimentally according to method A, methods from the design of experiments (DOE) offer themselves. This procedure is already used for method 2 (MSA) with two influences. The advantage is, on the one hand, to reduce the testing scope and, on the other hand, not to have to take certain influences into account multiple times compared to individual tests. The SOLARA evaluation software creates the test schedule to be carried out for the user, depending on the selection of the uncertainty components to be taken into account.

Method B

If the standard uncertainty either cannot be determined according to method A or cannot be efficiently determined, the relevant standard uncertainties can be estimated from previous information. Previous information includes:

- Data from earlier measurements
- Findings or knowledge regarding the behavior and properties of the relevant materials and measuring instruments (similar or identical instruments)
- Information of the manufacturer (e.g. MPE)
- Data from calibration certificates and other certificates
- Uncertainties assigned to reference data in handbooks
- Measured values based on fewer than n = 10 measurements

If the previous information contains values with an expanded measurement uncertainty U and information about the coverage factor k used, the coverage factor k must be taken into account, before the combined standard uncertainty $u(y)$ is created, in the following form:

$$u(x_i) = \frac{U}{k}$$

If this is not known, an error limit a or a different upper and lower limit must be used. Taking into account the distribution, the standard uncertainty $u(x_i)$ is calculated through transformation of the error limit. Typical distributions are shown in Figure 3-7. In the absence of information regarding distribution, uniform distribution is the safest variant to use.

$$u(x_i) = a \cdot b$$

with a = error limit and b = distribution factor

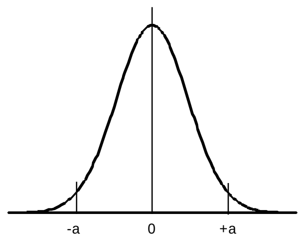
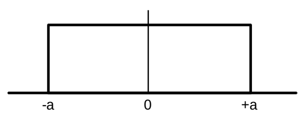
Model	***Diagram*** (*P* = probability with which the values lie within ± *a*)	***Distribution factor b***	***Standard uncertainty u(x)***
Normal dis-tribution	 (*P* = 95.45%)	0.5	$u(x_i) = 0{,}5 \times a$
Uniform dis-tribution	 (*P* = 100%)	$\frac{1}{\sqrt{3}}$	$u(x_i) = \frac{a}{\sqrt{3}}$

Figure 3-7: Typical distributions of error specification limits and their distribution factor b for determining standard uncertainty according to method B.

From the determined uncertainty components (method A and/or method B), the expanded uncertainty U_{MS} for the measuring system and U_{MP} for the measurement process is then calculated via the combined standard uncertainty *u(y)*.

The expanded uncertainty in relation to the tolerance of the characteristic to be examined results in the capability characteristic value *Q*.

3.2.2 Determination of Standard Uncertainties *u(xi)*

The uncertainty components of the measuring system and measurement process which typically occur in practice are determined as the standard uncertainty with the following method:

Standard uncertainties measuring system:

Uncertainty com-ponents in se-quence:	Recommendations / Notes	Method A/B	Source
Resolution of display / of readoff u_{RE}	RE= Smallest estimable scale value (between two graduation lines) for analog display units or reading off of the smallest increment (e.g. 0.1/0.5/1.0) with digital displays. The resolution should be ≤ 5% of the characteristic tolerance. The resolution is within the repeat variation in this case. If the standard uncertainty is to be taken into account due to the resolution, it must be calculated as follows. $u_{RE} = \frac{1}{\sqrt{3}} * \frac{RE}{2} = \frac{1}{\sqrt{12}} * RE$	D	read off / estimate or manufac-turer's specifica-tion

Uncertainty components in sequence:	Recommendations / Notes	Method A/B	Source
Calibration uncertainty of the measurement standard $\boldsymbol{u_{CAL}}$	Typically, the coverage factor k=2 is used for calculations in the area of the measuring technology. To determine the standard uncertainty u_{CAL}, the expanded uncertainty U_{CAL} must then be divided by 2. The respective applicable K-value is contained in the calibration documents. $u_{CAL} = U_{CAL} / k_{CAL}$ **Note** The calibration uncertainty U_{CAL} should be ≤ 5% of the characteristic tolerance	D	Calibration report Manufacturer's spec. Internal calibration
Repeatability $\boldsymbol{u_{EVR}}$ (on measurement standard) an determination of systematic measurement error $\boldsymbol{U_{BI}}$ **(Bias)** Repeatability (with 2 measurement standards at upper and lower tolerance limit) **max** $\boldsymbol{u_{EVR}}$	The uncertainty components can be determined with measuring tests. Before measuring with a measuring system is possible, setting with one or two measurement standards is generally necessary. The deviations from the calibrated value must be taken into account when doing so. **Notes** <u>Measuring test on one measurement standard</u> Generally, at least 20 repeat measurements on one measurement standard. Clamp and unclamp the measurement standard and measure it at the same position during the measuring test (if the influence of the measurement standard is not to be taken into account). Determination of u_{EVR} (standard deviation of random sample) Determination of U_{BI} (Bias) If the relationships of the influencing parameters of the systematic measurement error is known, the measuring system should be corrected using the bias. <u>Measuring test with 2 measurement standards</u> Validation of the tolerance limits or setting of operating points: zero point and amplification. 2x15 repeat measurements must generally be carried out. As for a measuring test with one measurement standard, however at the upper and lower tolerance limit. For the further evaluation, it is recommended that the largest standard uncertainty of u_{EVR1} and u_{EVR2} be used. <u>Model</u> If the influences of the setting procedure are known, then an expressive model can be formed. With mechanical length measuring devices, this can, for example, be the following variables: shape and position deviations of the setting measurement standards, positioning accuracy of the test object, device-dependent manufacturing and assembly tolerances, scanning strategy, evaluation algorithms, calibration and setting positions.	A A D	Measuring test Method 1 Measuring test 2x Method 1

Uncertainty components in sequence:	Recommendations / Notes	Method A/B	Source
Linearity deviation ***u_{LIN}***	<u>Case 1</u> <u>Use of manufacturer's data</u> With specification of value a from manufacturer: $u_{LIN} = 1/\sqrt{3} \times a$	D	Manufacturer's spec.
	<u>Case 2</u> <u>Measuring test with 3 measurement standards</u> Generally at least 10 repeat measurements each on at least 3 measurement standards (references) and from this. Minimum sample size is 30. Clamp and unclamp measurement standard and measure at same position during measuring test. Determine u_{EVR} and u_{BI} for each measurement standard. The respectively largest value is selected as the uncertainty component. $u_{EVR} = max. \{u_{EVR1}, u_{EVR2}, u_{EVR3}\}$ $u_{BI} = max. \{u_{BI1}, u_{BI2}, u_{BI3}\}$ *In this case, the standard uncertainty* u_{LIN} *is contained in* u_{BI}*,* *i.e.* $u_{LIN} = 0$.	A	Measuring test with three measurement standards
	<u>Case 3</u> <u>Measuring test with three or more measurement standards (regression function)</u> When using this method, the regression function must be taken into account computationally in the measuring software, as with this method for the evaluation of u_{LIN} only those computationally corrected values are output, which are not taken into account in the measuring system.	A	Measuring test with measurement standards

Figure 3-8: Typical uncertainty components of measuring system

Standard uncertainties of measurement process:

Uncertainty components in sequence:	Recommendations / Notes	Method A/B	Source
Comparability of operator (operator influence) with series production parts ***u_{AV}***	Generally 2 repeat measurements each on 10 test objects with 2 or 3 operators **Note** The test objects used for the measuring test should be distributed over the entire tolerance range. Clamp and unclamp the test objects and measure them at the same position during the measuring test.	A	Measuring test Method 2

	Sequence for repeat measurements: Measure test object 1 up to n and then repeat. With the measurement series, it must be ensured that the results of the previous measurement are no longer familiar to the individual operator. Determination of u_{AV} using the ANOVA method.		

Uncertainty components in sequence:	Recommendations / Notes	Method A/B	Source
Repeatability without operator influence with series production parts $\boldsymbol{u_{EVO}}$	Generally 2 repeat measurements each on 20 test objects. Use with (partially) automated measuring systems or when the operator has no influence on the measurement result. **Note** The test objects used for the measuring test should be distributed over the entire tolerance range. Clamp and unclamp the test objects and measure them at the same position during the measuring test. Sequence for repeat measurements: Test object 1 up to n and then repeat. With the measurement series, it must be ensured that the results of the previous measurement are no longer familiar to the operator. Mutual influencing of component, measuring system, etc. is included in the result.	A	Measuring test Method 3
Comparability of identical measuring systems (measuring points) $\boldsymbol{u_{GV}}$	Relevant from at least 2 measuring systems. **Analysis** <u>The following generally applies for the measurement standards:</u> Consideration of the variation share per measuring point. Comparison of the measured $\bar{x}$ values to the calibrated values (bias). Max – Min consideration of the measured $\bar{x}$ values for the various identical measuring systems. <u>The following generally applies for series production parts:</u> Consideration of the variation share per measuring point. Max – Min consideration of the measured $\bar{x}$ values or of the measured individual values xi per series production part for the various identical measuring systems. Mutual influencing of component, measuring systems, etc. is included in the result. These uncertainty components determined with tests will be taken into account with the variance analysis (ANOVA). **Note** Conducting with the same setting measurement standards and series production parts. Clamp and unclamp the test objects in the 2 to n measuring systems and measure them at the same position during the measuring test.	A	Measuring test Method 1 and 3

Uncertainty components in sequence:	Recommendations / Notes	Method A/B	Source
Comparability at different points in time $\boldsymbol{u_{STAB}}$	<u>Short-term consideration</u> The stability of a measuring instrument is generally not the object of examination in a short-term consideration. <u>Long-term stability analysis</u> If during the first or basic examinations it is suspected that the measurement results change over time, it is recommended that this uncertainty be determined with defined measurement series <u>Long-term stability monitoring of measurement process capability (stability of a measuring instrument)</u> Used for continuous monitoring of critical characteristics or measurement processes **Note** Setting measurement standards or series production parts can be used as checking parts. For example, the values will be entered in control charts and the measurement process monitored with action limits. If the action limits are violated, U_{MP} must be corrected accordingly.	A	Measuring tests Method 1 and Method 2 or 3
Shape deviation / surface texture / material property of test parts $\boldsymbol{u_{OBJ}}$	The following options are available for determining the standard uncertainty as a result of a shape deviation: - Drawing specification (max. permissible shape deviation) $u_{OBJ} = \frac{a_{OBJ}}{\sqrt{3}}$ - Control chart for production (actual shape deviation) - Test objects for measuring test (actual shape deviation) The test objects used for the measuring test (at least 5) should be distributed over the entire tolerance range and should be representative for the shape deviation to be expected. All additional possible properties must be taken into account separately if it is suspected or existent through measuring tests, from table or manufacturer's data.	D D A	Drawing Control chart Measuring test Technical data manual/Materials data sheet

Uncertainty components in sequence:	Recommendations / Notes	Method A/B	Source
Temperature $\boldsymbol{u_T}$	To determine the uncertainty due to the temperature influence, the following considerations must be taken into account: is temperature compensation provided Yes/No? Regardless of a compensation or if complex relationships with unknown expansion coefficients exist, the actual expansion behavior should be determined with a measuring test. In the process, the measurement standards and the test objects are heated and examined during the cool-down phase. The difference *a* between the *max* and *min* value will be utilized to estimate u_T.	A/B	Measuring test See Appendix
Further influences $\boldsymbol{u_{rest}}$	All additional possible influences must be taken into account separately if it is suspected or existent through measuring tests, from table or manufacturer's data.	A/B	Measuring test Various documents

Figure 3-9: Typical uncertainty components of measurement process

3.2.3 Determination of Combined Standard Uncertainty *u(y)*

The combined standard uncertainty *u(y)* is calculated with quadratic addition of all standard uncertainty components determined according to method A and B.

$$u(y) = \sqrt{\sum_{i=1}^{n} u(x_i)^2} = \sqrt{u(x_1)^2 + u(x_2)^2 + \ldots + u(x_i)^2}$$

Note: The calculation is carried out under the assumption: sensitivity coefficient = 1.

3.2.4 Determining the Expanded Measurement Uncertainty

Expanded measurement uncertainty is obtained by expanding the combined standard uncertainty *u(y)*

$$U_{MS/MP} = k \cdot u(y) \qquad \text{with } k = \text{coverage factor}$$

k = 2 (confidence level 95.45%) must be selected as the coverage factor.

Note:
The calculation of the expanded uncertainty U_{MS} or U_{MP} is based on a probable density function of the combined measurement uncertainty limited bilaterally to the level of $P = 1 - \alpha = 0{,}9545$ with $\alpha / 2$ in each case outside the quantile limits.
With a symmetrical distribution, $U_{MP} = k \cdot u(y)$ therefore results for the calculation of the expanded measurement uncertainty and with assumption of a measurement standard distribution of $k = z_{1-\alpha/2} = 2$.

Should the conditions with regard to the random sample size for the assumption of the measurement standard distribution be violated during the experimental determination (Method A) of the uncertainty components, then k must be calculated from the quantiles of the Student/t distribution via the degree of freedom. The coverage factor k with the degree of freedom $f = n-1$ can be found in Table 7-1.

Theoretically, indications could be available with components estimated from method B that they are only to be considered reliable in a certain percentage. In this case, the effective degree of freedom will be calculated with the Welch-Satterthwaite formula, with which k is determined from the quantiles of the Student/t distribution (see Table 7-1).
Degrees of freedom are rounded down and the coverage factor is rounded up.

3.2.5 Determining Capability Characteristic Values

To evaluate the measuring-related requirement for the measuring system and the measurement process, the capability characteristic values Q_{MS} will be introduced for the measuring system and Q_{MP} for the measurement process. They are defined as a percentage of the ratio:

$$Q_{MS} = \frac{2 \cdot U_{MS}}{TOL} \cdot 100\% \quad \text{or} \quad Q_{MP} = \frac{2 \cdot U_{MP}}{TOL} \cdot 100\%$$

The capability characteristic values are assigned corresponding specification limits Q_{MS_max} or Q_{MP_max}.
If the requirement for

the measuring system	$Q_{MS} \leq Q_{MS\_max}$	with Q_{MS_max} = ***15%***	and
the measurement process	$Q_{MP} \leq Q_{MP\_max}$	with Q_{MP_max} = **30%**.	

are met, the capability has been verified. On failure to meet this requirement, the variation shares of the uncertainty components must be reduced until the requirement is met (also see the procedure "Non-capable measurement process" on this subject).

Note:
If conformity tests are conducted, the calculated expanded measurement uncertainty U_{MP} according to DIN 14253-1 [4] must be taken into account at the specification limits, refer to Chapter 1.4.

3.2.6 Minimum Possible Tolerance for Measuring Systems/Measurement Processes

By converting the capability characteristic value formula according to TOL and use of Q_{MS_max} or Q_{MP_max} in Q_{MS} or Q_{MP}, the minimum tolerance can be calculated for which both the measuring system and the measurement process is just barely suitable.

$$TOL_{MIN\text{-}UMS} = \frac{2 \times U_{MS}}{Q_{MS\_\max}} \times 100\% \qquad \text{or} \qquad TOL_{MIN\text{-}UMP} = \frac{2 \times U_{MP}}{Q_{MP\_\max}} \times 100\%$$

This procedure can be especially useful for standard measuring instruments and universally used measuring systems, as it enables the user to choose a suitable measuring system for his/her measuring task. However, TOL_{MIN} always applies for the examined measuring ask with identical conditions (also refer to T_{min} with Method1/2/3).

3.2.7 Capability Verification of Measuring System Q_{MS}

Before the entire measurement process is examined, first the capability of the measuring system Q_{MS} must be verified. Should the measuring system already fail to meet the requirements, the further consideration of the measurement process Q_{MP} is generally void, as the additional influences or uncertainty components of the measurement process will only make it worse.

The following describes procedure for the verification of capability of the measuring system. The individual uncertainty components and their determination are explained in detail in Chapter 3.2.1.

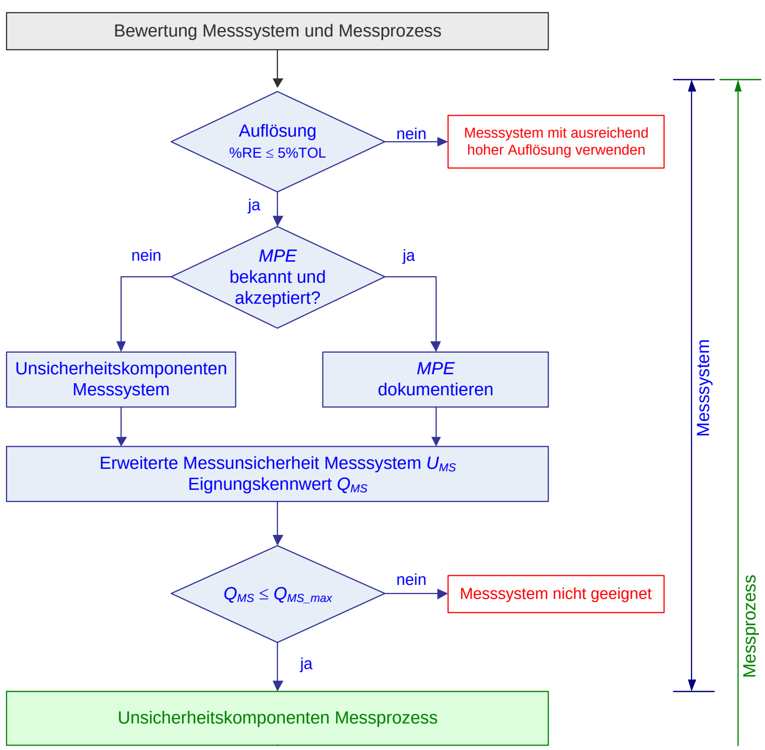


Figure 3-10: Procedure for verification of capability of measuring system

Note:
The selection of the standard uncertainties to be taken into account is the responsibility of the expert and must be redefined for each measuring system. To simplify the selection and the expense of the uncertainty components for the user, a table with standard measuring tasks is provided in Chapter 3.2.9. These standard measuring tasks categorized in models are simulated in the SOLARA evaluation software and can be used for the calculation.

Determining standard uncertainty of the test equipment type u_{MS} from error specification limits MPE (method B)

The determination of the uncertainty component of the measuring system can be eliminated if the error limit MPE is verified and documented. Error specification limits are the maximum permissible errors of a measuring instrument or measuring system. For this type, each value can occur within the limits with the same probability (uniform distribution). The estimation of the standard uncertainty is therefore calculated from the error limits as:

$$u_{MS} = MPE \big/ \sqrt{3}$$

If more than one MPE value affects the combined standard uncertainty of the measuring system, it can be calculated according to the following formula.

$$u_{MS} = \sqrt{\frac{MPE_1^{\;2}}{3} + \frac{MPE_2^{\;2}}{3} + \ldots}$$

Note:
This procedure is recommended especially for universally used measuring instruments or measuring system. Should no further influences result from the measurement process, it can be determined and documented with the MPE TOL_{min} (Chapter 3.2.6). The user can then selected a capable measuring instrument or measuring system depending on the measuring task and the characteristic tolerance to be checked.

3.2.8 Verification of Capability of Measurement Process Q_{MP}

In addition to the described uncertainty components of the measuring system, the further uncertainty components of the measurement process $u(xi)$ must be determined for when evaluating the measurement process.

The individual standard uncertainties and their determination are described in Chapter 3.2.2. The procedure of the verification of capability of the measurement process is shown in the following illustration.

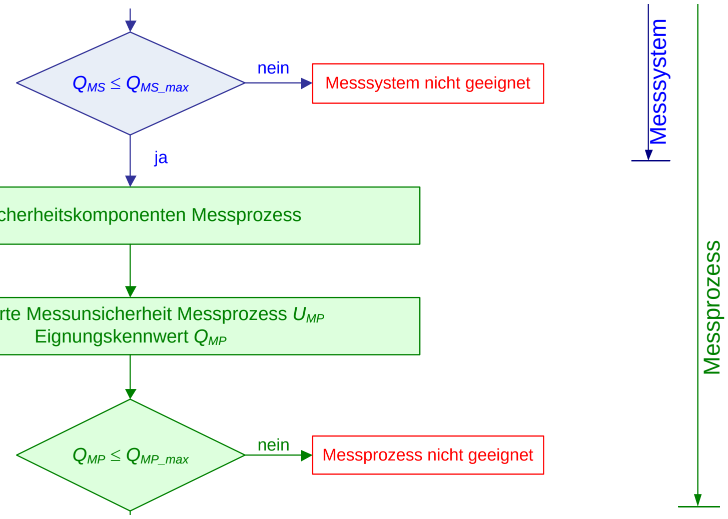


Figure 3-11: Procedure for verification of capability of measurement process

Finally, a general overview of the measurement uncertainty analysis including the algorithm for determining the characteristic values is provided in the following. According to this procedure, the SOLARA evaluation software automatically calculates the capability characteristic value Q_{MP} and the individual standard uncertainties *u(xi).*

Unsicherheits-komponenten	Symbol	Kombinierte Messunsicherheiten	Erweiterte Messun-sicherheiten	Eignung Minimale Toleranz
Kalibrierung Normal	u_{CAL}	$u_{MS} = \sqrt{u_{CAL}^2 + \max\{u_{EVR}^2,\ u_{RE}^2\} + u_{BI}^2 + u_{LIN}^2 + u_{MS\_REST}^2}$ oder $\sqrt{\frac{MPE^2}{3}}$ oder $\sqrt{\frac{MPE_1^2}{3} + \frac{MPE_2^2}{3} \ldots}$	$U_{MS} = k \cdot u_{MS}$	$Q_{MS} = \frac{2 \cdot U_{MS}}{TOL} \cdot 100\%$ $T_{MIN-UMS} = \frac{2 \cdot U_{MS}}{Q_{MS\_max}} \cdot 100\%$
Systemtische Messabweichung	u_{BI}			
Linearitätsabweichung	u_{LIN}			
Wiederholbarkeit am Normal	u_{EVR}			
Rest MS	u_{MS_REST}			
Grenzwert der Messabweichung	MPE			
Wiederholbarkeit am Prüfobjekt	u_{EVO}	$u_{MP} = \sqrt{u_{CAL}^2 + \max\{u_{EVR}^2,\ u_{EVO}^2,\ u_{RE}^2\} + u_{BI}^2 + u_{LIN}^2 + u_{AV}^2 + u_{GV}^2 + u_{STAB}^2 + u_{OBJ}^2 + u_T^2 + u_{REST}^2 + \sum_i u_{IA_i}^2}$	$U_{MP} = k \cdot u_{MP}$	$Q_{MP} = \frac{2 \cdot U_{MP}}{TOL} \cdot 100\%$ $T_{MIN-UMP} = \frac{2 \cdot U_{MP}}{Q_{MP\_max}} \cdot 100\%$
Vergleichbarkeit der Bediener	u_{AV}			
Vergleichbarkeit d. Messvorrichtungen	u_{GV}			
Vergleichbarkeit Zeitpunkte	u_{STAB}			
Wechselwirkung(en)	u_{IAi}			
Inhomogenität Prüfobjekt	u_{OBJ}			
Auflösung Anzeige	u_{RE}			
Temperatur	u_T			
Rest	u_{REST}			

Figure 3-12: *Determination of the expanded uncertainty of the measuring system, the measurement process and their capability*

3.2.9 Overview of Typical Measurement Process Models

To simplify the selection of the uncertainty components to be taken into account for the user, standard measuring tasks are categorized in models in the following table. These are shown in the SOLARA evaluation software and can be used directly for calculation.

	1 Auflösung der Anzeige u_{RE}	2 Kalibrierunsicherheit u_{CAL} oder Fehlergrenzen MPE	3 Einstellunsicherheit u_{BI} oder Bias	4 Wiederholbarkeit mit Normal(en) u_{EVR}	5 Linearität mit Normalen u_{LIN}	6 Vergleichbarkeit der Bediener mit Serienteilen u_{AV}	7 Wiederholbarkeit mit Serienteilen u_{EVO}	8 Vergleichbarkeit gleicher Messsysteme (Messstellen) u_{GV}	9 Vergleichbarkeit zu unterschiedlichen Zeitpunkten u_{Stab}	10 Formabweichung / Oberflächen-Materialeigenschaft Messobjekte u_{OBJ}	11 Temperatur u_T	12 Weitere Einflüsse u_{Rest}
Model A Kalibrierunsicherheit des Normals	Green	Green	Yellow	Green	Yellow	Gray	Gray	Gray	Green	Green	Green	Yellow
Model B Annahmeprüfung des Messprozesses für Standardmesssysteme	Green	Green	Yellow	Gray	Gray	Yellow	Yellow	Yellow	Gray	Yellow	Yellow	Yellow
Model C Abnahme-/ Annahmeprüfung von Messsystemen	Green	Green	Green	Green	Yellow	Gray	Gray	Yellow	Gray	Gray	Gray	Yellow
Model D1 Annahmeprüfung des Messprozesses mit Bedienereinfluss ohne Serienteileinfluss (Serienteile lageorientiert messen)	Green	Green	Green	Green	Yellow	Green	Green	Yellow	Yellow	Gray	Green	Yellow
Model D2 Annahmeprüfung des Messprozesses **ohne Bedienereinfluss** ohne Serienteileinfluss (Serienteile lageorientiert, halb / automatisch zugeführt)	Green	Green	Green	Green	Yellow	Gray	Green	Yellow	Yellow	Gray	Green	Yellow
Model E1 Konformitäts- / Annahmeprüfung des Messprozesses mit Bedienereinfluss mit Serienteileinfluss	Green	Green	Green	Green	Yellow	Green	Gray	Yellow	Yellow	Green	Green	Yellow
Model E2 Konformitäts- / Annahmeprüfung des Messprozesses **ohne Bedienereinfluss** mit Serienteileinfluss (Serienteile halb / automatisch zugeführt)	Green	Green	Green	Green	Yellow	Gray	Green	Yellow	Yellow	Green	Green	Yellow

Green = Must always be taken into account
Yellow = Take into account if existent
Gray = Eliminated with the model

Figure 3-13:: Typical measurement process models and respective uncertainty components

3.3 Stability of a Measuring Instrument / Stability (u_{STAB})

The aforementioned methods for performing capability and uncertainty analyses generally only involve short-time analyses, which is why continuous monitoring of the capability is recommended.

Preparation:

1. A measurement standard/master or calibrated component must be available whose correct value is traceable to national or international measurement standards and does not change over time. The measurement uncertainty with which the correct value for this measurement standard is determined must be specified.
2. The stability of a measuring instrument is monitored with a Shewhart quality control chart (QCC). Here the specification of the specification limits is based on
    - the mean value with: -the reference value of the measurement standard or
      -the mean value from Method 1
    - and the variation with: -the standard deviation s_g from Method 1 or u_{EV} or
      -3.75% of the tolerance (with k=2).
3. For the stability verification, the first step is to perform checks at short intervals. Based on the results, an interval must be defined at which further, regular checks should take place. For this purpose, a random sample whereby n=2 or 3 must be taken at different times, from different layers and so on and entered in the quality control chart.

Measurement and analysis:

Step 1
Document the data regarding the measuring system, measurement standard, characteristic, tolerance, etc.

Step 2
Enter the action limits in the control chart. The sample size can be between 2 and 5.

Step 3
Using the measurement standard, set the measuring system in accordance with the relevant instructions.

Step 4
Perform at least two individual measurements on the measurement standard and/or workpiece at the defined test intervals in accordance with the relevant instructions. Do not make any adjustments during the measurement stability check.

Step 5
After each stability check, enter the measurement results in the quality control chart.

Step 6

Assessment and measures during the measurement stability check:

I. Case: The measured values lie within the action limits.

⇨ **The stability has been verified**

It is sufficient to set the measuring system at specified intervals.

II. Case: The specified action limits are exceeded or not reached due to a trend:

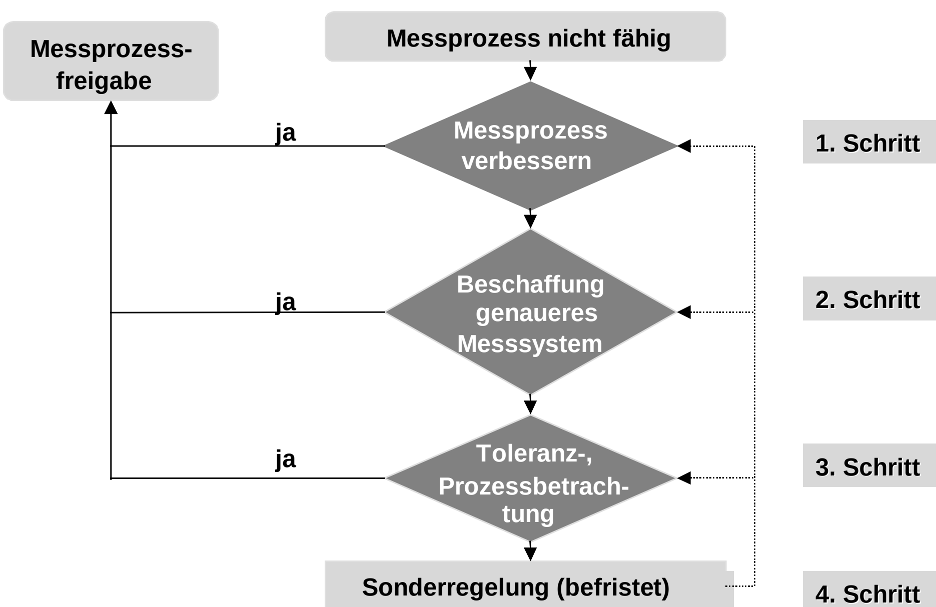
⇨ **Stability is not ensured; the interval is too long.**
The interval must be shortened so that no action limit violations occur.

III. Case: The specified limits are exceeded and are not reached in short periods so that no stable phase can be recognized for the measuring system.

⇨ **Stability is not ensured; the measurement process is not suitable.**
Improvements must be made (see also "Procedure: Non-Capable Measurement Processes").

3.4 "Non-Capable Measurement Processes" Procedure

If a measurement process is deemed not capable in accordance with the aforementioned methods, the following procedure and resulting potential measures are recommended:



<u>Step 1: Check/improve measurement process</u>

- **Measuring equipment, setting gages**
  - Measuring, application and hold-down forces
  - Measurement locations, definition of measurement points
  - Holders, alignment of test object, measuring sensor
  - Probe element; quality of setting gage(s)
  - Guides, friction, wear
  - Positioning, tilt of test object
  - Measurement procedure; warm-up phase, etc.

- **Measuring method, strategy**
  - Datum feature, basis for recording
  - Measurement speed, settling times
  - Multi-point measurements/scanning instead of individual measured value
  - Average value from repeat measurements
  - Measuring technology, statistics software
  - Calibration chain, adjustment procedure, etc. (e.g. re-adjustment prior to each measurement)
- **Ambient conditions**
  - Jarring, vibrations
  - Dust, oil mist, drafts, humidity
  - Temperature fluctuations
  - Electrical interference, voltage peaks
  - Energy fluctuations (air, current, etc.)
- **Test object**
  - Cleanliness, wash residue
  - Surface texture, burrs
  - Formal defects, reference basis
  - Material properties
  - Temperature coefficient, etc.
- **Operator**
  - Instructed, trained
  - Care, handling
  - Cleanliness, (skin, hand grease, etc.)
  - Heat transfer, etc.

<u>Step. 2: Obtain a more accurate measuring system</u>

Potential measures:

- Resolution < 5%
- Use linear systems
- Give preference to absolutely measuring systems
- Sturdy measuring system (mounts, guides, measuring lever, transmission elements, etc.)
- Operator-independent measuring system
- New (non-contact) measuring method, etc.

<u>Step 3: Characteristic, tolerance, process analysis</u>

Potential measures:

- Check functional interdependency of characteristic (if necessary, define a new characteristic, e.g. leak tightness instead of roundness)
- Read out 100% with reduced tolerances
- Deduct measuring system variation from tolerance
- Take into account impact on process control and capability
- Adjust tolerance (statistical toleration; contrast tolerance with process variation; "honesty" of tolerance); Coordination with Production Engineering, Production, Quality Assurance, Product Engineering, customer

Step 4: Special rule

- Additional validation (e.g. stability monitoring, additional quality feedback loop, more precise measuring equipment in precision measurement room, functional validation and checking)
- Specify special rules for a limited time; coordination with measuring technology experts, Production Engineering, Production, Quality Assurance, Product Engineering, customer

Reassess this rule, for example every year, as described in steps 1 to 4 and, if necessary, revise the rule or keep it in place for a further period of time.

Note:

It must be noted that the measuring instrument is not always the cause of a non-suitable measurement process. The creator, environment or measurement strategy is often at fault.

4 Case Studies

The procedure of the measurement process capability and the user interface of the SOLARA evaluation software differ depending on the selected procedure chosen for the validation of capability.

The following case studies use concrete data to show the different possibilities and methods of verifying measurement process capability. All examples can be called in SOLARA as a DFQ file in the folder GC/Daimler/ or VDA5_Case examples.

Note:
Before the measurement process capability is verified, all the required organizational preparations must be made to ensure that the process runs smoothly. The acceptance should be performed in consultation with the process managers (e.g. operator, measuring center, etc.). It is irrelevant here whether the acceptance takes place at the contractor's site or at the final installation location. In particular, the contractor should confirm on the basis of a completed and signed checklist that the required preparations have been made. Above all, the agreed specification limits contained in the requirements specification must be observed.

4.1 Conducting a Capability Analysis with SOLARA

The basic procedure for a capability analysis (Method 1/2/3) and the entry of the data in SOLARA are described here. Any differences in the details will be explained in the case studies themselves.

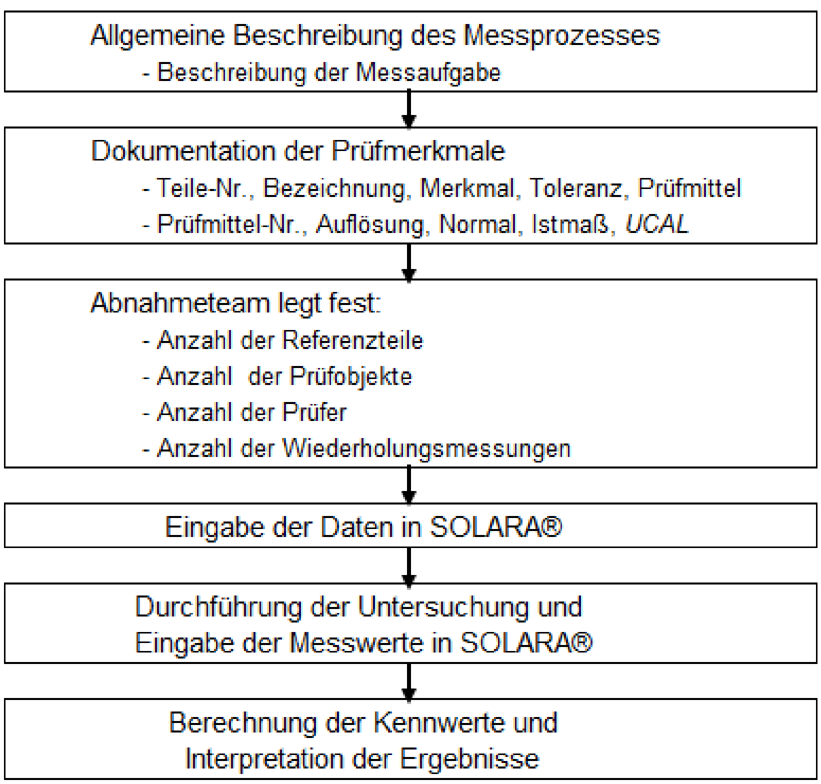


Figure 4-1: Flow diagram for conducting capability analysis

4.1.1 Creation and Data Input

Depending on the phase of the capability analysis, the corresponding Method 1, 2 or 3 must be selected.

Open SOLARA, New file, 1 characteristic Method 1, 2 or 3.

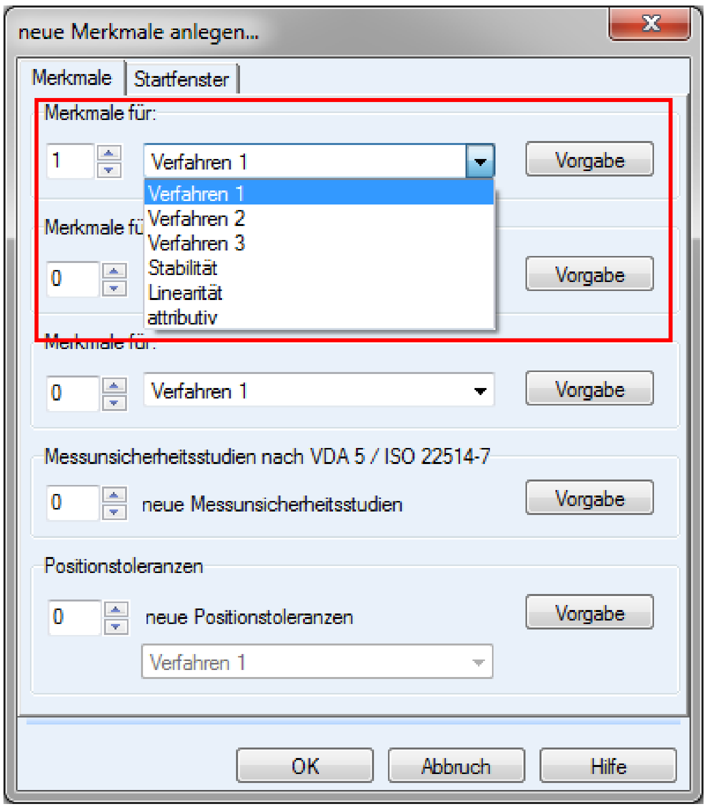


Figure 4-2: Creating a capability analysis

After selection and confirmation, the parts, characteristic and values mask appears.

Key part information is first entered in the part form  (see Figure 4-3). All the fields in this form are optional. However, it is always a good idea to enter the part number and designation.

Often, information about the start and end of testing is also useful. The reason for testing should also be entered, as well as additional information about the measurement process in the "comments" column.

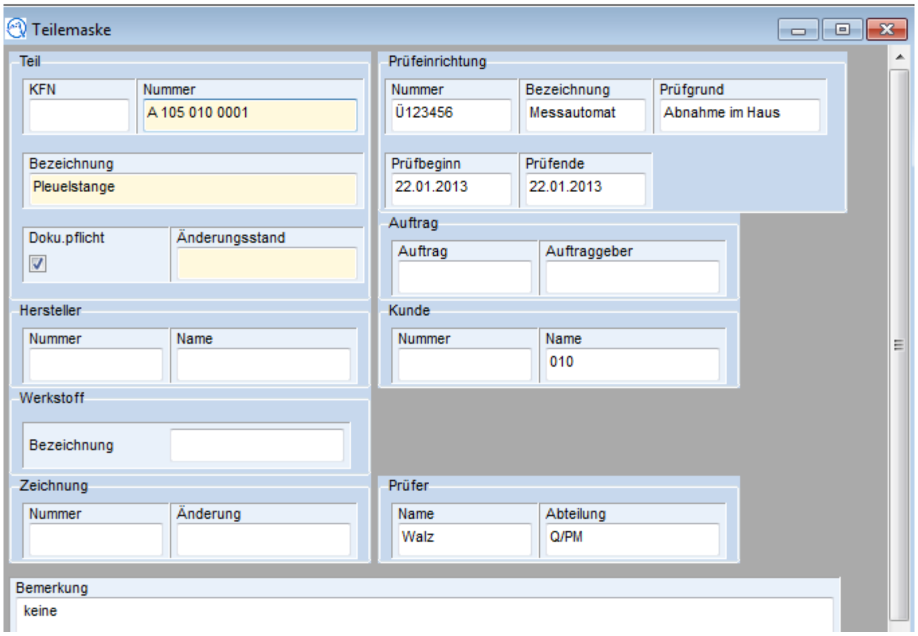


Figure 4-3: Key part data

Information important for the analysis can be found in the characteristic form (see Figure 4-4). In addition to the characteristic name and number, the specification thresholds and resolution must always be entered. In the "Digits after decimal point" (Nachkommastellen) field, you can specify how many digits after the decimal point are displayed when the data are entered or when the data are transferred automatically from the measuring instrument.

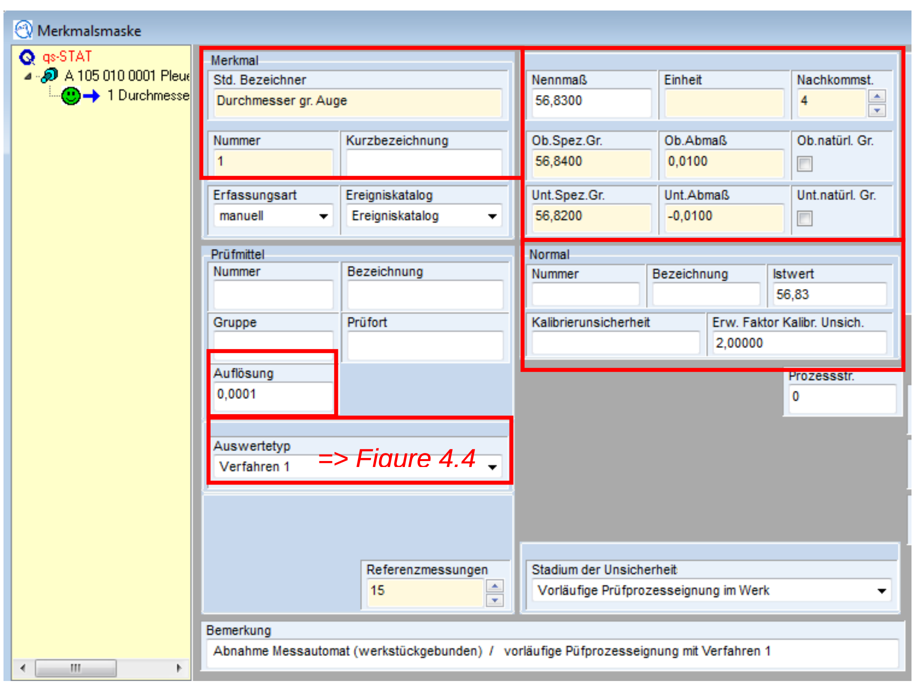
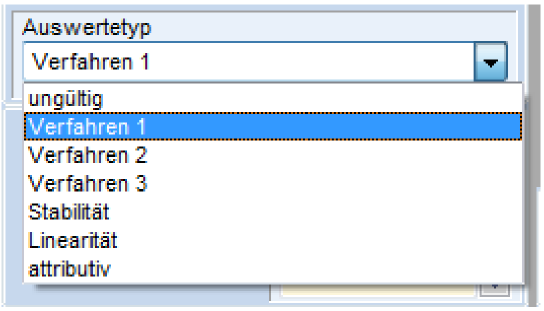


Figure 4-4: Important characteristic data and selection of the analysis method

The actual value of the measurement standard and the calibration uncertainty of the measurement standard U_{CAL} must be entered in the "Measurement Standard" section. This is the expanded measurement uncertainty specified on the calibration certificate, which is why the coverage factor (k) used during calibration must also be entered.



The method to be carried out is specified in the evaluation type. Dependent on this is whether further data need to be specified, such as the number of parts to be measured, the number of testers and their repeat measurements as well as the number of reference measurements. Correspondingly, the input form for the measured values (Figure 4-6) is displayed.

Figure 4-5: Evaluation type

4.1.2 Conducting and Entry of Measured Values

To verify measurement process capability, the measurements are performed in accordance with the specifications. The measured values are then entered in the value form supplied from the characteristics form in accordance with the specifications (Figure 4-6).

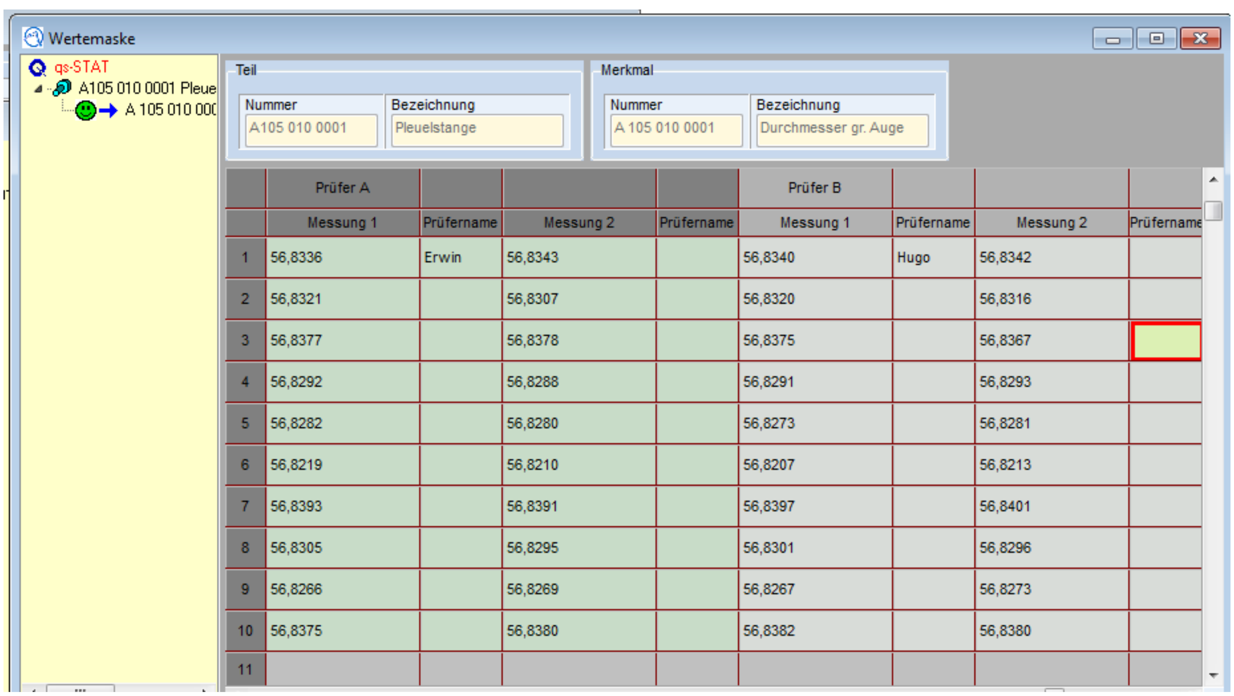


Figure 4-6: Entering measured values

4.1.3 Calculating and Analyzing Characteristic Values

To calculate the characteristic values, choose "Analysis" (Auswertung). The results of the calculation can either be opened via the "Numerics / Forms" (Numerik / Formblätter) menu (Figure 4-7) or printed out as a standard report.

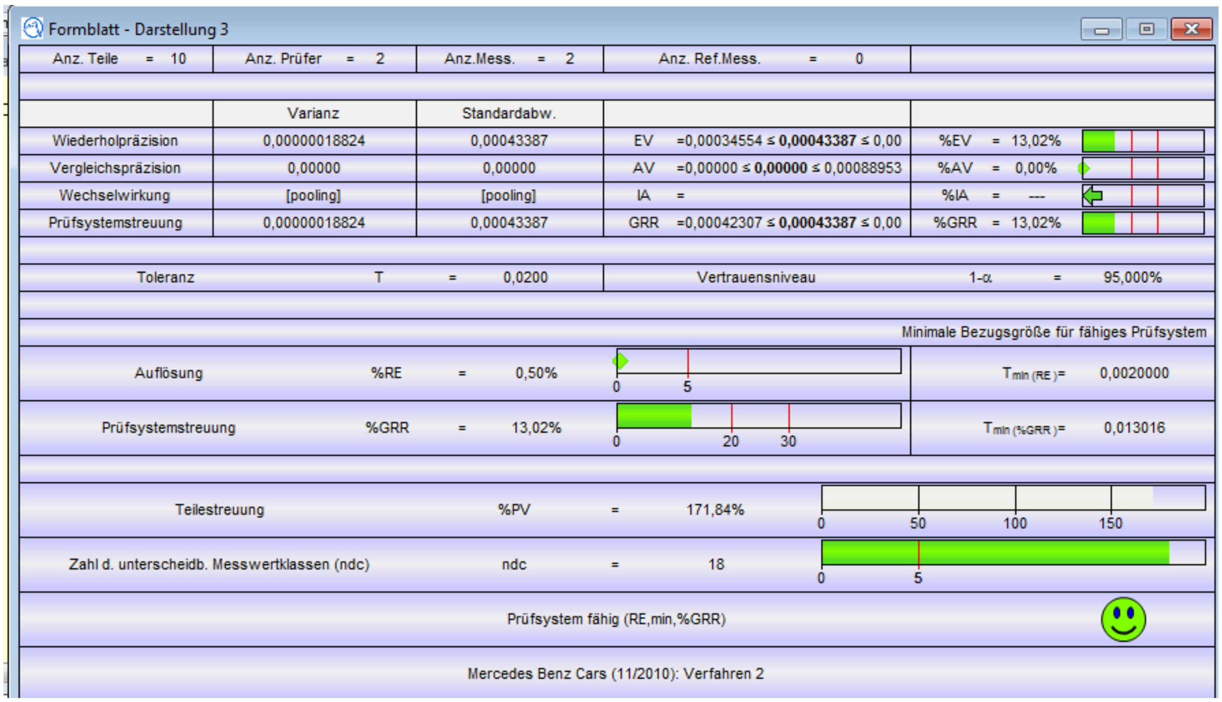


Figure 4-7: Analysis results

4.1.4 Case Study for Method 1

(*SOLARA file: LF05 V1.DFQ*)

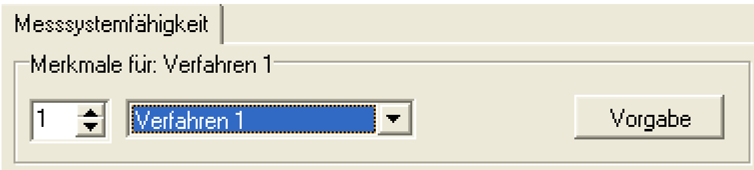
You have been tasked with performing an acceptance test on an automatic measuring system for connecting rods. The automatic measuring system was recently constructed on a production line.

It is used on a workpiece-specific basis and is designed to determine, among other things, the diameter of the large eye on a connecting rod. The characteristic is specified at 56.83 +/- 0.01 mm.

A measurement standard with the calibration value 56.83 mm is available and measurement process capability is provisionally to be verified with a method 1 capability analysis.

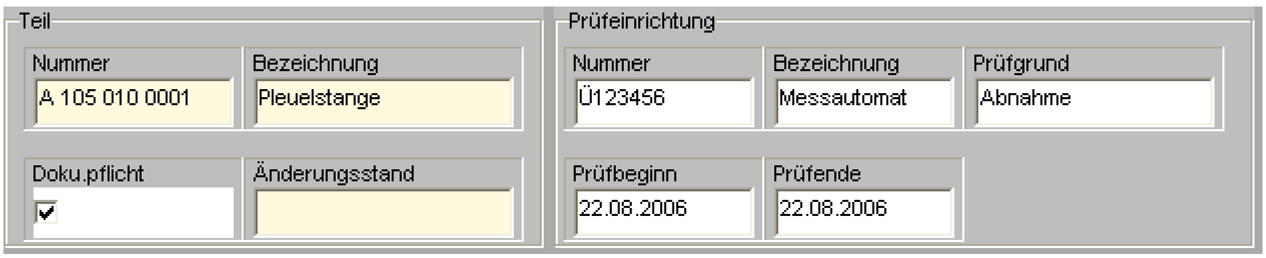
Procedure:

- To create a new method 1 capability analysis, choose "File / New" (Datei / neu) in SOLARA.

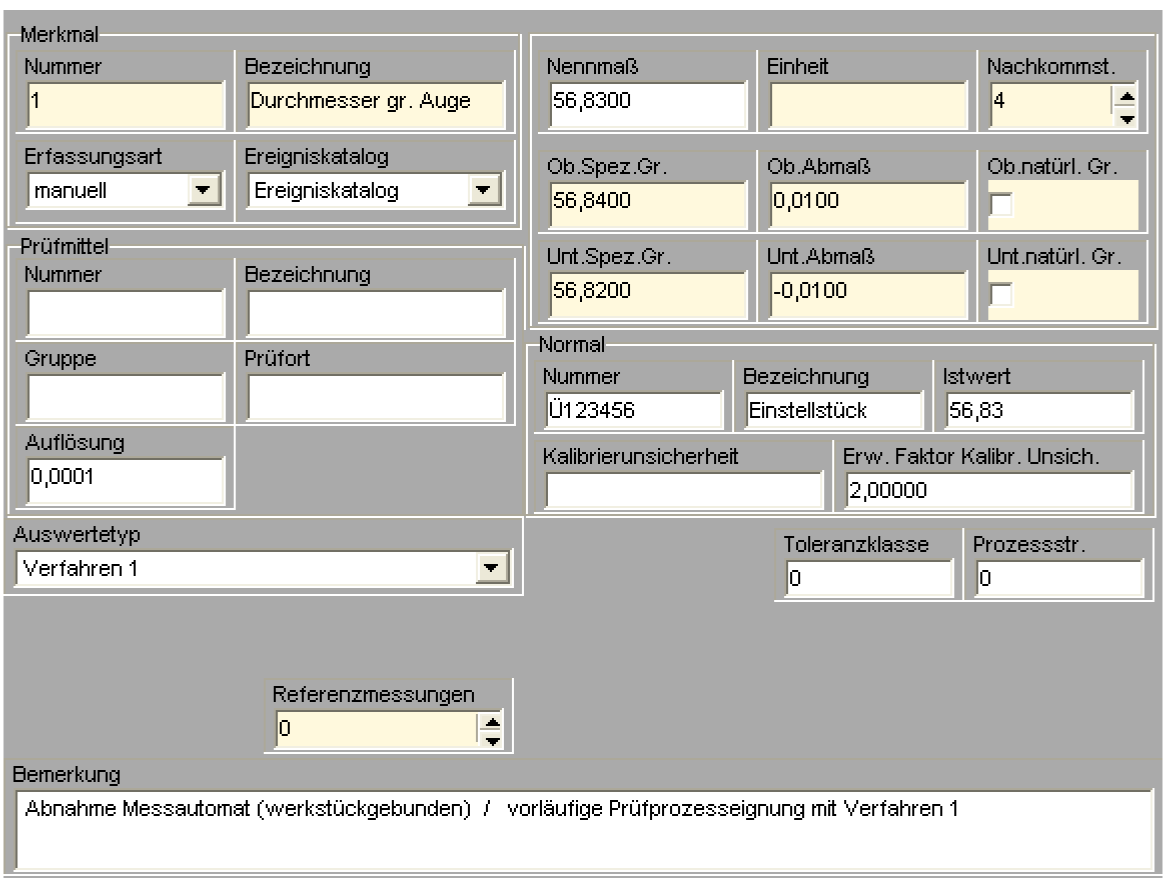


- Alternatively, open an existing method 1 capability analysis by choosing "Open" (öffnen).

- Open the part form and enter the component and test facility data.

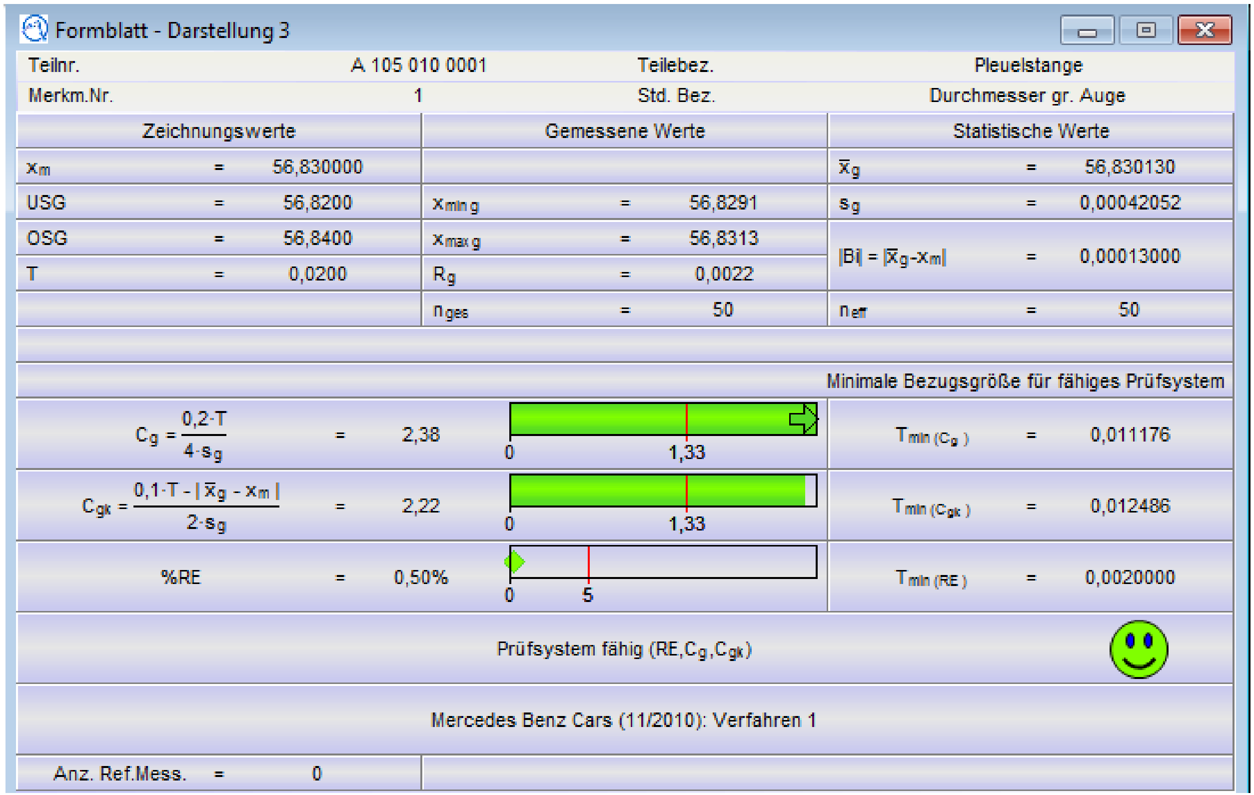


- Open the characteristic form and enter the characteristic data.



- Perform measurements according to method 1 and enter the measured values in the value form .

- Then perform a calculation by choosing "Analysis" (Auswertung). The results of the calculation can either be opened via "Numerics / Forms" (Numerik / Formblätter) or printed out as a standard report ("Method 1 capability analysis").



Formblatt - Darstellung 3

Teilnr.	A 105 010 0001	Teilebez.	Pleuelstange
Merkm.Nr.	1	Std. Bez.	Durchmesser gr. Auge

Zeichnungswerte	Gemessene Werte	Statistische Werte
x_m = 56,830000		$\bar{x}_g$ = 56,830130
USG = 56,8200	$x_{min\,g}$ = 56,8291	s_g = 0,00042052
OSG = 56,8400	$x_{max\,g}$ = 56,8313	$\lvert Bi \rvert = \lvert \bar{x}_g - x_m \rvert$ = 0,00013000
T = 0,0200	R_g = 0,0022	
	n_{ges} = 50	n_{eff} = 50

Minimale Bezugsgröße für fähiges Prüfsystem

$C_g = \frac{0{,}2 \cdot T}{4 \cdot s_g}$	= 2,38	0 … 1,33	$T_{min\,(C_g)}$ = 0,011176
$C_{gk} = \frac{0{,}1 \cdot T - \lvert \bar{x}_g - x_m \rvert}{2 \cdot s_g}$	= 2,22	0 … 1,33	$T_{min\,(C_{gk})}$ = 0,012486
%RE	= 0,50%	0 … 5	$T_{min\,(RE)}$ = 0,0020000

Prüfsystem fähig (RE,C_g,C_{gk})

Mercedes Benz Cars (11/2010): Verfahren 1

Anz. Ref.Mess. = 0

Assessment of results

- The test system is capable.

4.1.5 Case Study for Method 1: Imbalance

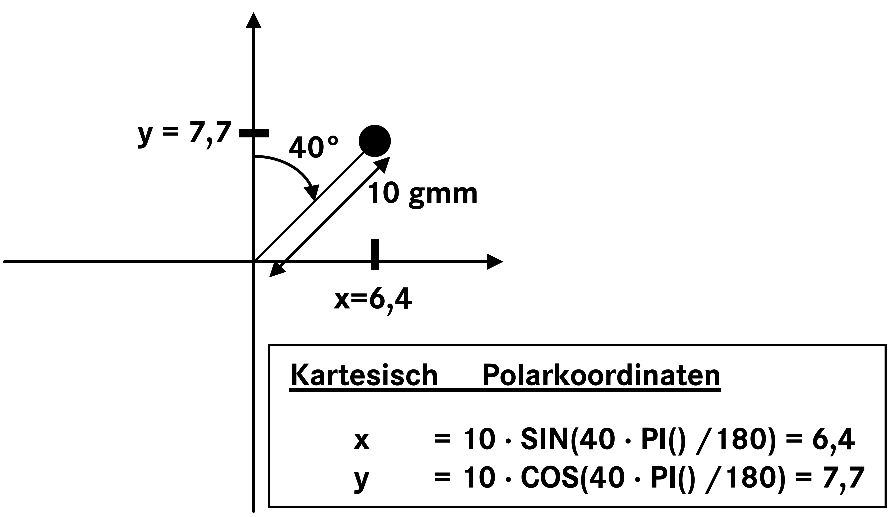
Acceptance and requalification of measurement and production processes with multi-dimensional quality characteristics on the basis of multi-dimensional capability characteristics.

Introduction

This section describes by way of example the acceptance procedure for **balancers**.

Balancers are devices used for both **measuring** and **balancing** (e.g. by drilling or grinding) imbalances. This balancing takes place on the basis of the previously measured imbalances.

The **vectorial** variable "imbalance" here is **two-dimensional** and **bivariate**. To specify imbalance, either the scalar quantities "imbalance value" and "imbalance direction" (polar coordinates) or "imbalance horizontal component" and "imbalance vertical component" (Cartesian coordinates) are used.



Regardless of the imbalance variable under analysis here, the methods used can also be applied if the multi-dimensionality is the result not of a vectorial measurand, but for example **multiple coordinates** of a position.

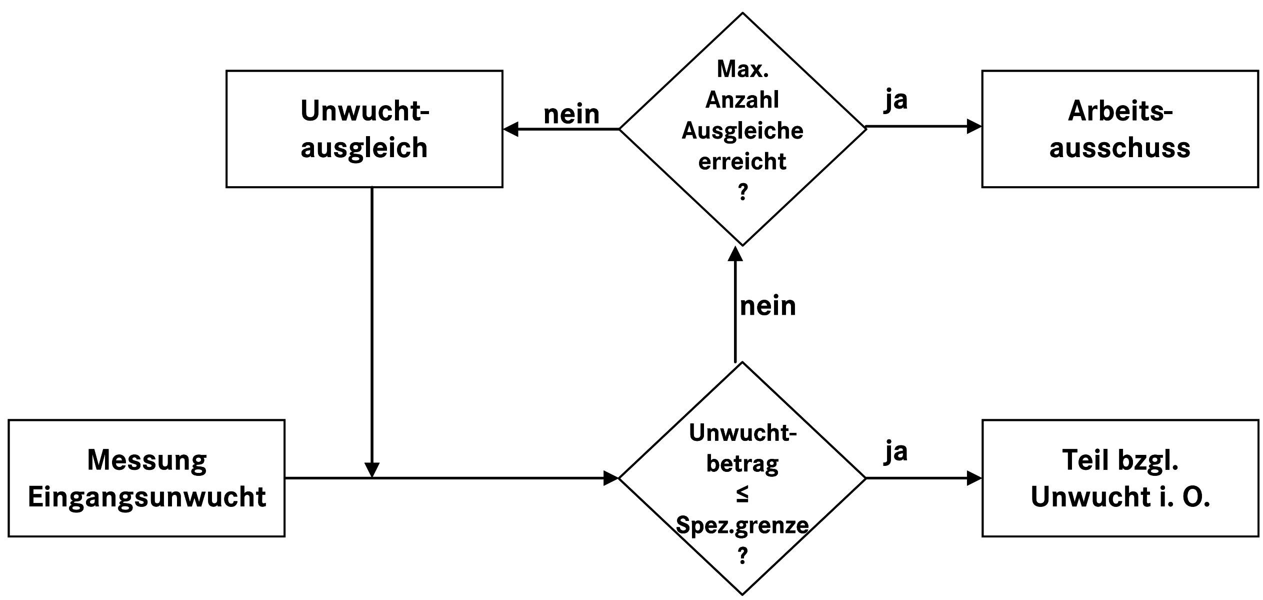
Imbalance is the result of unequal mass distribution in relation to a given axis of rotation. The centrifugal forces and oscillations caused by imbalance can reach magnitudes that place considerable stress on not only the rotors (crankshafts, brake disks, articulated shafts, articulated flange, turbocharger basic units, etc.), but also their bearings or at least give rise to noise complaints.

Acceptance of balancers

The **acceptance** procedure for balancers (imbalance measuring equipment **combined** with a device for balancing imbalance) involves **two steps**:

1. Verification of capability of the measurement process $\boldsymbol{C_g/C_{gk}}$ (measure imbalance)
2. Verification of capability of the production process $\boldsymbol{C_m/C_{mk}}$ (balance imbalance)

If the requirements regarding C_m/C_{mk} are not fulfilled, but the capability of the measurement process C_g/C_{gk} has been verified, this is not particularly critical because the aforementioned combination (i.e. de facto **100% check of residual imbalances**) is sufficient to ensure that no defective parts will be installed. Of course, this does not rule out the possibility that, in this case, the ppm rates for waste from work processes will be very high.



The following **distinctions** (variants) must always be taken into account:

A rotor can have **several** measurement **planes**, sensor planes, tolerance planes and balancing planes. As a rule, however, the imbalances output by the measuring system relate to the tolerance planes. If this is not the case, the fundamental theorem of proportionality must be used for conversion.

In this section, it is assumed that in each case **only one of these planes** exists and that the measured values relate to the tolerance plane.

If a rotor (e.g. a brake disk) **does not have its own angle reference system** and if no corresponding reference is created (e.g. with the magnetic marking of an angular position), the C_m/C_{mk} values are calculated using the imbalance value only (i.e. one-dimensionally).

Degree of detail of the information via the actual, **reference value of the measurement standard**:

a) **Actual value** is **0** in both Cartesian coordinates (theoretical only)

b) **Actual value** is **unknown** in both Cartesian coordinates

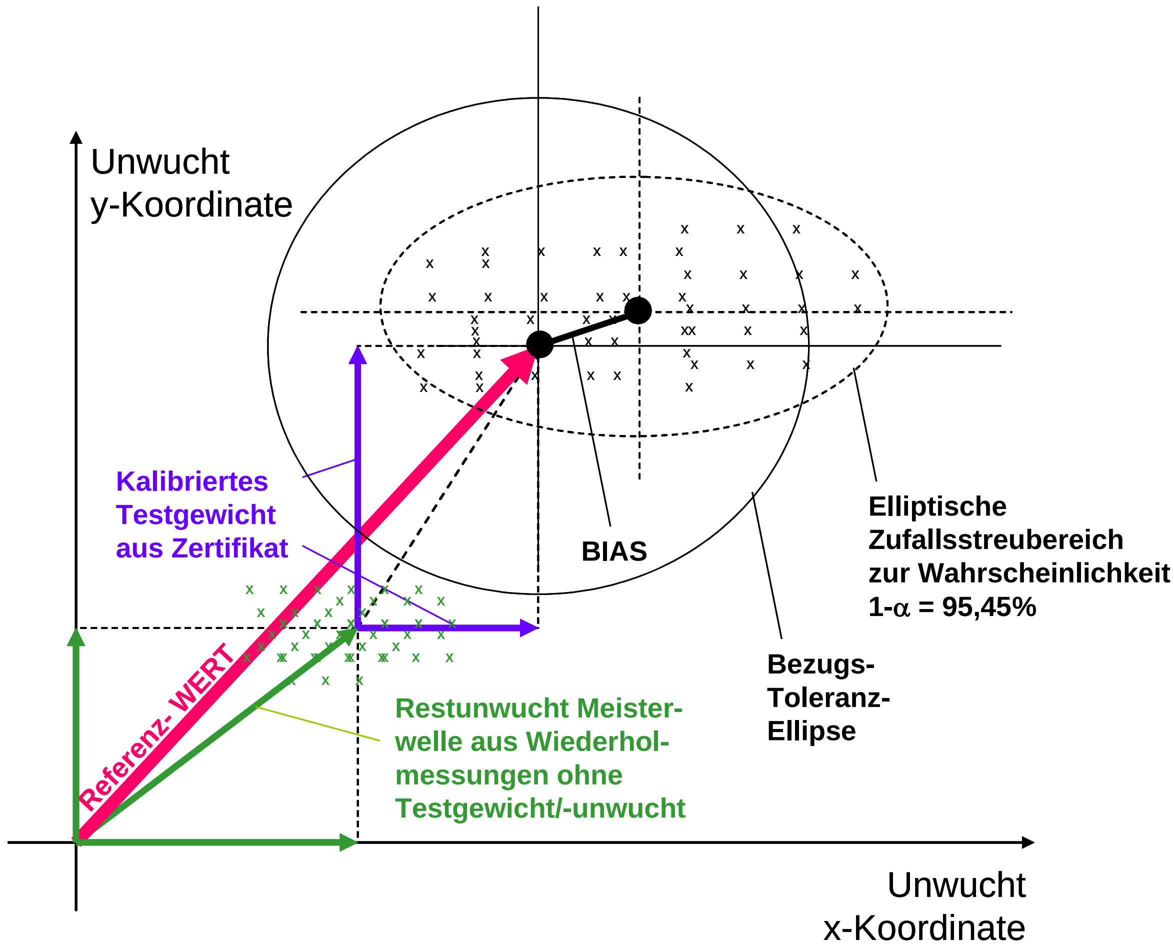
c) **Actual value** is **known, ≠ 0** in both Cartesian coordinates (normal)

This value is entered in the appropriate field in the SOLARA characteristic form.

In case b), the field is left empty. However, this means that only one C_g value and no C_{gk} value can be calculated.

The following example illustrates case c).

Visualization of the reference value in the C_g/C_{gk} calculation

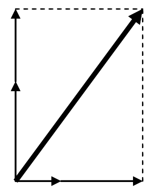


The actual/reference value is thus the **sum** of the <u>residual imbalance</u> of the master shaft and the attached <u>test imbalance</u>.

The <u>test imbalance</u> here is the **product** of the <u>test weight mass</u> and its <u>center of gravity radius</u>.

Determining the reference value in the C_g/C_{gk} calculation

1. **Mean** from repeated measurements of the measurement standard (without test imbalance)
2. **Transformation** of the mean from polar to Cartesian coordinates (residual imbalance)
3. Coordinate-by-coordinate **addition** of the test imbalance as per the calibration report (This is straightforward if the test weight acts horizontally or vertically only, i.e. the angular position of the test imbalance is a multiple of 90°.)



Example: Acceptance of a balancer for brake disks

Supply the required data and calculations:

	1. Richtiger Wert		2. Cg/Cgk (zweidimensional)				3. Cm/Cmk (eindimensional)
	20 Wiederholmessungen **ohne** Testunwucht		20 Wiederholmessungen **mit** Testunwucht				50 Restunwuchtbeträge aus dem Wuchtprozess
	Betrag	**Richtung**	**Betrag**	**Richtung**	**X**	**Y**	**Betrag**
	27,9	88	324	3	**17,0**	**323,6**	**50**
	31,2	89	326	3	**17,1**	**325,6**	**197**
	39,4	83	328	4	**22,9**	**327,2**	**15**
	29,4	87	326	4	**22,7**	**325,2**	**237**
	23,5	85	326	4	**22,7**	**325,2**	**53**
	40,4	83	324	4	**22,6**	**323,2**	**180**
	39,4	84	324	4	**22,6**	**323,2**	**232**
	26,6	89	325	3	**17,0**	**324,6**	**157**
	25,1	87	324	3	**17,0**	**323,6**	**266**
	27,5	89	325	3	**17,0**	**324,6**	**289**
	26,4	83	324	4	**22,6**	**323,2**	**187**
	28,6	86	325	4	**22,7**	**324,2**	**26**
	26,3	87	326	4	**22,7**	**325,2**	**134**
	28,4	84	324	4	**22,6**	**323,2**	**205**
	32,4	84	326	3	**17,1**	**325,6**	**219**
	33,8	87	328	4	**22,9**	**327,2**	**234**
	30,1	82	322	4	**22,5**	**321,2**	**29**
	27,8	88	325	4	**22,7**	**324,2**	**185**
	27,7	86	324	4	**22,6**	**323,2**	**50**
	30,2	87	323	4	**22,5**	**322,2**	**14**
							34
Mittel (polar)	**30,1**	**86**					**152**
Mittel (kart.)	**30,0**	**2,1**					**71**
							110
Restunwucht	**30,0**	**2,1**					**99**
Testunwucht	0,0	299,0					**69**
ISTWERTE	**30,0**	**301,1**					**43**
							290

See information on determining

22 values not shown!

Evaluation with SOLARA

Open SOLARA, New file, 1 Position tolerance,

Presettings: "Coordinates" (Koordinaten) measurand, nominal size, dimensions, unit, digits after decimal point, no. of reference measurements

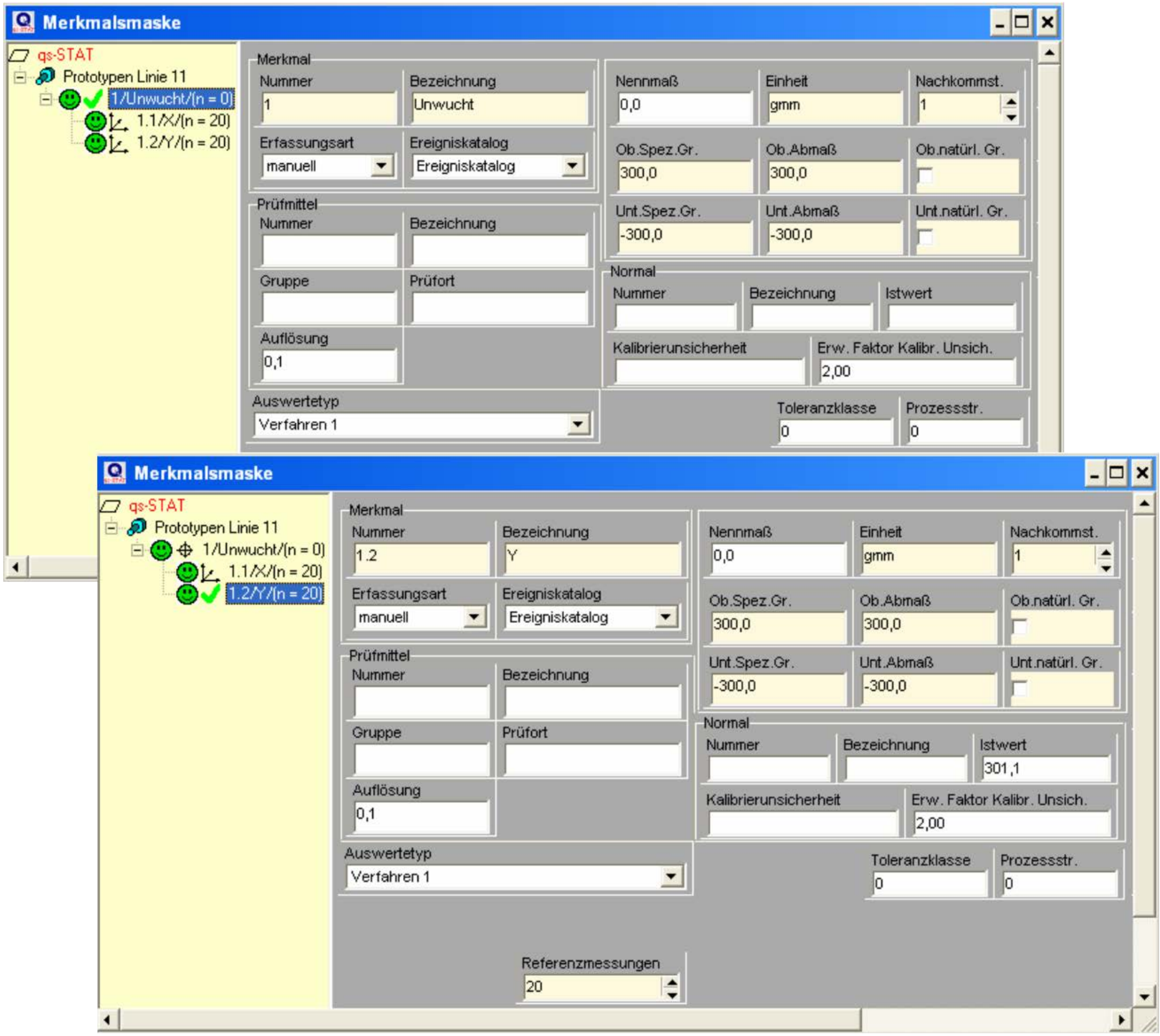
Fill out the part form and characteristic form(s).

Copy the measured values (Cartesian) to the value form (e.g. from Excel) or enter them.

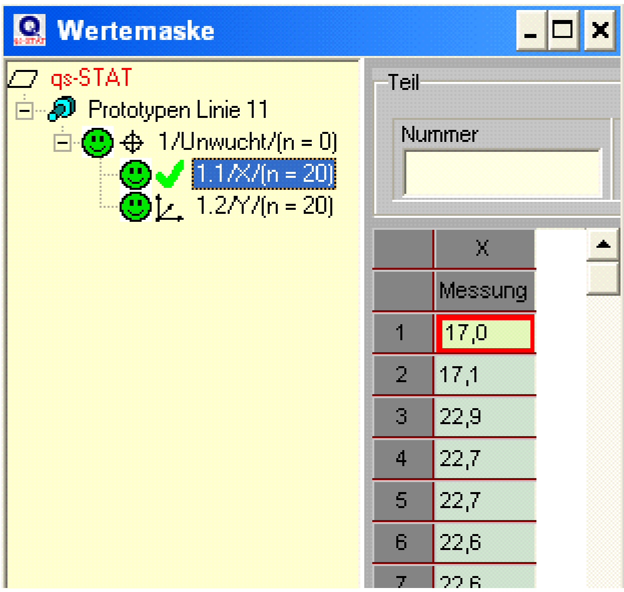
Save the file; analyze the data.

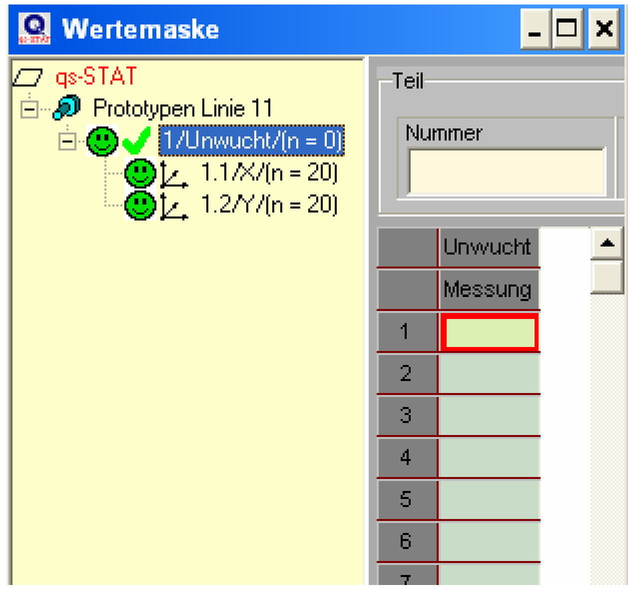
x-y plot position tolerances (specification limits hidden) and numerics form 3.

Characteristic forms:

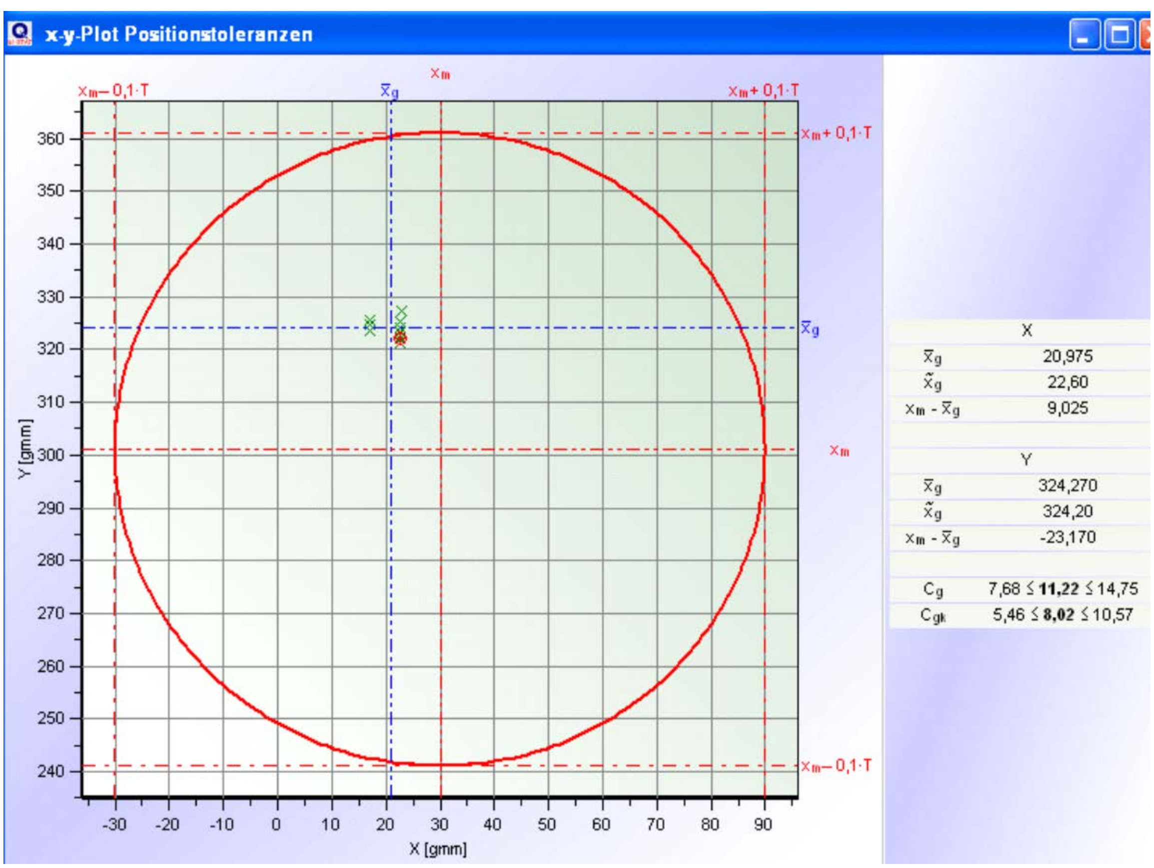


Value form:

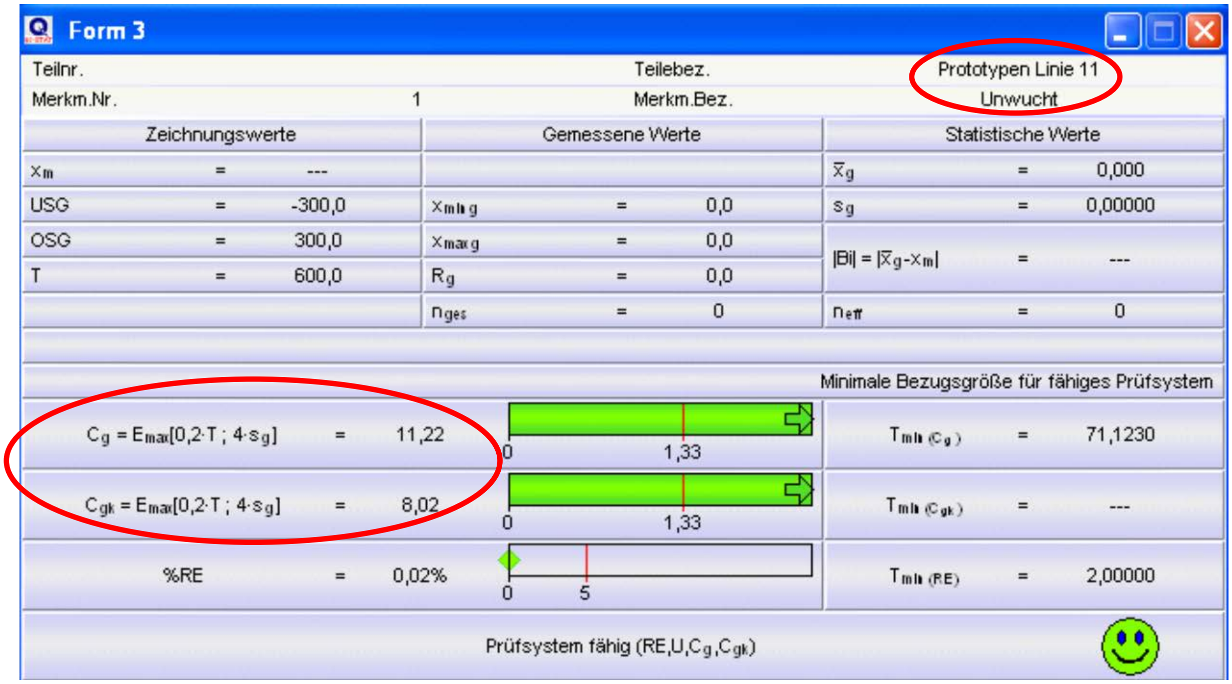


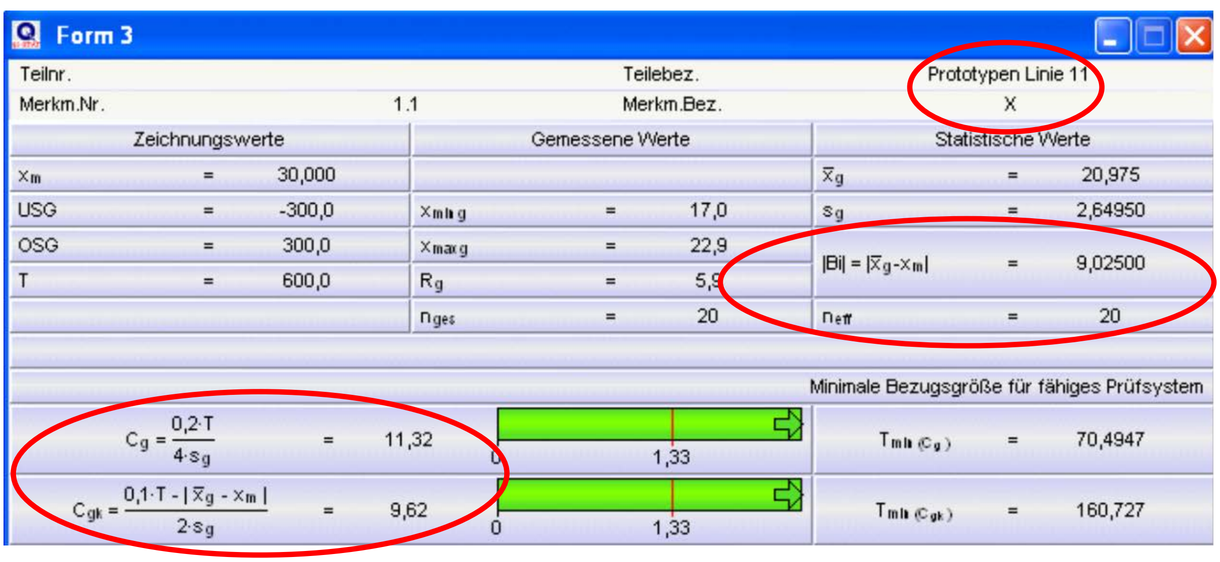


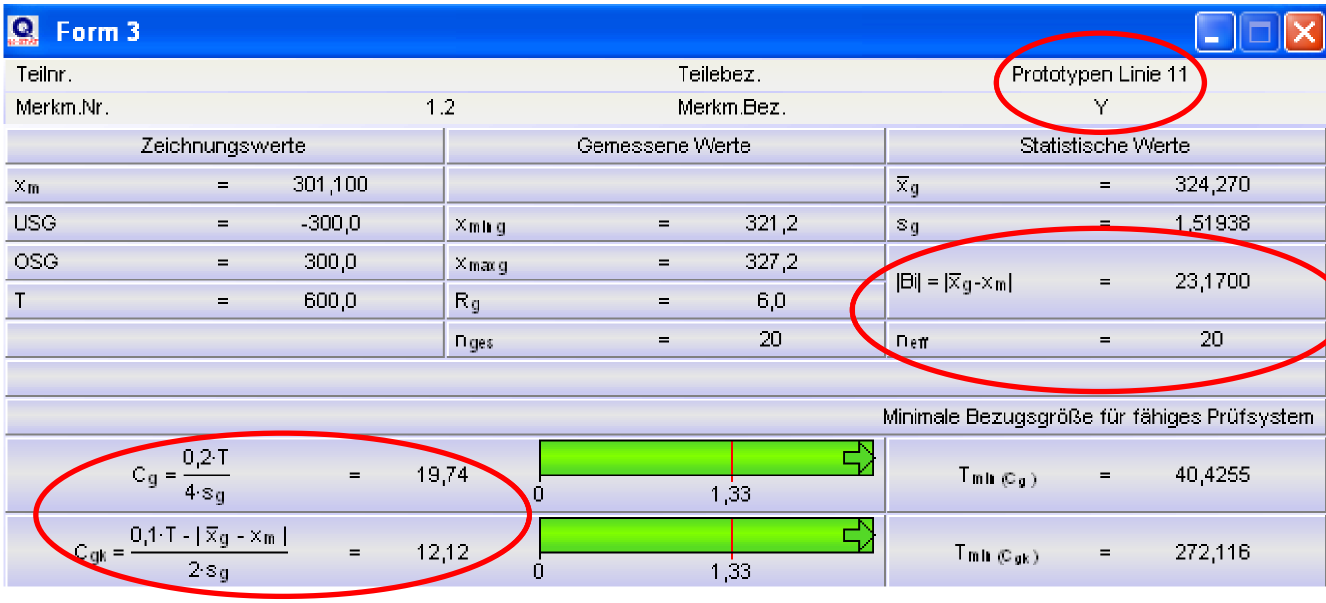
Individual measurement errors shown in x-y plot:



SOLARA analysis: C_g/C_{gk}, bias Bi and variation s_g for both components







Possible reasons for the required capabilities not being fulfilled and their impact on production tolerances

If the measuring system does not fulfill the requirements regarding C_g/C_{gk}, the specified imbalance tolerance in production must be restricted under consideration of bias and variation. In accordance with VDA 5, the measurement process variation can be obtained as follows:

$$2 \cdot \sqrt{s_g^2 + \left(\frac{1}{\sqrt{3}} \cdot Bias\right)^2}$$

Values s_g and $Bias$ are specified separately in form 3 for the horizontal (x) and vertical (y) components. In each case, the larger of the two values must be used.

In this example, the following new production tolerance for the amount of imbalance would be obtained:

$$300gmm - 2 \cdot \sqrt{(2.65gmm)^2 + \left(\frac{1}{\sqrt{3}} \cdot 23.17gmm\right)^2} = 273gmm$$

Remarks:

Restricting the production tolerance increases the average number of balancing steps (takt time) and leads to more waste.

Experience shows that centering the process and, in turn, minimizing the bias and also increasing C_{gk} to C_g is much easier than reducing the variation.

Key variables include:

Tolerances of the calibration weights (mass and radius), specification and monitoring of the balancing speed, quality of the cooling lubricant, design of the balancing unit, conditions at the installation location, etc.

Capability of the balancing process (one-dimensional):

Open qa-STAT, module prel. Process capability, New file, 1 characteristic,

Presettings: "Imbalance" (Unwucht) measurand, nominal size, dimensions, unit, digits after decimal point, characteristic class "non-critical" (unkritisch)

Fill out the part form and characteristic form(s).

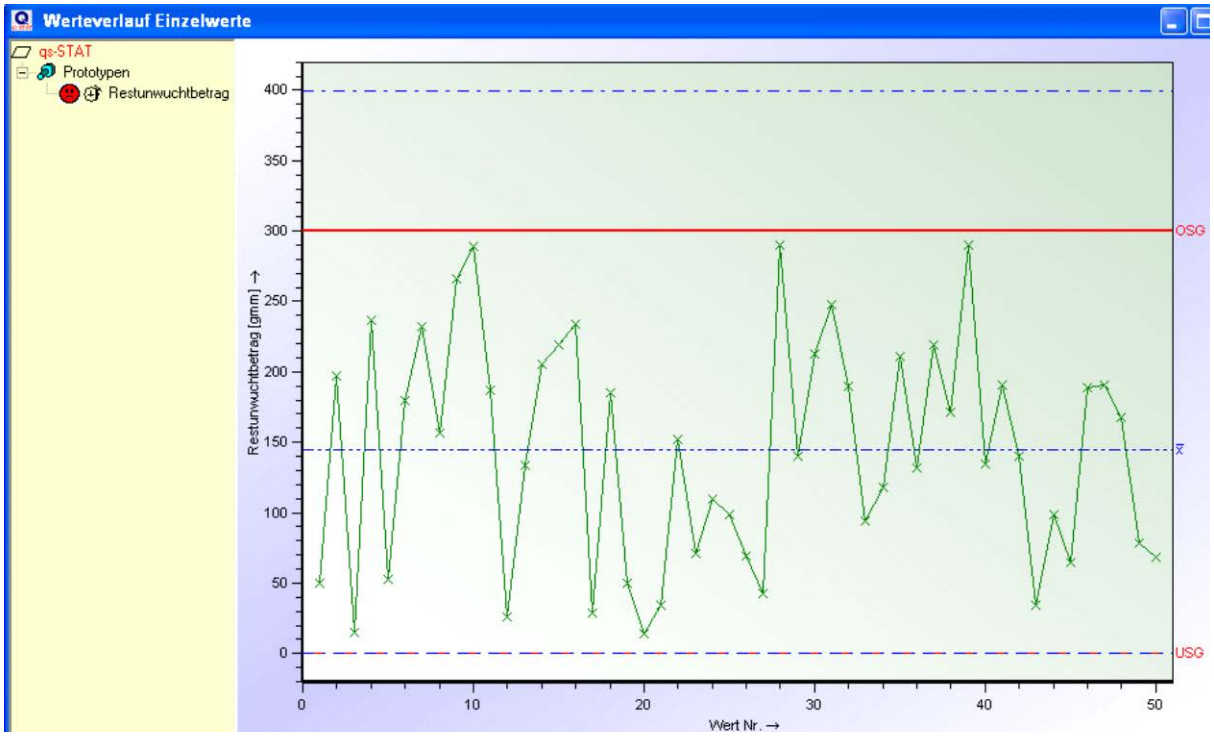
Copy the measured values (amounts of imbalance) to the value form.

Save the file; analyze the data.

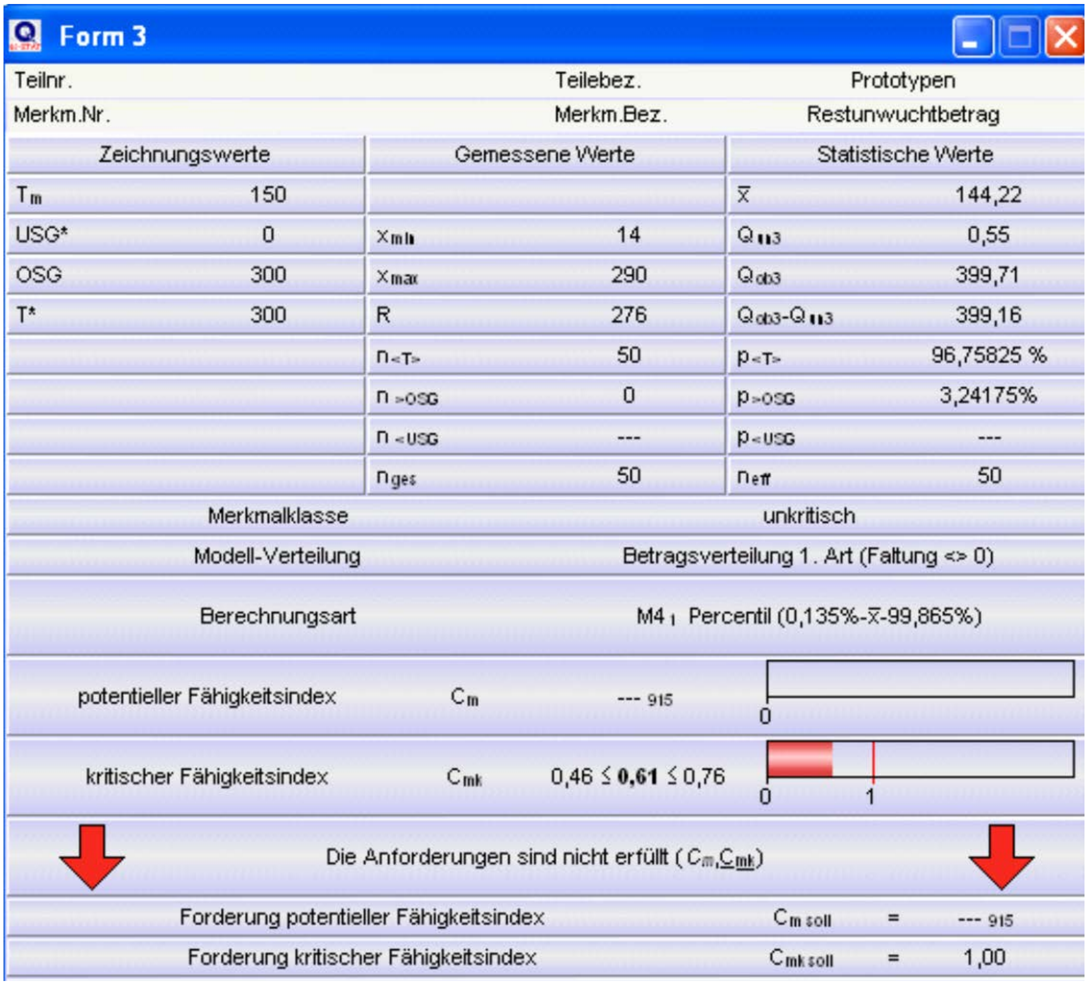
Value patterns and numerics form 3.

Characteristic form:

Value pattern:



Analysis:



Form 3

Teilnr.		Teilebez.	Prototypen
Merkm.Nr.		Merkm.Bez.	Restunwuchtbetrag

Zeichnungswerte		Gemessene Werte		Statistische Werte	
T_m	150			$\bar{x}$	144,22
USG*	0	x_{min}	14	Q_{un3}	0,55
OSG	300	x_{max}	290	Q_{ob3}	399,71
T*	300	R	276	Q_{ob3}-Q_{un3}	399,16
		$n_{<T>}$	50	$p_{<T>}$	96,75825 %
		$n_{>OSG}$	0	$p_{>OSG}$	3,24175%
		$n_{<USG}$	---	$p_{<USG}$	---
		n_{ges}	50	n_{eff}	50

Merkmalklasse	unkritisch
Modell-Verteilung	Betragsverteilung 1. Art (Faltung <> 0)
Berechnungsart	M4 1 Percentil (0,135%-$\bar{x}$-99,865%)

potentieller Fähigkeitsindex	C_m	--- 915	0
kritischer Fähigkeitsindex	C_{mk}	0,46 ≤ **0,61** ≤ 0,76	0 1

Die Anforderungen sind nicht erfüllt (C_m,C_{mk})

Forderung potentieller Fähigkeitsindex	$C_{m\,soll}$	=	--- 915
Forderung kritischer Fähigkeitsindex	$C_{mk\,soll}$	=	1,00

The views for the two-dimensional analysis as well (for information purposes):

Open qs-STAT, module prel. Process capability, New file, 1 position tolerance,

Presettings: "Imbalance" (Unwucht) measurand, nominal size, dimensions, unit, digits after decimal point, characteristic class "non-critical" (unkritisch)

Fill out the part form and characteristic form(s).

Copy the measured values for imbalance to the value form component by component.

Save the file; analyze the data.

x-y plot position tolerances and numerics form 3.

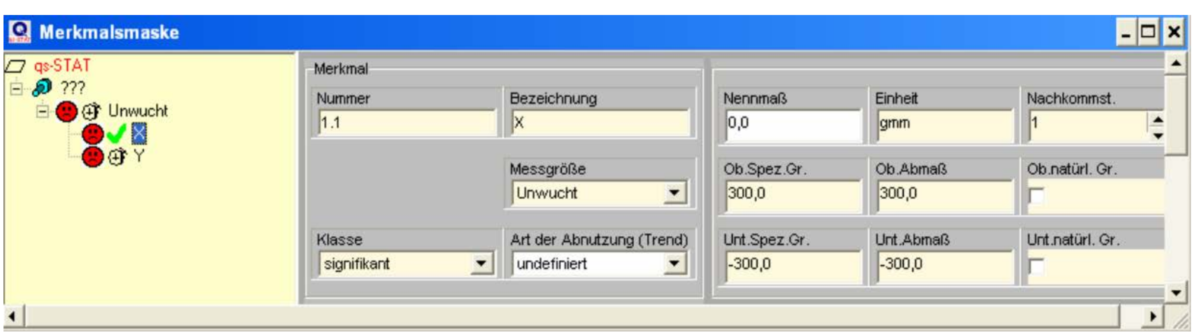
Measured Values

Cm/Cmk (ein-/zwei-dimensional)
50 Restunwuchten
aus dem Wuchtprozess

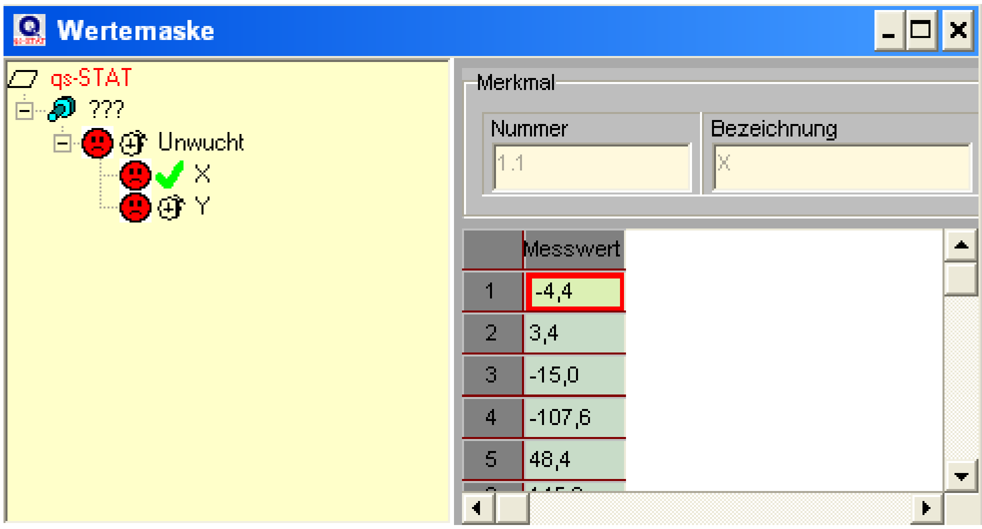
Betrag	Richtung	X	Y
50	355	**-4,4**	**49,8**
197	1	**3,4**	**197,0**
15	267	**-15,0**	**-0,8**
237	207	**-107,6**	**-211,2**
53	114	**48,4**	**-21,6**
180	54	**145,6**	**105,8**
232	230	**-177,7**	**-149,1**
157	239	**-134,6**	**-80,9**
266	231	**-206,7**	**-167,4**
289	26	**126,7**	**259,8**

40 imbalance values not shown!

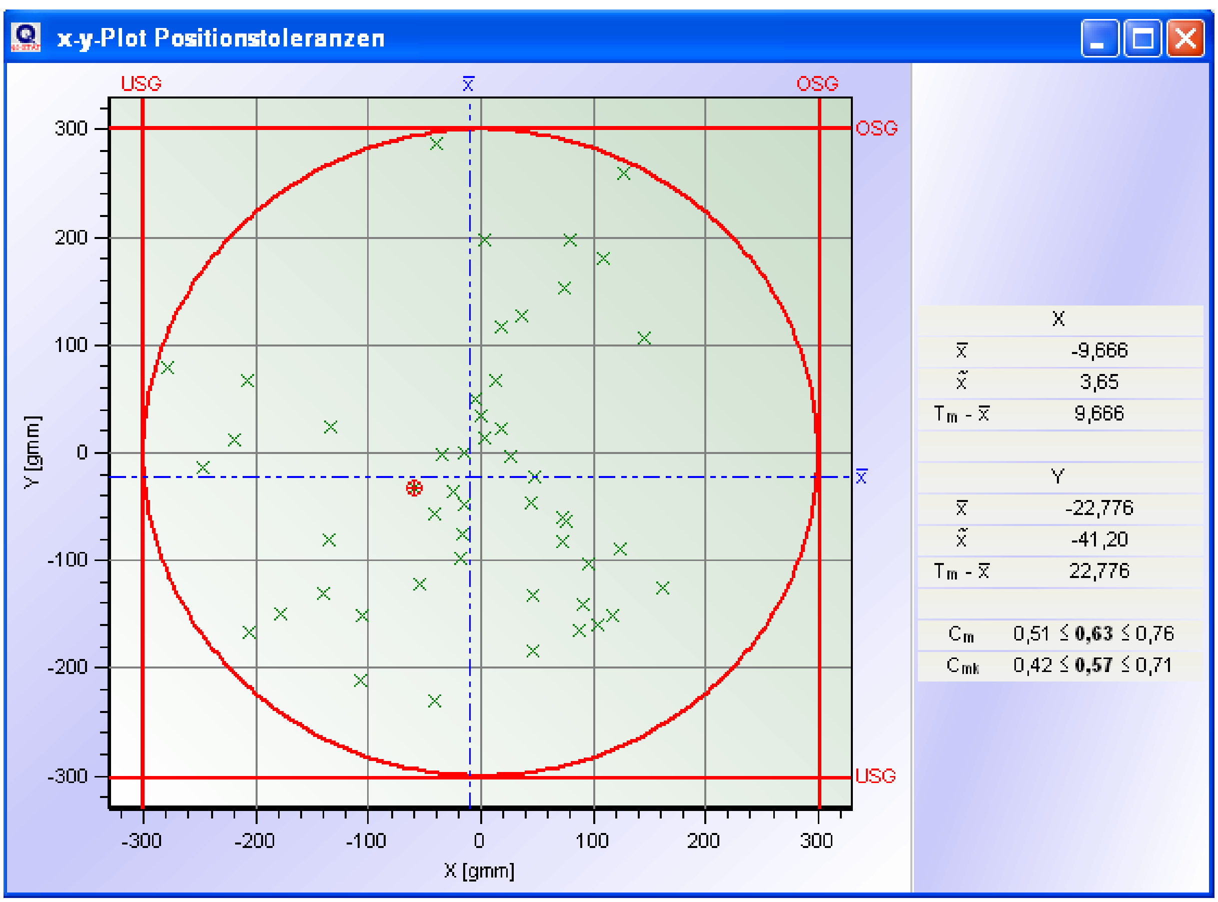
Characteristic form:



Value form:



x-y plot:



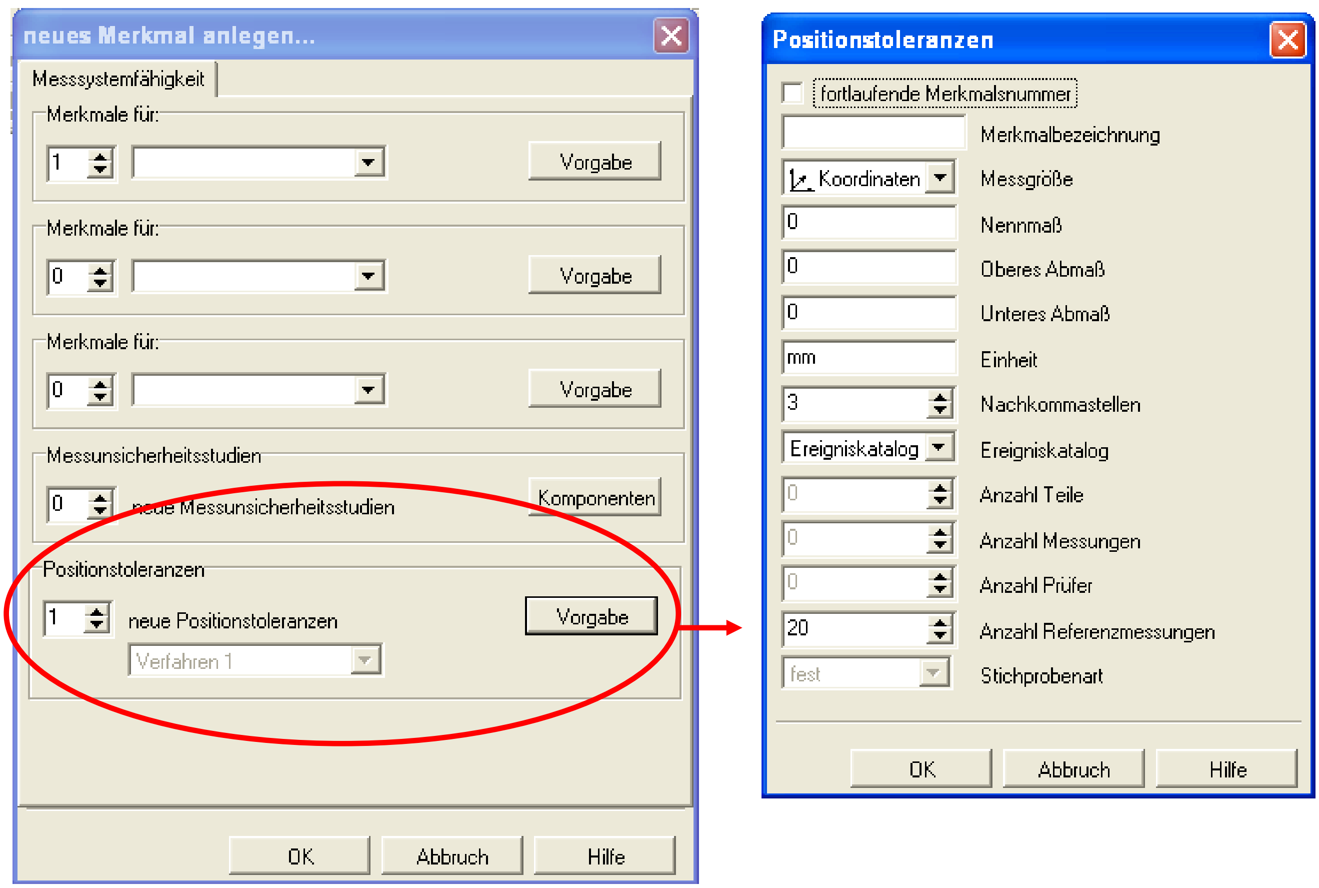
4.1.6 Case Study for Method 1: Two-Dimensional Position Tolerance

The center point of a drilled hole on a workpiece is measured. The nominal size here are 80 mm in the X direction and 87.3 mm in the Y direction. No. of measured parts n = 50.

Specification thresholds:	Lx = 79.750	Hx = 80.250
	Ly = 87.050	Hy = 87.550

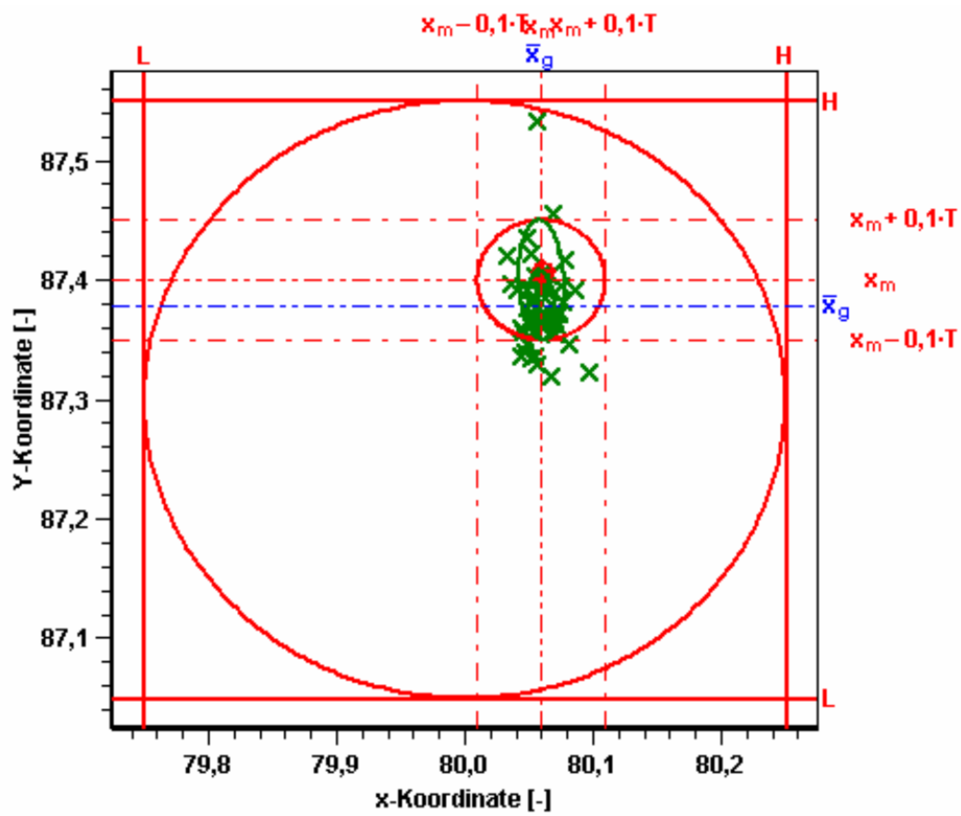
Procedure:

- Open SOLARA, New file, 1 Position tolerance,

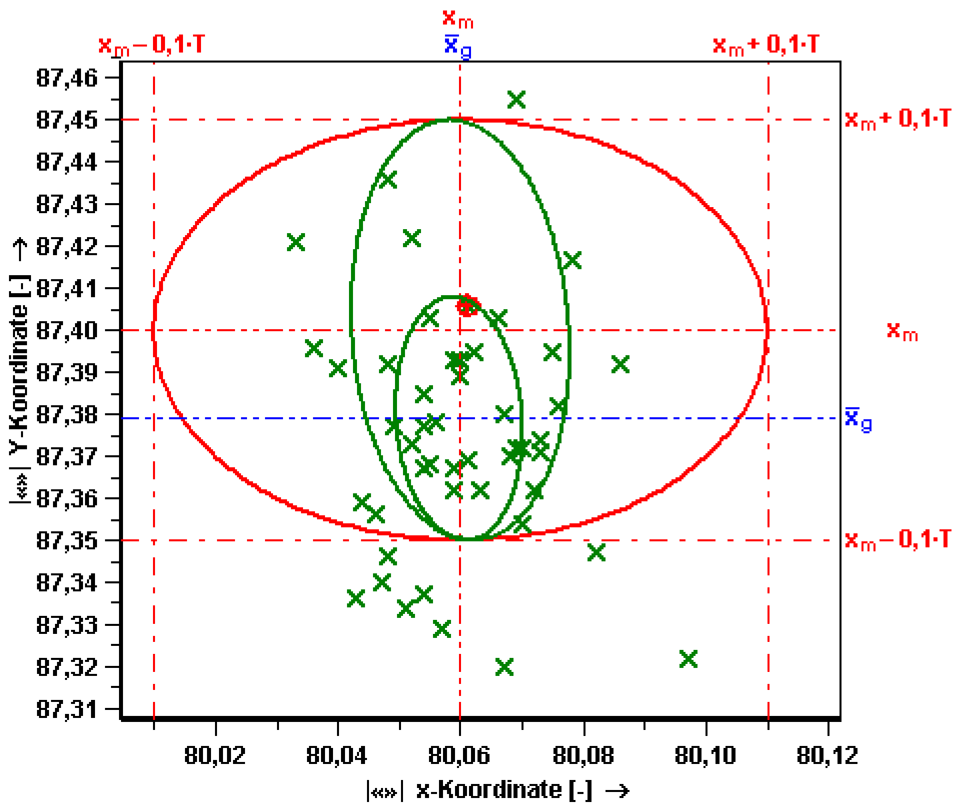


- Presettings: "Imbalance" (Unwucht) measurand, nominal size, dimensions, unit, digits after decimal point, characteristic class "non-critical" (unkritisch)
- Open the characteristic form and enter the characteristic data.
- Perform measurements according to method 1 and enter the measured values in the value form .
- Save the file and then perform a calculation by choosing "Analysis" (Auswertung) .

- The results of the calculation can either be opened via the "Numerics / Forms" (Numerik / Formblätter) menu
  or
  displayed as a graph under individual values, x-y plot position tolerances.



Magnified view:



Results:

Measuring system capability potential	$C_g = 0.44$
Measuring system capability index	$C_{gk} = 0.18$

4.1.7 Case Study for the Linearity Test

(*SOLARA file: LF05 linearity.DFQ*)

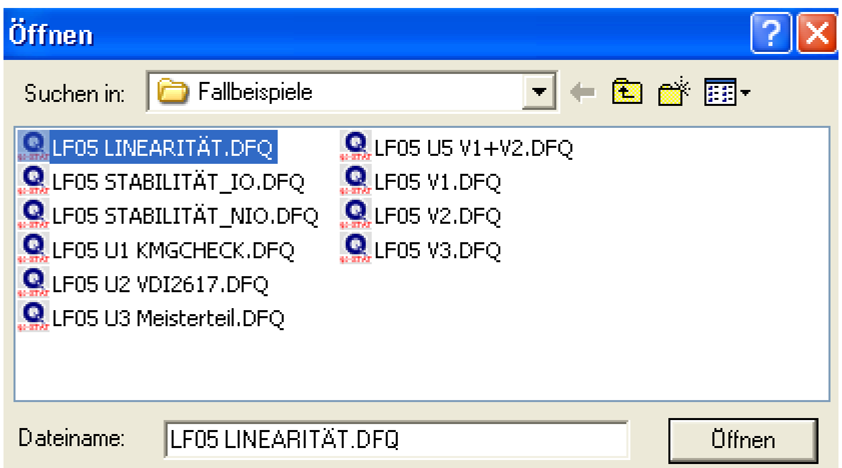
The manufacturing department has doubts about the linearity of the measuring system, so it decides to perform a linearity test as well.

It selects three workpieces: One at the lower tolerance limit, one in the tolerance mean and one at the upper tolerance limit.

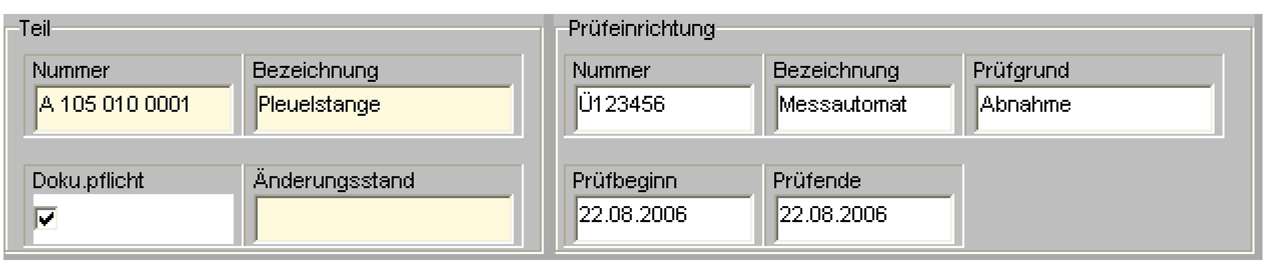
The measurement standards/master parts are calibrated in the precision measuring center; the calibration values are 56.8201 mm, 56.8302 mm and 56.8398 mm.

Procedure:

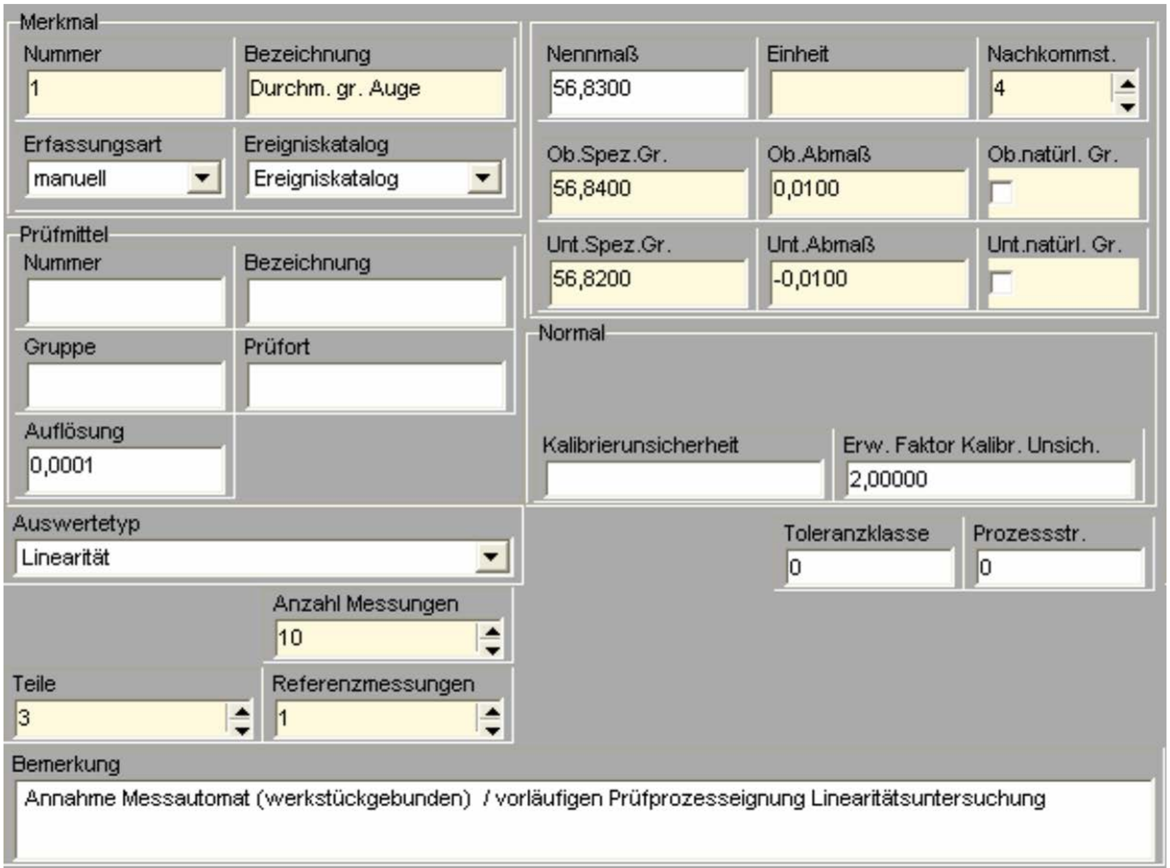
- To create a new linearity test, choose "File / New" (Datei / neu) in SOLARA.
- Alternatively, open an existing linearity test by choosing "Open" (öffnen).



- Open the part form and enter the component data

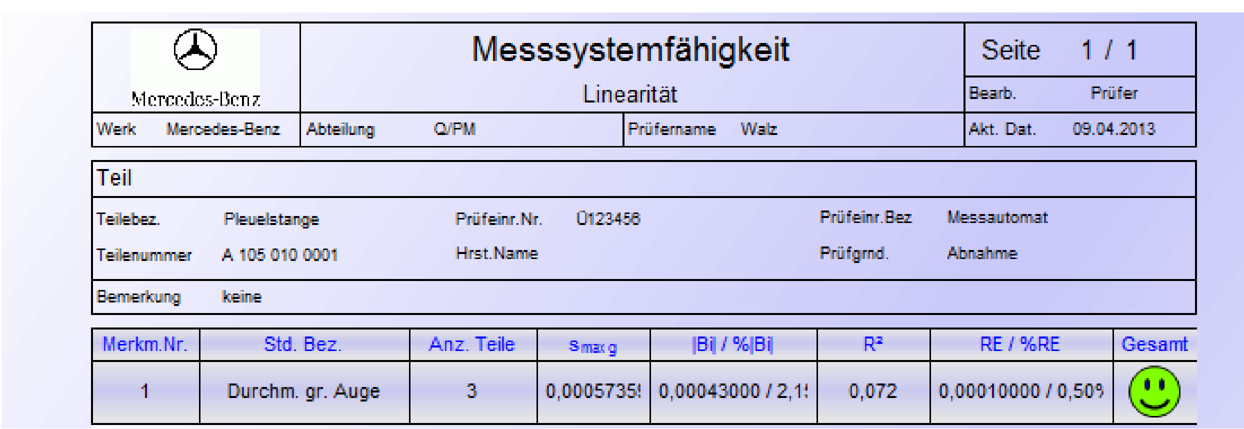


- Open the characteristic form and enter the characteristic data.



- Perform 10 measurements on each of the measurement standards under repeatability conditions and enter the measured values in the value form .

- Then perform a calculation by choosing "Analysis" (Auswertung). The results of the calculation can either be opened via "Numerics / Forms" (Numerik / Formblätter) or printed out as a standard report ("Linearity test").



Mercedes-Benz

Messsystemfähigkeit

Linearität

Seite 1 / 1

Werk Mercedes-Benz	Abteilung Q/PM	Prüfername Walz	Akt. Dat. 09.04.2013
			Bearb. Prüfer

Teil

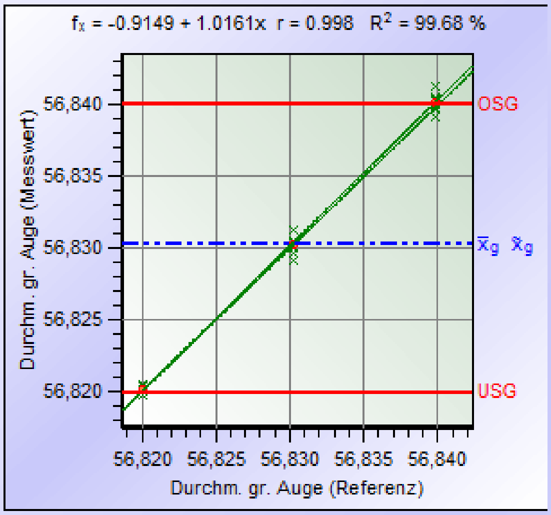
Teilebez.	Pleuelstange	Prüfeinr.Nr.	0123456	Prüfeinr.Bez	Messautomat
Teilenummer	A 105 010 0001	Hrst.Name		Prüfgrnd.	Abnahme
Bemerkung	keine				

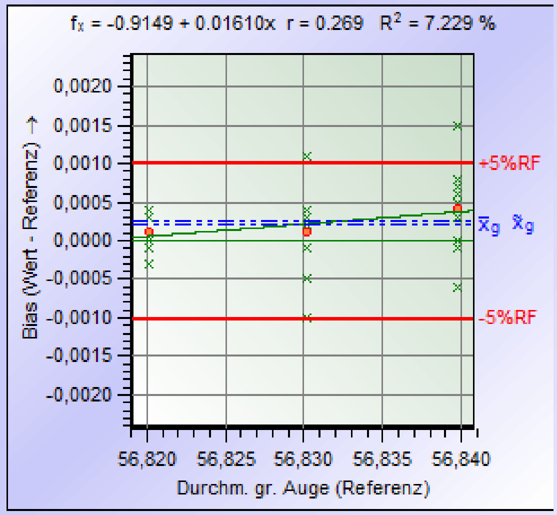
Merkm.Nr.	Std. Bez.	Anz. Teile	$s_{max\,g}$	|Bi| / %|Bi|	R²	RE / %RE	Gesamt
1	Durchm. gr. Auge	3	0,0005735	0,00043000 / 2,1	0,072	0,00010000 / 0,50	

Mercedes-Benz	**Messsystemfähigkeit** Linearität		Seite 1 / 1 Bearb. Prüfer
Werk Mercedes-Benz	Abteilung Q/PM	Prüfername Walz	Akt. Dat. 09.04.2013

Teilnr. A 105 010 0001	Teilebez. Pleuelstange		Doku.pflicht ja
	Std. Bez. Durchm. gr. Auge Merkm.Nr. 1 Kurzbez.	Nennm. 56,8300 0,0100 Einh. -0,0100	OSG 56,8400 USG 56,8200
Merkm.Art variabel	Merkm.Klasse signifikant	Erfass.Art manuell	Nachkommst. 4
Normal Bez. Normal Nr. Normal-Istw. 56,82	Prfm.Grp. Prfm.Nr.	Prfm.Bez. Prfm.Aufl. 0,0001	

Auswertung von 22.08.2006 bis 22.08.2006
Bemerkung Annahme Messautomat (werkstückgebunden) / vorläufigen Prüfprozesseignung Linearitätsuntersuchung





n	$\bar{x}_{g\,Ref.}$	$x_{A;1}$	$x_{A;2}$	$x_{A;3}$	$x_{A;4}$	$x_{A;5}$	$x_{A;6}$	$x_{A;7}$	$x_{A;8}$	$x_{A;9}$	$x_{A;10}$	$\bar{x}_{g\,j}$	$s_{g\,j}$
1	56,8201	56,8204	56,8205	56,8201	56,8198	56,8202	56,8205	56,8204	56,8200	56,8202	56,8200	56,8202	0,00024
2	56,8302	56,8304	56,8297	56,8313	56,8305	56,8306	56,8292	56,8304	56,8305	56,8304	56,8301	56,8303	0,00056
3	56,8398	56,8401	56,8398	56,8397	56,8404	56,8413	56,8405	56,8406	56,8392	56,8403	56,8404	56,8402	0,00057

USG = 56,8200	T_m = 56,8300	OSG = 56,8400
	T = 0,0200	

Bias	=	|Bi|	=	0,00043000
Bias	=	%|Bi|	=	2,15%
Korrelationskoeffizient	=	R²	=	7,229%
Auflösung	=	RE	=	0,00010000
Auflösung	=	%RE	=	0,50%

Prüfsystem fähig (RE,Bi)

Mercedes Benz Cars (11/2010): Linearität

Result: The linearity of the measuring system is verified.

4.1.8 Case Study for Method 2

(*SOLARA file: LF05 V2.DFQ*)

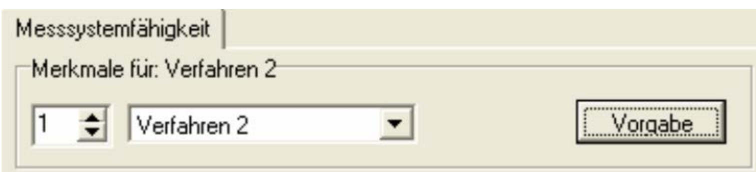
Next to the automatic measuring system is a hand-held measuring device that, if necessary, can also be used for measuring the connecting rods. The hand-held measuring device underwent acceptance testing according to method 1; it is suspected that the operator influenced the measuring instrument. You have been tasked with verifying the measurement process capability.

The manual measuring station is used on a workpiece-specific basis and is designed to determine, among other things, the diameter of the large eye on a connecting rod. The characteristic is specified at 56.83 +/- 0.01 mm.

You decide to assess the operator influence by using a method 2 capability analysis. To do so, take 10 components with a random distribution across the tolerance range, number them and then choose two operators with whom you want to perform Method 2.

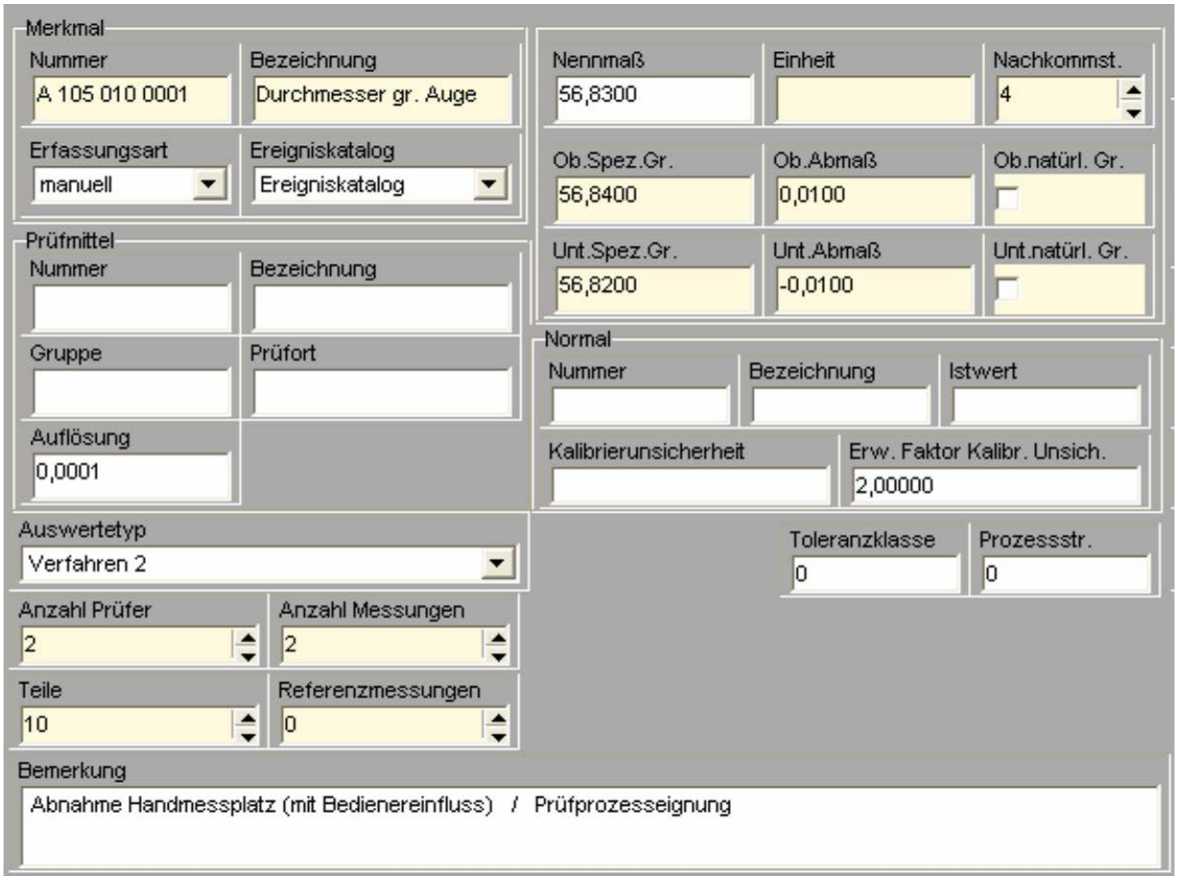
Procedure:

- To create a new method 2 capability analysis, choose "File / New" (Datei / neu) in SOLARA.



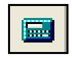
- Alternatively, open an existing method 2 capability analysis by choosing  "Open" (öffnen).
- Open the part form  and enter the component data.

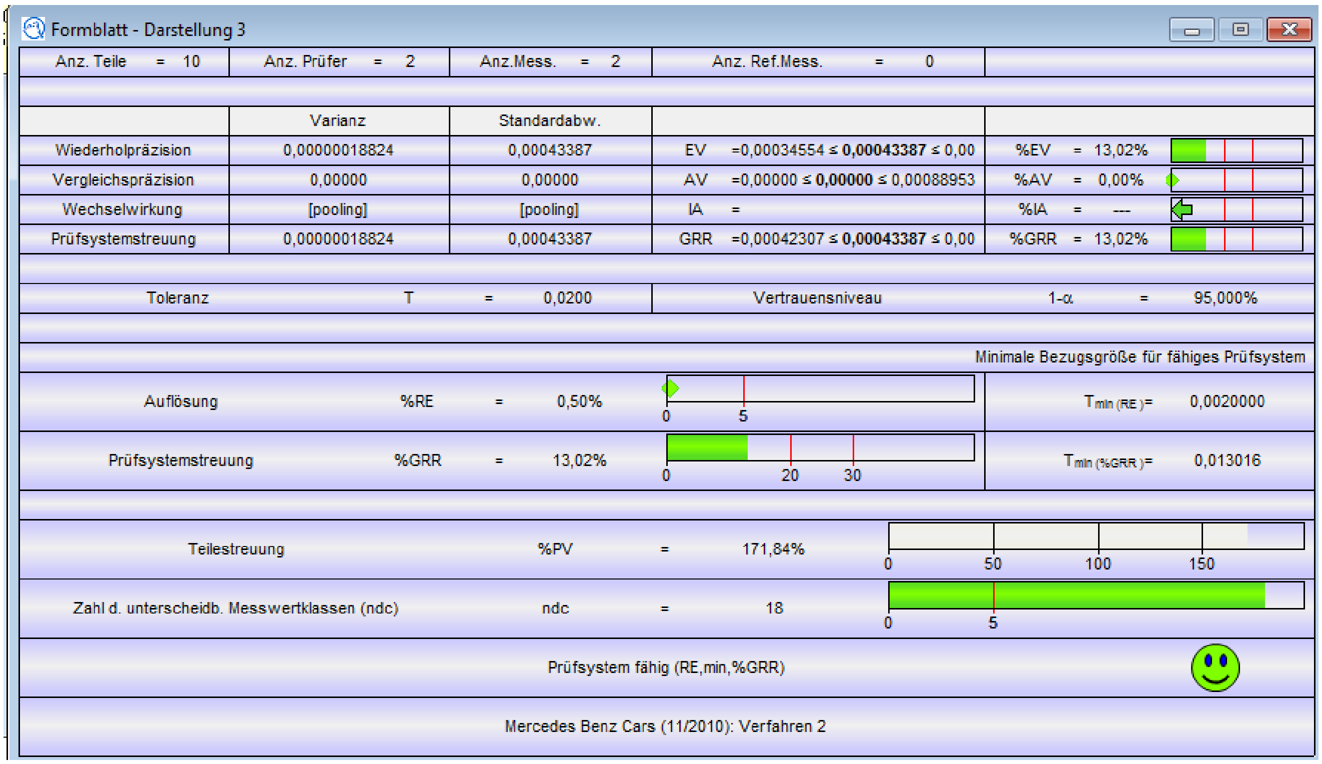
- Open the characteristic form and enter the characteristic data.



- Both operators each perform two measurement series according to method 2 and enter the measured values in the value form .

	Prüfer 1				Prüfer 2			
	Messung 1	Prüfername	Messung 2	Prüfername	Messung 1	Prüfername	Messung 2	Prüfername
1	56,8336	[1]	56,8343		56,8340	[2]	56,8342	
2	56,8321		56,8307		56,8320		56,8316	
3	56,8377		56,8378		56,8375		56,8367	
4	56,8292		56,8288		56,8291		56,8293	
5	56,8282		56,8280		56,8273		56,8281	
6	56,8219		56,8210		56,8207		56,8213	
7	56,8393		56,8391		56,8397		56,8401	
8	56,8305		56,8295		56,8301		56,8296	
9	56,8266		56,8269		56,8267		56,8273	
10	56,8375		56,8380		56,8382		56,8380	

- Then perform a calculation by choosing  "Analysis" (Auswertung). The results of the calculation can either be opened via "Numerics / Forms" (Numerik / Formblätter) or printed out as a standard report ("Method 2 capability analysis").



Assessment of results

- The measurement process is suitable.

4.1.9 Case Study for Method 3

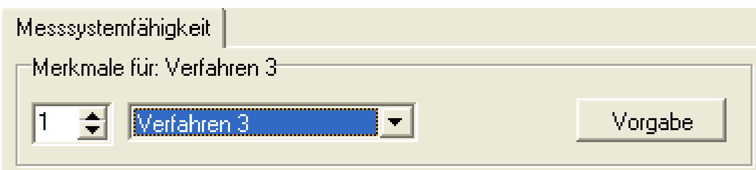
(*SOLARA file: LF05 V3.DFQ*)

The new automatic measuring from the example in 4.1.4 underwent acceptance testing according to method 1; the connecting rods are fed in automatically and the measurement also takes place automatically. It can be assumed that the operator has no influence here. You have been tasked with verifying the measurement process capability.

You decide to perform a simplified method 3 capability analysis. To do so, take 10 components with a random distribution across the tolerance range, number them and then choose one operator with whom you want to perform the method 3 capability analysis.

Procedure:

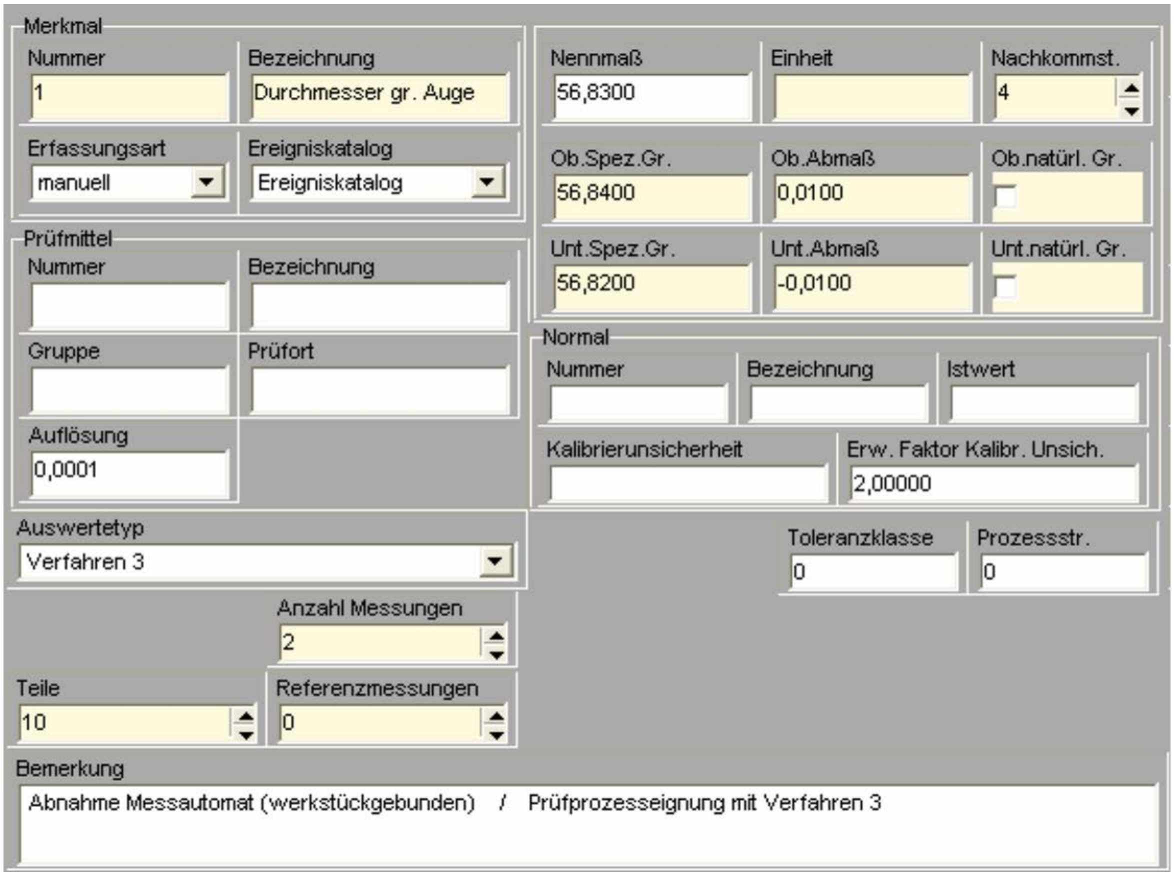
- To create a new method 3 capability analysis, choose "File / New" (Datei / neu) in SOLARA.



- Alternatively, open an existing method 3 capability analysis by choosing "Open" (öffnen).

- Open the part form and enter the component data.

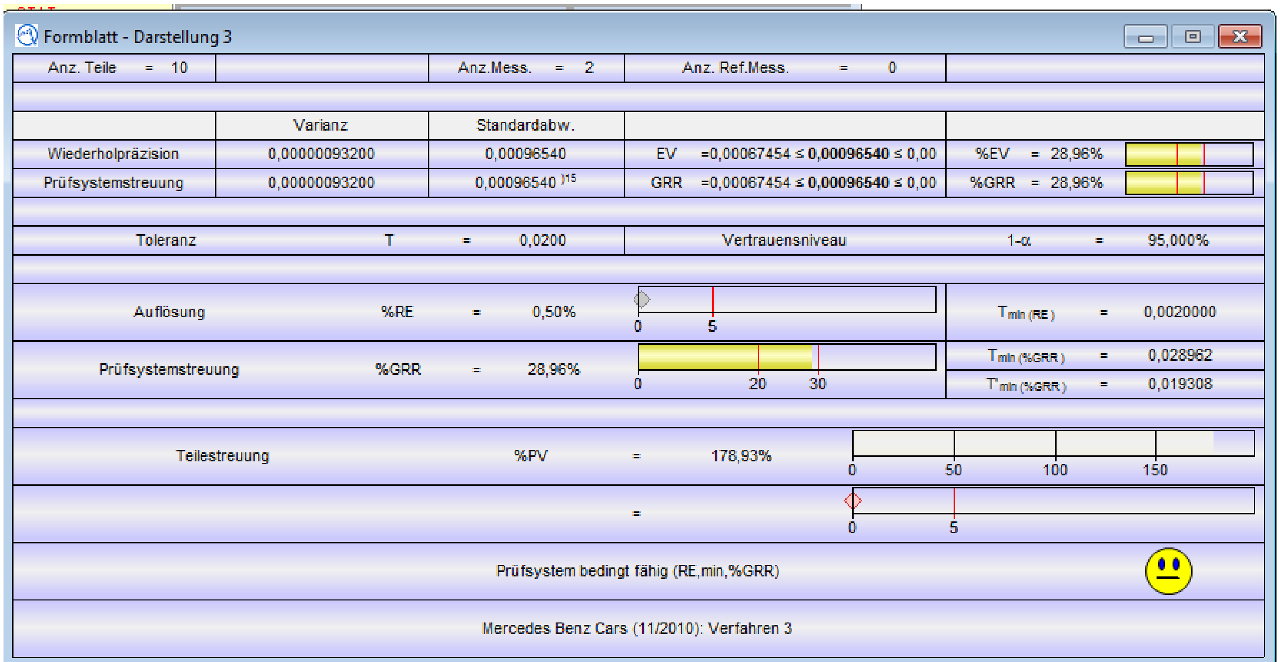
- Open the characteristic form and enter the characteristic data.



- The operator performs two measurement series according to method 3 and enters the measured values in the value form .

	Durchmesser gr. Auge			
	Messung 1	Prüfername	Messung 2	Prüfername
1	56,8338	[1]	56,8321	
2	56,8310		56,8320	
3	56,8359		56,8368	
4	56,8291		56,8257	
5	56,8294		56,8290	
6	56,8206		56,8202	
7	56,8410		56,8401	
8	56,8305		56,8295	
9	56,8269		56,8274	
10	56,8386		56,8386	

- Then perform a calculation by choosing "Analysis" (Auswertung). The results of the calculation can either be opened via "Numerics / Forms" (Numerik / Formblätter) or printed out as a standard report ("Method 3 capability analysis").



Assessment of results

- The test system is not capable because the requirement %GRR ≤ 20% is not fulfilled for new measurement processes (see the "Non-capable measurement processes" procedure).

4.2 Conducting an Uncertainty Analysis with SOLARA

In the following the basic procedure for an uncertainty analysis according to VDA Volume 5 and the entry of the data in SOLARA are described. Any differences in the details will be explained in the case studies themselves.

4.2.1 Creation and Data Input

Open SOLARA, New file, 1 measurement uncertainty study.

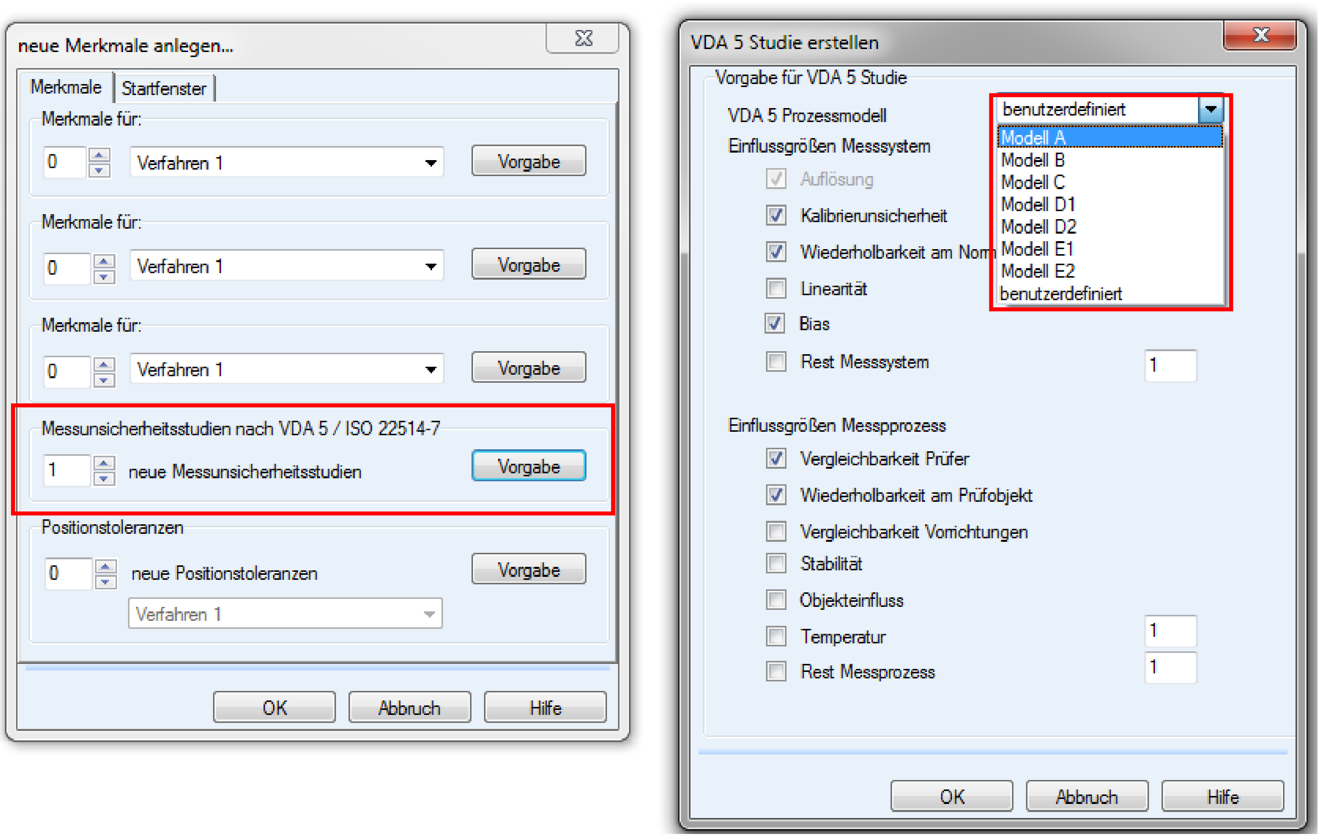
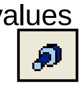


Figure 4-8: Creating an uncertainty study

Depending on the selection of the uncertainty components to be examined, they must be freely selected in with *"user-defined"* in the selection window or specified with the categorized standard measuring tasks via the models.

After selection and confirmation, the parts, characteristic and values mask appears.

The main information on the part is entered in the parts form . All the fields in this form are optional. However, it is always a good idea to enter the part name, the part designation and the reason for the examination.

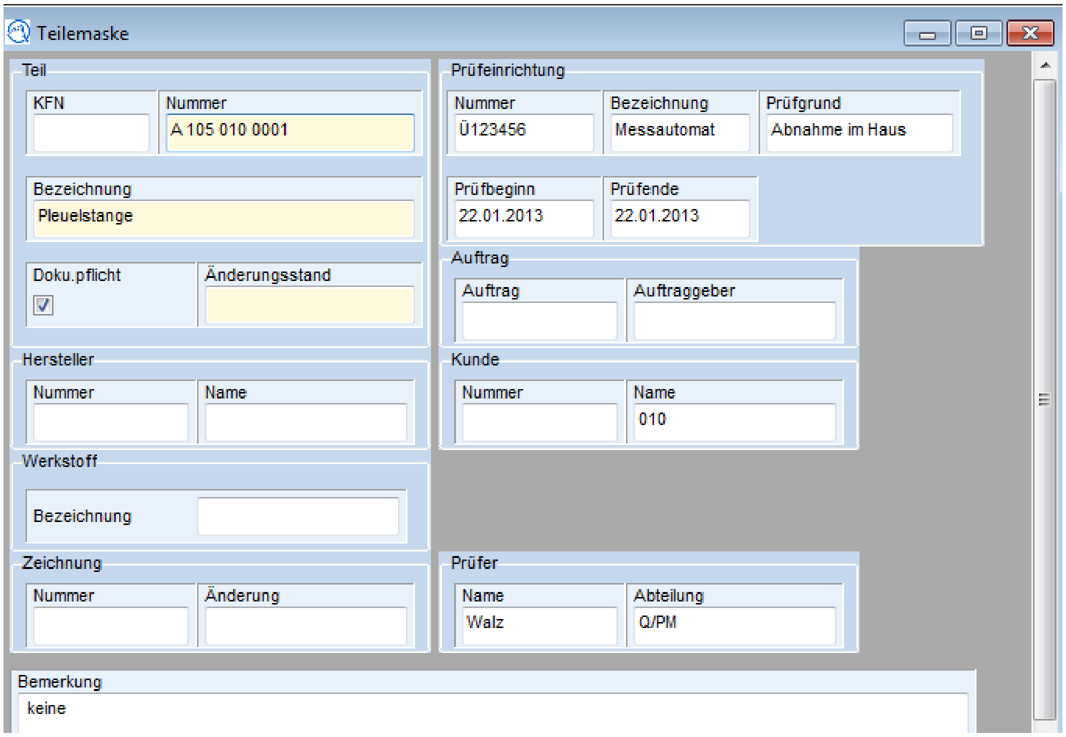
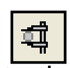


Figure 4-9: Part form with important data on part

Information important for the analysis can be found in the characteristic form  (see Figure 4.10). The specification limit must always be entered in addition to the number and designation of the characteristic.

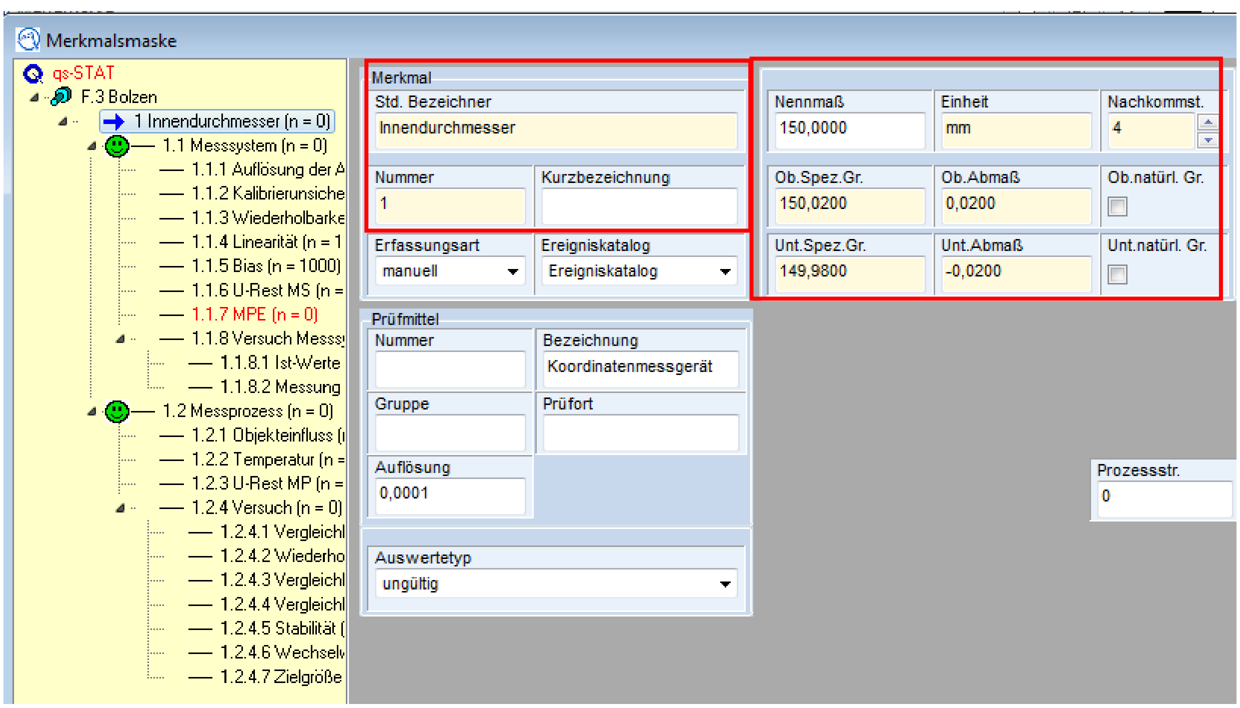


Figure 4-10: Important data on a characteristic

The uncertainty budget will be displayed for the screens already described. Here the relevant uncertainty components are shown with a great deal of information. In addition to the selected uncertainties, these are the determination method A or B, in the further course of events the calculated uncertainty $u_{ix,}$ and their ranks among each other, which is dependent on the amount of the uncertainty.

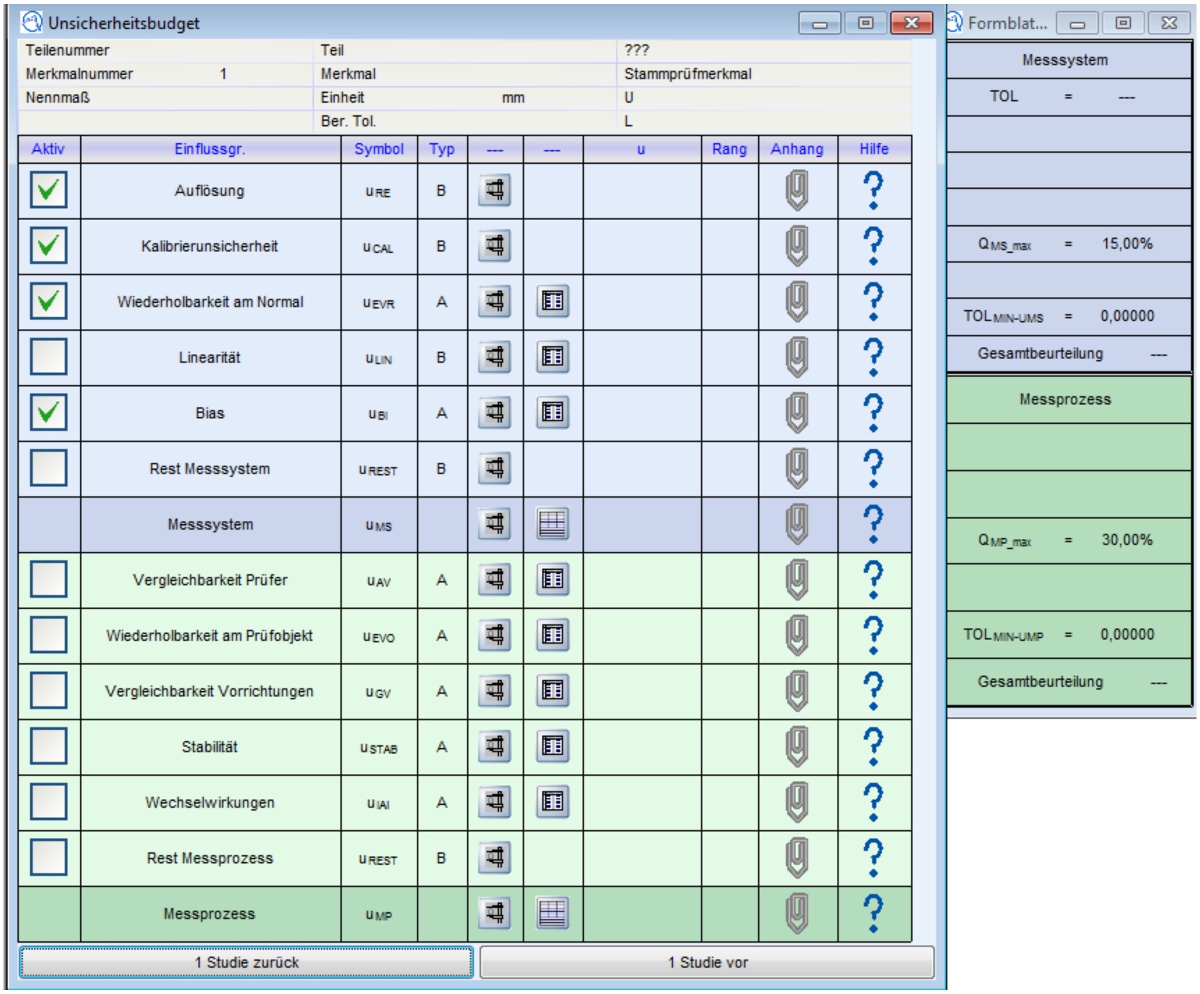


Figure 4-11: Uncertainty budget

Selecting the icon results  in an input field for the values according to Method A or B depending on the uncertainty component. With Method A, direct access to the measured values is also provided via the icon  .

4.2.2 Conducting and Entry of Measured Values

For the quantification of the individual uncertainty components, the data must be entered depending on the determination method A or B.

With uncertainty components determined with **Method A**, the values screen must be displayed with the icon and filled with the measured values which were measured in accordance with the specifications.

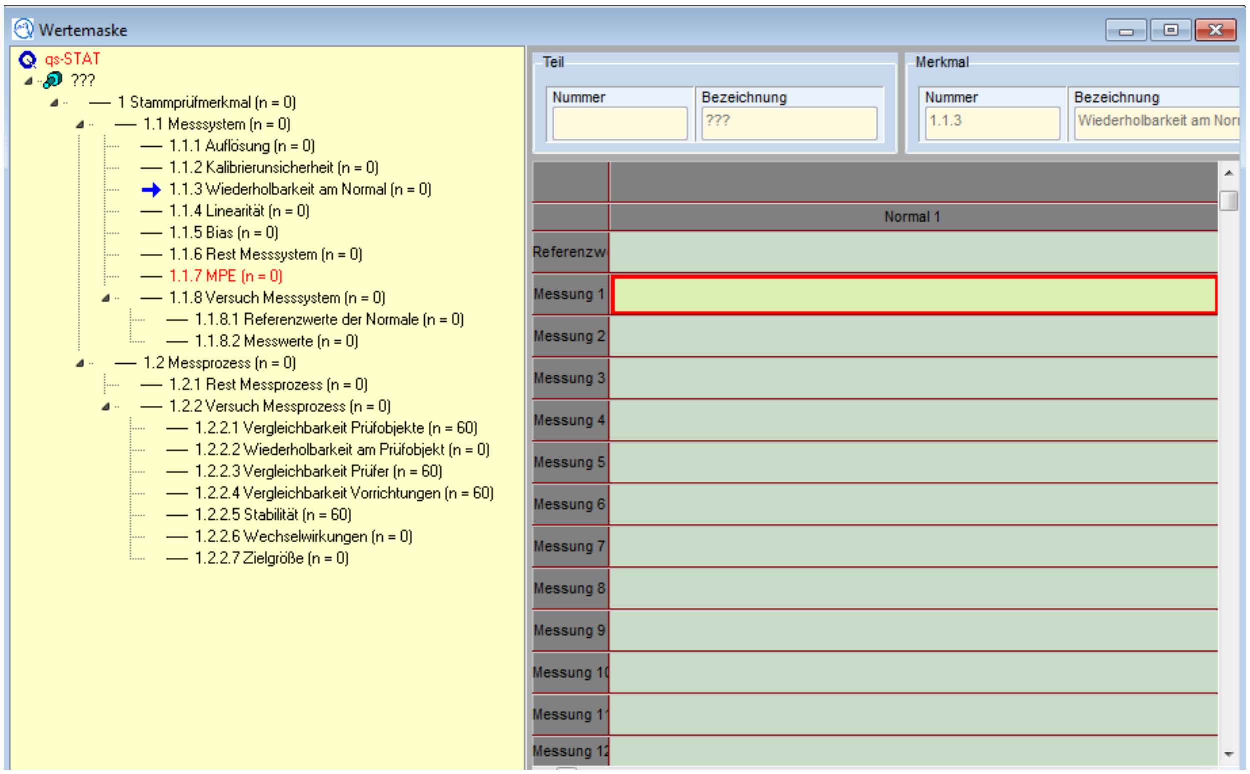


Figure 4-12: Entry of measured values with Method A

With uncertainty components determined with **Method B**, the following input windowmust be opened with the icon and the relevant data must be entered.

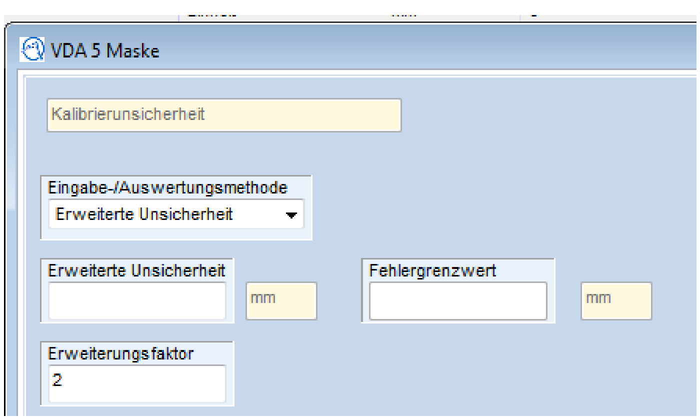
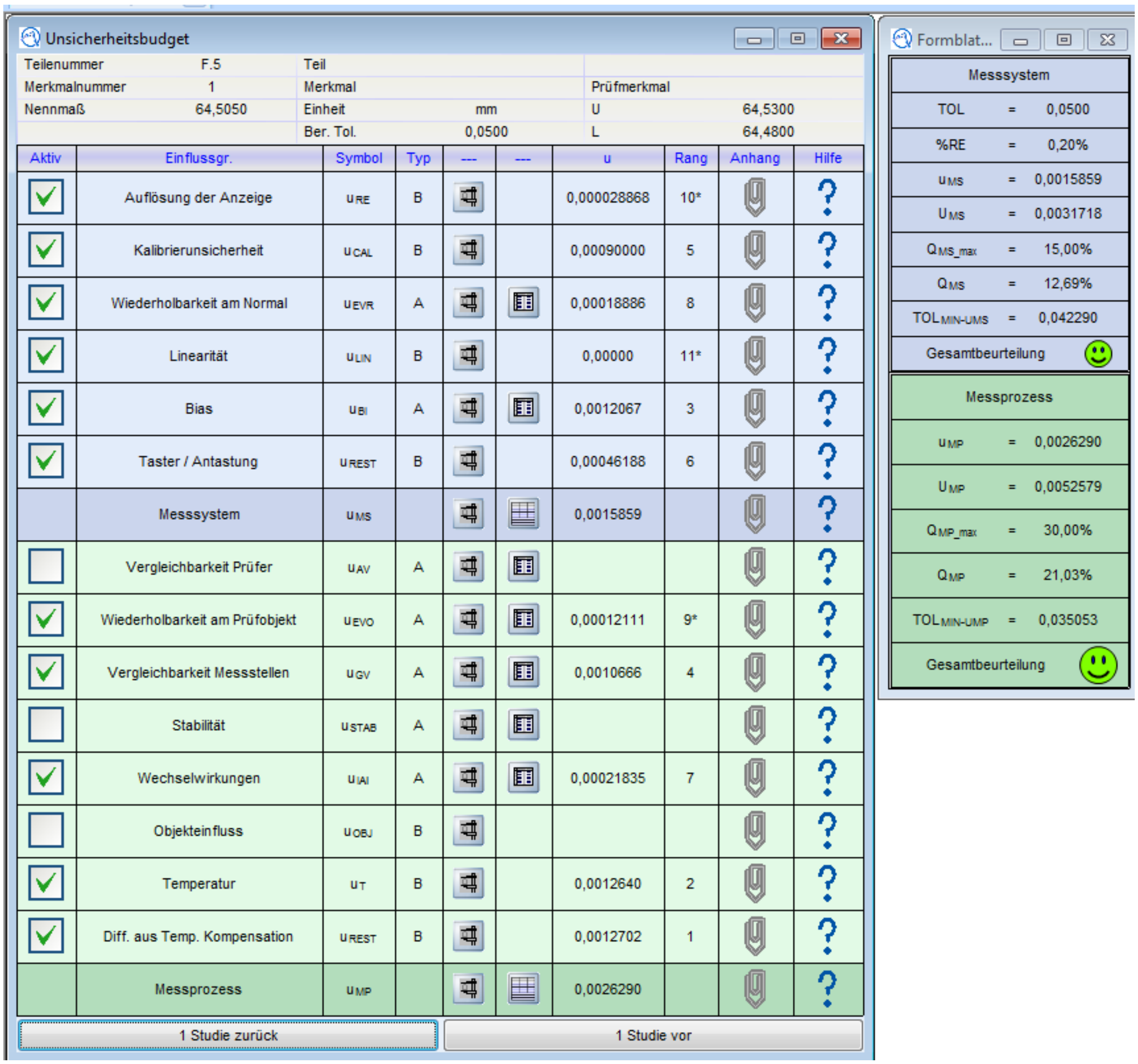


Figure 4-13: Entry of data for Method B

4.2.3 Calculating and Analyzing the Characteristic Values

After all selected uncertainty components have been saved with data (Method A or B), the amounts of the individual uncertainties u_{xi}, the expanded measurement uncertainty U and the capability characteristic values Q_{MS} and Q_{MP} are automatically calculated and displayed.



Unsicherheitsbudget

Teilenummer	F.5	Teil			
Merkmalnummer	1	Merkmal		Prüfmerkmal	
Nennmaß	64,5050	Einheit	mm	U	64,5300
		Ber. Tol.	0,0500	L	64,4800

Aktiv	Einflussgr.	Symbol	Typ	---	---	u	Rang	Anhang	Hilfe
✓	Auflösung der Anzeige	u_{RE}	B			0,000028868	10*		?
✓	Kalibrierunsicherheit	u_{CAL}	B			0,00090000	5		?
✓	Wiederholbarkeit am Normal	u_{EVR}	A			0,00018886	8		?
✓	Linearität	u_{LIN}	B			0,00000	11*		?
✓	Bias	u_{BI}	A			0,0012067	3		?
✓	Taster / Antastung	u_{REST}	B			0,00046188	6		?
	Messsystem	u_{MS}				0,0015859			?
	Vergleichbarkeit Prüfer	u_{AV}	A						?
✓	Wiederholbarkeit am Prüfobjekt	u_{EVO}	A			0,00012111	9*		?
✓	Vergleichbarkeit Messstellen	u_{GV}	A			0,0010666	4		?
	Stabilität	u_{STAB}	A						?
✓	Wechselwirkungen	u_{IAI}	A			0,00021835	7		?
	Objekteinfluss	u_{OBJ}	B						?
✓	Temperatur	u_T	B			0,0012640	2		?
✓	Diff. aus Temp. Kompensation	u_{REST}	B			0,0012702	1		?
	Messprozess	u_{MP}				0,0026290			?

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Formblat...

Messsystem		
TOL	=	0,0500
%RE	=	0,20%
u_{MS}	=	0,0015859
U_{MS}	=	0,0031718
Q_{MS_max}	=	15,00%
Q_{MS}	=	12,69%
$TOL_{MIN-UMS}$	=	0,042290
Gesamtbeurteilung		

Messprozess		
u_{MP}	=	0,0026290
U_{MP}	=	0,0052579
Q_{MP_max}	=	30,00%
Q_{MP}	=	21,03%
$TOL_{MIN-UMP}$	=	0,035053
Gesamtbeurteilung		

Figure 4-14: Uncertainty budget and evaluation results

The overall evaluation is divided by the measuring system and the measurement process.

The Mercedes-Benz standard report can be generated and printed under File, Report View, GC-VDA5.

4.2.4 Case Study for Uncertainty Analysis 1: Coordinate Measurement with CMM-Check

(*SOLARA file: LF05 U1 KMGCHECK.DFQ*)

Coordinate measuring machines are used in measuring centers for a wide range of measurement tasks and tolerances. To verify the capability of CMM, the smallest checkable tolerance T_{min} for representative measurement tasks must be determined.

The following example aims to show how measurement process capability in stage 2 can be verified for a universal coordinate measuring machine. The conventional CMM-Check is used as the measurement standard.

The "CMM-Check" is characterized by

- Low weight and easy handling.
- Universality: All coordinate measuring machine characteristics can be checked.
- The ability to be used across the entire range of the coordinate measuring machine.

The probing strategy as well as the measurement and analysis strategy for the material measures integrated in CMM-Check are standardized and described in detail in test instructions. Measuring instrument manufacturers offer standard measurement programs for all standard coordinate measuring machines. This ensures that a procedure for verifying measurement process capability that is comparable as well as standardized and recognized in the field of coordinate measurement is employed.

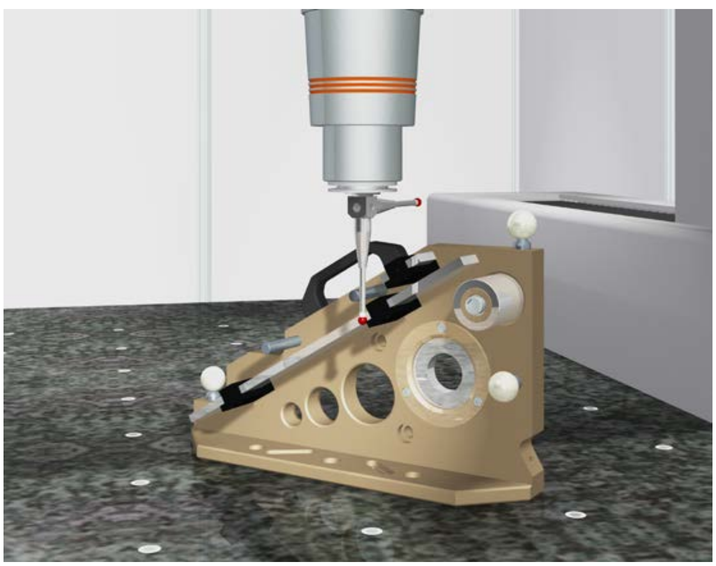


Figure 4-15: Probe with CMM-Check

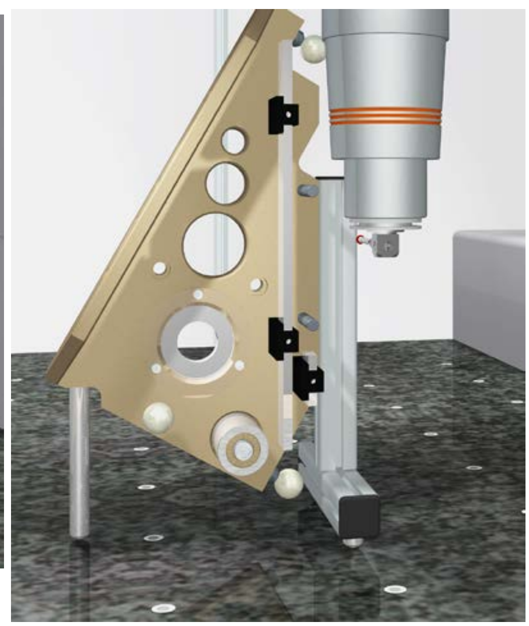


Figure 4-16: Probe with CMM-Check

The CMM-Check is used as a measurement standard for the verification of the measurement process capability of the coordinate measuring machine and must be calibrated on a more exact measuring system. The following points must be taken into account here:

- The measurement uncertainty is to be one accuracy class higher ($U_{CAL} \leq 5\%$ T).

- The calibration device must be traceable.
- Calibration must be repeated on a regular basis.

As repeat measurements are already to be available after Method 1, these are to be used for the uncertainty study. The additional uncertainty components will be supplemented.

Note:

If no standard measuring system is used, the following points must be taken into account when the CNC sequence is programmed:

- All the coordinate measuring machine components used (e.g. temperature compensation systems, sensor changing systems, etc.) must be integrated in the sequential program.
- All the measuring methods used (e.g. point probing, scanning, etc.) must be integrated.
- The same probe elements must be used as in the CNC sequences for the workpieces.

Procedure:

Open SOLARA, File new via menu bar or via VDA5 menu bar (right-hand edge of screen), import data from Method 1, OK

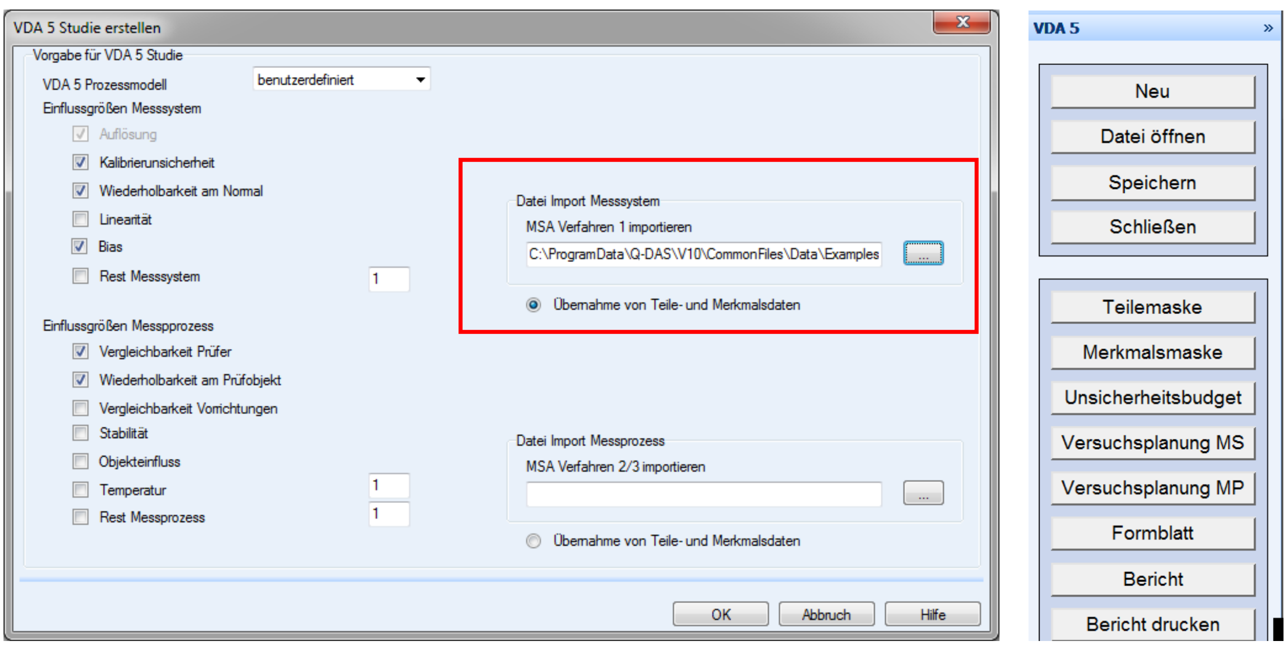
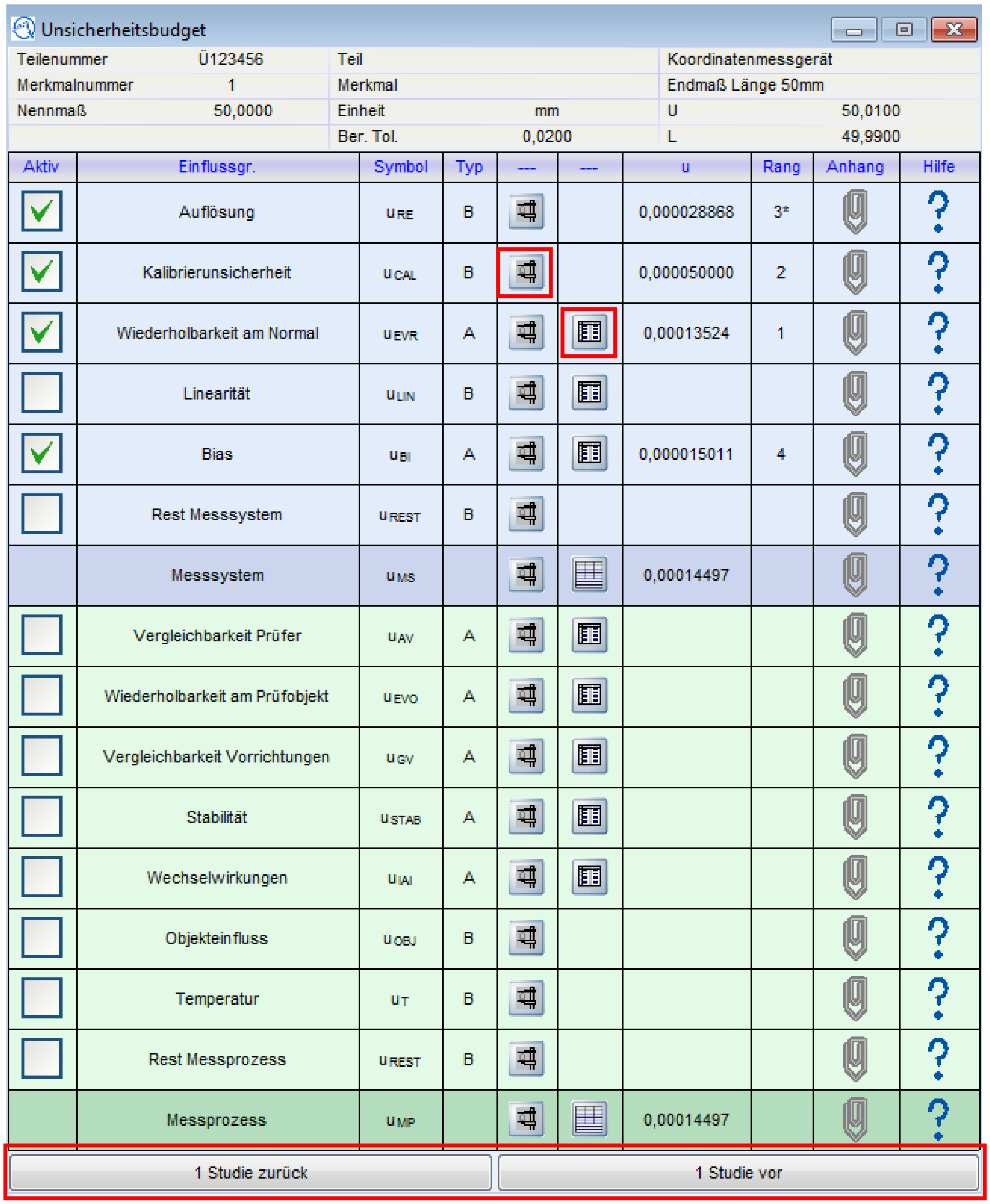


Figure 4-17: Create uncertainty study and import data

The generated uncertainty budget shows the uncertainty components calculated based on the Method 1 data.



Unsicherheitsbudget

Teilenummer	Ü123456	Teil		Koordinatenmessgerät	
Merkmalnummer	1	Merkmal		Endmaß Länge 50mm	
Nennmaß	50,0000	Einheit	mm	U	50,0100
		Ber. Tol.	0,0200	L	49,9900

Aktiv	Einflussgr.	Symbol	Typ	---	---	u	Rang	Anhang	Hilfe
✓	Auflösung	u_{RE}	B			0,000028868	3*		
✓	Kalibrierunsicherheit	u_{CAL}	B			0,000050000	2		
✓	Wiederholbarkeit am Normal	u_{EVR}	A			0,00013524	1		
	Linearität	u_{LIN}	B						
✓	Bias	u_{BI}	A			0,000015011	4		
	Rest Messsystem	u_{REST}	B						
	Messsystem	u_{MS}				0,00014497			
	Vergleichbarkeit Prüfer	u_{AV}	A						
	Wiederholbarkeit am Prüfobjekt	u_{EVO}	A						
	Vergleichbarkeit Vorrichtungen	u_{GV}	A						
	Stabilität	u_{STAB}	A						
	Wechselwirkungen	u_{IAi}	A						
	Objekteinfluss	u_{OBJ}	B						
	Temperatur	u_T	B						
	Rest Messprozess	u_{REST}	B						
	Messprozess	u_{MP}				0,00014497			

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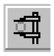
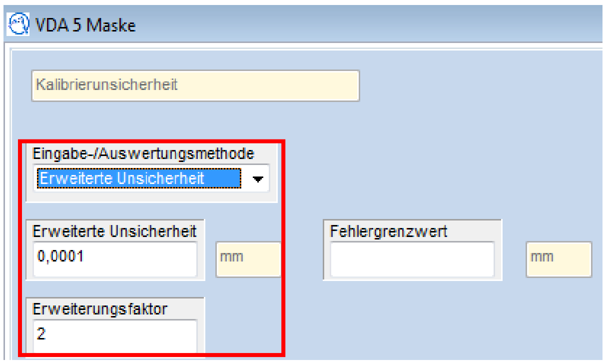
Figure 4-18: Uncertainty budget

In the example the 6 characteristics of the CMM-Check are examined. It is possible to change between the characteristics with the icons "*1Study forward/back*".

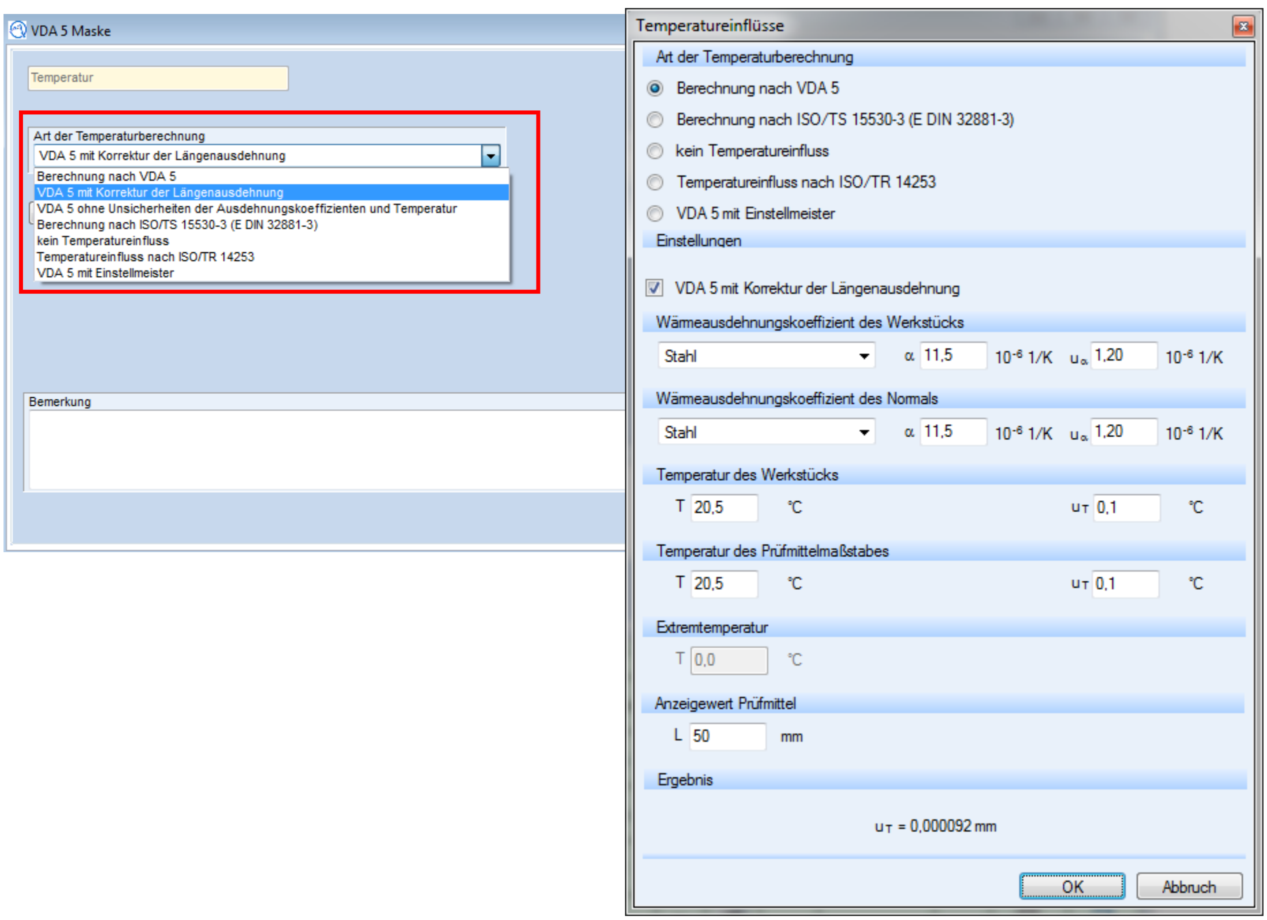
The temperature compensation is switched on and the CMM is in the precision measuring center according to VDI/VDE 2617 [18]. The calibration uncertainty of the measurement standard is additionally specified.

The entry of the additional uncertainty influences is entered directly in the uncertainty budget as follows:

- Calibration uncertainty of the measurement standard with a coverage factor is taken from the calibration certificate and entered in the corresponding field after calling the input form with the icon  (*U*=0.0001; *k*=2).



- Select the method for calculating the temperature. Enter and confirm the relevant temperatures, expansion components and the value displayed on the measuring system (measured value).



Assessment of results

The result of the individual uncertainty components is shown in the uncertainty budget. The uncertainty due to the measurement repeatability on the measurement standard u_{EVR} has the largest amount, followed by the temperature influence $u_{T.}$
With the numerics, form "*Form VDA5*" the characteristic values *U, Q* and T_{MIN} are called.

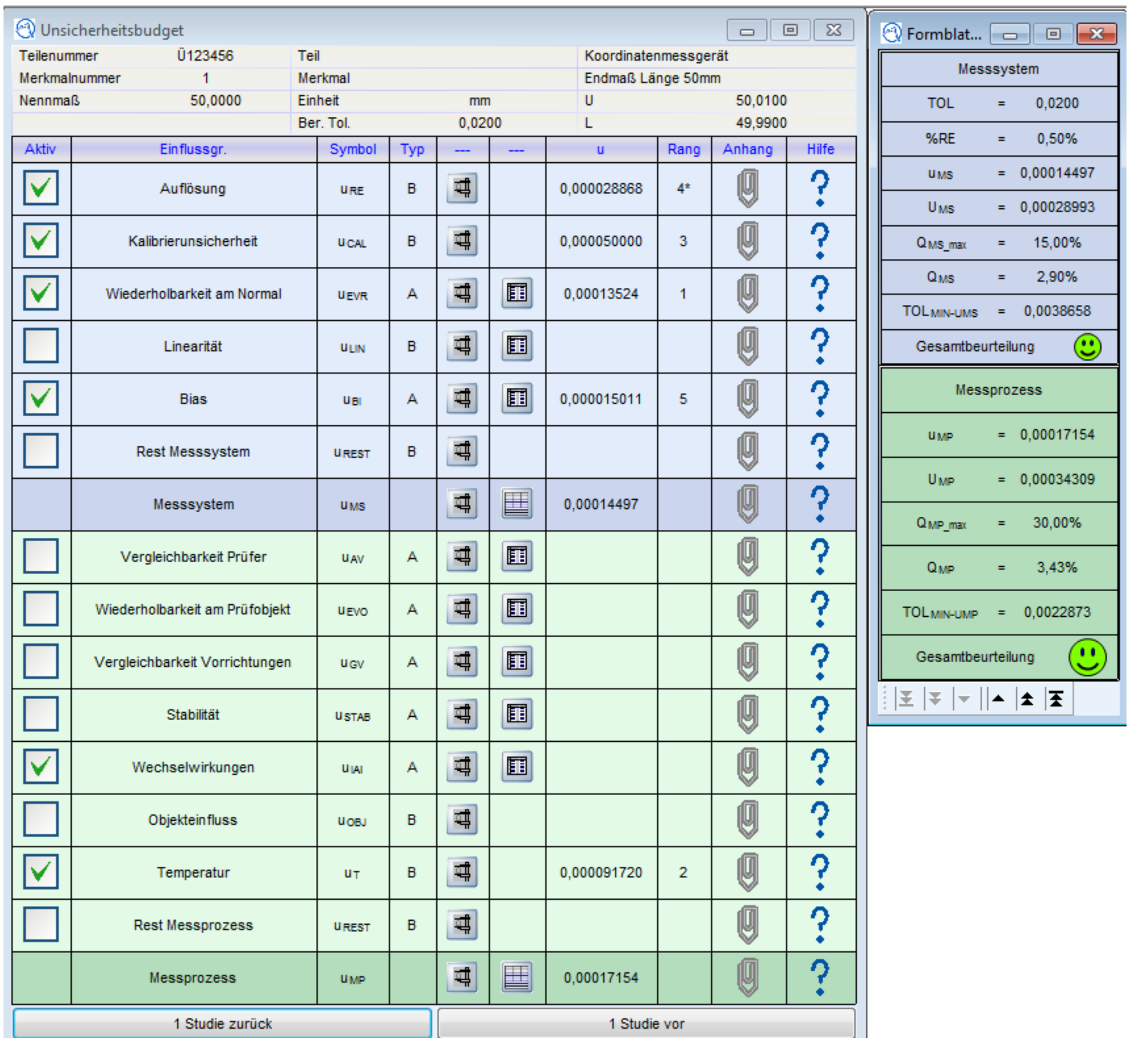


Figure 4 11: Display of result

- The measurement process has passed the verification of capability with Q_{MP} = 3.43%.
- The calculated smallest checkable tolerances $T_{\min}$ show the tolerances as of which the coordinate measuring machine can be used under the conditions defined above.
- Depending on how the CMM is used (e.g. with special probe design and for lengths that deviate from the lengths under analysis), other values for $T_{\min}$ may result.
- Component-related uncertainty components are not taken into account due to the geometry and relatively flawless surface of CMM-Check.

4.2.5 VDA Example F1 - Measurement Process Capability with Three Reference Measurement Standards

For a pin bore measuring instrument, a measurement process capability is to be verified and documented for an inside diameter. Occurring uncertainties caused by the object and temperature influence were evaluated as negligible in advance and are not included in the evaluation.

Specifications for measuring system and measurement process	
Nominal dimension	30.000 mm
Upper tolerance limit U	30.008 mm
Lower tolerance limit L	30.003 mm
Test equipment resolution RE (1 digit = 0.0001 mm)	0.1 µm
Calibration uncertainty U_{CAL}	0.026 µm
Coverage factor k_{CAL}	2
Linearity	0
Reference value measurement standard for upper tolerance limit x_{mu}	30.0076 mm
Reference value measurement standard for center of tolerance x_{mm}	30.0050 mm
Reference value measurement standard for lower tolerance limit x_{ml}	30.0025 mm
Capability limit for measuring system Q_{MS_max}	15%
Capability limit for measurement process Q_{MP_max}	30%

To determine the standard uncertainties caused by the repeatability on the measurement standard and the bias, 10 repeat measurements were carried out in a measuring test on 3 measurements standards.

	Normal 1	Normal 2	Normal 3
Referenzwert	30,0076	30,0050	30,0025
Messung 1	30,0075	30,0050	30,0025
Messung 2	30,0075	30,0051	30,0024
Messung 3	30,0077	30,0051	30,0024
Messung 4	30,0075	30,0050	30,0023
Messung 5	30,0076	30,0052	30,0025
Messung 6	30,0076	30,0051	30,0024
Messung 7	30,0076	30,0050	30,0023
Messung 8	30,0075	30,0051	30,0023
Messung 9	30,0076	30,0051	30,0024
Messung 10	30,0076	30,0052	30,0024

The information on the measuring system and the measured values of the measuring test result in the following uncertainty budget and the result overview.

Einflussgrößen	Symbol	Typ	u	Rang
Auflösung der Anzeige	u_{RE}	B	0,0000289	3*
Kalibrierunsicherheit	u_{CAL}	B	0,0000130	4
Wiederholbarkeit am Normal	u_{EVR}	A	0,0000738	1
Linearität	u_{LIN}	B		
Bias	u_{BI}	A	0,0000635	2
Messsystem	u_{MS}		0,0000982	

Toleranz	TOL	=	0,0050	
Auflösung	%RE	=	2,00%	0 5
Kombinierte Standardunsicherheit	u_{MS}	=	0,0000982	
Erweiterte Messunsicherheit	U_{MS}	=	0,000196	
Eignungsgrenzwert	Q_{MS_max}	=	15,00%	
Eignungskennwert	Q_{MS}	=	7,86%	0 15
minimale Toleranz	$TOL_{MIN\text{-}UMS}$	=	0,00262	

With a percentage resolution %RE of 2.00% and a capability characteristic value Q_{MS} of 7.86%, the measuring system of the pin bore measuring instrument can be considered suitable.

The measurement process is considered after the measuring system. For this purpose, the operator influence, the repeatability on test objects and their interactions are determined in a test under process conditions. In this measuring test 10 test objects are measured 2 times each by 3 inspectors.

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

The individual standard uncertainties can be determined and assigned from the detected measured values using the ANOVA analysis. This results in the following uncertainty budget and the result overview for the measurement process.

Einflussgrößen	Symbol	Typ	u	Rang
Auflösung der Anzeige	u_{RE}	B	0,0000289	5*
Kalibrierunsicherheit	u_{CAL}	B	0,0000130	6
Wiederholbarkeit am Normal	u_{EVR}	A	0,0000738	3*
Linearität	u_{LIN}	B		
Bias	u_{BI}	A	0,0000635	4
Messsystem	u_{MS}		0,0000982	
Vergleichbarkeit Prüfer	u_{AV}	A	0,0000892	2
Wiederholbarkeit am Prüfobjekt	u_{EVO}	A	0,000151	1
Wechselwirkungen	u_{IAi}	A	[pooling]	
Messprozess	u_{MP}		0,000187	

Kombinierte Standardunsicherheit	u_{MP}	=	0,000187
Erweiterte Messunsicherheit	U_{MP}	=	0,000374
Eignungsgrenzwert	Q_{MP_max}	=	30,00%
Eignungskennwert	Q_{MP}	=	14,98%
minimale Toleranz	$TOL_{MIN-UMP}$	=	0,00250

With a capability characteristic value Q_{MP} of 14.98% for a capability limit Q_{MP_max} of 30%, the measurement process of the pin bore measuring instrument can be considered suitable.

4.2.6 VDA Example F2 - Measurement Process Capability with D-Optimum Plan

Analogous to the practical example in F1, a repeat measurement process capability is to be carried out again for the pin bore measuring instrument. However this time with the additional influence component object influence. This is to be determined by additional measurements on 4 different measuring points of the inside diameter. To keep the overall test effort to a minimum, a test reduction will be carried out using a D-optimum test schedule.

The specifications, measured values and results of the measuring system remain the same as in the practical example F1 and can be adopted from it

A D-optimum test schedule with 3 inspectors, 10 test objects and 4 measuring points and 2 repeat measurements is created for the measurement process. The D-optimum test schedule reduces the test effort from 240 to 128 individual measurements. These will be carried out in the random resulting combinations of inspector/test object/measuring point and then evaluated using the ANOVA method.

The information on the measuring system (see F1) and the measured values of the D-optimum plan result in the following values form, the uncertainty budget and the results overview.

	Teil	Prüfer	Messstelle	Messwert		Teil	Prüfer	Messstelle	Messwert		Teil	Prüfer	Messstelle	Messwert
1	1	2	3	30,0059	45	9	2	4	30,0059	89	10	2	3	30,0062
2	2	3	1	30,0057	46	7	1	4	30,0054	90	1	3	3	30,0060
3	1	3	1	30,0054	47	7	3	3	30,0055	91	4	2	3	30,0046
4	6	1	1	30,0050	48	4	1	1	30,0041	92	1	1	2	30,0055
5	2	1	4	30,0060	49	5	3	4	30,0053	93	4	1	4	30,0045
6	4	1	2	30,0042	50	4	2	1	30,0043	94	1	2	4	30,0060
7	7	3	4	30,0054	51	8	1	4	30,0057	95	7	2	3	30,0052
8	5	2	3	30,0058	52	2	3	4	30,0060	96	2	2	1	30,0059
9	4	3	1	30,0045	53	6	3	3	30,0059	97	7	3	1	30,0051
10	3	2	1	30,0055	54	7	2	4	30,0052	98	3	2	2	30,0056
11	6	1	4	30,0054	55	8	1	2	30,0055	99	3	3	4	30,0060
12	8	3	2	30,0058	56	8	2	4	30,0062	100	1	3	2	30,0058
13	10	3	4	30,0061	57	4	3	4	30,0049	101	9	3	3	30,0057
14	6	1	3	30,0053	58	10	1	2	30,0058	102	9	3	2	30,0055
15	10	1	4	30,0061	59	4	3	3	30,0050	103	2	1	1	30,0058
16	3	2	4	30,0058	60	10	3	2	30,0059	104	10	1	3	30,0060
17	5	3	1	30,0056	61	1	1	3	30,0057	105	3	1	4	30,0057
18	10	2	2	30,0060	62	6	2	4	30,0058	106	8	2	3	30,0060
19	8	3	1	30,0058	63	5	3	3	30,0056	107	8	1	3	30,0059
20	2	3	3	30,0059	64	2	2	4	30,0063	108	6	3	4	30,0058
21	9	1	3	30,0056	65	2	2	3	30,0062	109	10	3	1	30,0057
22	6	3	2	30,0056	66	3	1	1	30,0053	110	6	1	2	30,0052
23	3	1	3	30,0055	67	10	2	4	30,0062	111	1	1	4	30,0058
24	1	1	1	30,0055	68	3	2	3	30,0058	112	6	2	1	30,0054
25	9	1	1	30,0054	69	4	1	3	30,0045	113	9	2	2	30,0057
26	5	3	4	30,0055	70	10	2	1	30,0061	114	5	1	4	30,0055
27	10	1	1	30,0057	71	8	1	1	30,0053	115	9	1	4	30,0058
28	6	2	2	30,0055	72	7	1	1	30,0050	116	3	3	2	30,0059
29	3	3	3	30,0059	73	5	1	3	30,0055	117	7	2	1	30,0049
30	6	3	1	30,0055	74	5	1	1	30,0051	118	9	1	2	30,0055
31	9	3	4	30,0058	75	3	3	2	30,0060	119	8	2	1	30,0057
32	1	2	2	30,0058	76	2	2	2	30,0060	120	7	1	3	30,0053
33	3	1	2	30,0054	77	6	2	3	30,0057	121	9	1	3	30,0058
34	10	2	1	30,0059	78	8	2	2	30,0059	122	7	2	2	30,0050
35	3	3	1	30,0059	79	1	2	2	30,0058	123	1	3	4	30,0061
36	2	3	2	30,0059	80	8	3	3	30,0061	124	5	2	1	30,0055
37	4	2	4	30,0048	81	7	1	2	30,0050	125	2	2	3	30,0058
38	5	3	2	30,0054	82	2	1	2	30,0058	126	4	3	2	30,0045
39	7	3	2	30,0052	83	2	1	3	30,0060	127	5	2	4	30,0058
40	9	3	1	30,0054	84	1	2	1	30,0057	128	10	3	3	30,0061
41	6	1	4	30,0055	85	9	2	1	30,0056	129				
42	7	1	1	30,0049	86	9	2	3	30,0059	130				
43	5	1	2	30,0053	87	5	2	2	30,0055	131				
44	4	2	2	30,0044	88	8	3	4	30,0062	132				

Unsicherheitsbudget

Teilenummer	F.2	Teil		Kolben	
Merkmalnummer	1	Merkmal		Innendurchmesser	
Nennmaß	30,0000	Einheit	mm	U	30,0080
		Ber. Tol.	0,0050	L	30,0030

Aktiv	Einflussgr.	Symbol	Typ	---	---	u	Rang	Anhang	Hilfe
✓	Auflösung der Anzeige	u_{RE}	B			0,000028868	7*		?
✓	Kalibrierunsicherheit	u_{CAL}	B			0,000013000	8		?
✓	Wiederholbarkeit am Normal	u_{EVR}	A			0,000073786	5*		?
✓	Linearität	u_{LIN}	B			0,00000	9*		?
✓	Bias	u_{BI}	A			0,000063509	6		?
☐	Rest MS	u_{REST}	B						?
	Messsystem	u_{MS}				0,000098218			?
✓	Vergleichbarkeit Prüfer	u_{AV}	A			0,00011662	2		?
✓	Wiederholbarkeit am Prüfobjekt	u_{EVO}	A			0,000096244	4		?
✓	Vergleichbarkeit Vorrichtungen	u_{GV}	A			0,00015947	1		?
☐	Stabilität	u_{STAB}	A						?
✓	Wechselwirkungen	u_{IAi}	A			0,00011144	3		?
☐	Objekteinfluss	u_{OBJ}	B						?
☐	Temperatur	u_T	B						?
☐	Rest MP	u_{REST}	B						?
	Messprozess	u_{MP}				0,00025478			?

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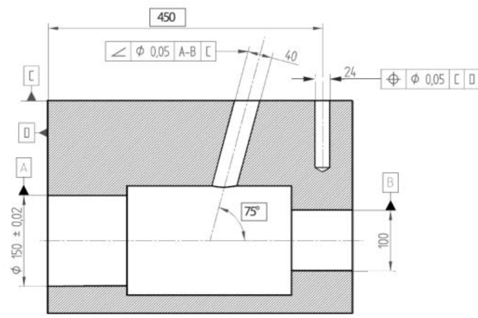
Kombinierte Standardunsicherheit	u_{MP}	=	0,000255
Erweiterte Messunsicherheit	U_{MP}	=	0,000510
Eignungsgrenzwert	Q_{MP_max}	=	30,00%
Eignungskennwert	Q_{MP}	=	20,38%
minimale Toleranz	$TOL_{MIN-UMP}$	=	0,00340

With a capability characteristic value Q_{MP} of 20.38% for a capability limit Q_{MP_max} of 30%, the measurement process of the pin bore measuring instrument can be considered suitable.

4.2.7 VDA Example F3 - Measurement Process Capability of a CMM

The capability of measurement processes must be verified and documented for the measurement of an inside diameter of a pump housing from a measurement standard with a coordinate measuring machine.



Schnitt A-A / Section A-A

Specifications for measuring system and measurement process	
Nominal dimension	150.00 mm
Upper tolerance limit *U*	150.02 mm
Lower tolerance limit*L*	149.98 mm
Test equipment resolution RE (1 digit = 0.0001 mm)	0.1 µm
Reference value of measurement standard	150.0015 mm
Calibration uncertainty U_{CAL}	2 µm
Coverage factor k_{CAL}	2
Linearity	0
Capability limit for measuring system Q_{MS_max}	15%
Standard uncertainty of the thermal expansion coefficient from the test object $u_{\alpha OBJ}$	$1 \cdot 10^{-6}$/K
Mean temperature of measurement process	22°C
Display value of measuring system	150.00 mm
Capability limit for measurement process Q_{MP_max}	30%

To determine the standard uncertainties caused by the repeatability on the measurement standard and the bias, 20 repeat measurements were carried out on one measurement standard. As the linearity deviation is specified with 0, this can be neglected for the further consideration.

	Normal 1		Normal 1
Messung 1	150,0037	Messung 11	150,0021
Messung 2	150,0043	Messung 12	150,0024
Messung 3	150,0030	Messung 13	150,0024
Messung 4	150,0021	Messung 14	150,0030
Messung 5	150,0033	Messung 15	150,0031
Messung 6	150,0039	Messung 16	150,0034
Messung 7	150,0032	Messung 17	150,0022
Messung 8	150,0027	Messung 18	150,0020
Messung 9	150,0025	Messung 19	150,0018
Messung 10	150,0032	Messung 20	150,0030

The information on the measuring system and the measured values of the measuring test result in the following uncertainty budget and the result overview.

Einflussgrößen	Symbol	Typ	u	Rang
Auflösung der Anzeige	u_{RE}	B	0,0000289	4*
Kalibrierunsicherheit	u_{CAL}	B	0,00100	1
Wiederholbarkeit am Normal	u_{EVR}	A	0,000678	3
Linearität	u_{LIN}	B		
Bias	u_{BI}	A	0,000788	2
Messsystem	u_{MS}		0,00144	

Toleranz	TOL	=	0,0400
Auflösung	%RE	=	0,25%
Kombinierte Standardunsicherheit	u_{MS}	=	0,00144
Erweiterte Messunsicherheit	U_{MS}	=	0,00288
Eignungsgrenzwert	Q_{MS_max}	=	15,00%
Eignungskennwert	Q_{MS}	=	14,42%
minimale Toleranz	$TOL_{MIN-UMS}$	=	0,0385

With a percentage resolution %RE of 0.25% and a capability characteristic value Q_{MS} of 14.42%, the measuring system of the CMM can be considered suitable.

As the capability of measurement processes refers exclusively to a measurement standard and with CMM no classic inspector influence exists, the uncertainty of the temperature according to DIN ISO TS 15530-3 [6] is only additionally taken into consideration for the measurement process.

This results in the following uncertainty budget and the result overview for the measurement process.

Einflussgrößen	Symbol	Typ	u	Rang
Auflösung der Anzeige	u_{RE}	B	0,0000289	5*
Kalibrierunsicherheit	u_{CAL}	B	0,00100	1
Wiederholbarkeit am Normal	u_{EVR}	A	0,000678	3
Linearität	u_{LIN}	B		
Bias	u_{BI}	A	0,000788	2
Messsystem	u_{MS}		0,00144	
Temperatur	u_{T}	B	0,000300	4
Messprozess	u_{MP}		0,00147	

Kombinierte Standardunsicherheit	u_{MP}	=	0,00147
Erweiterte Messunsicherheit	U_{MP}	=	0,00295
Eignungsgrenzwert	Q_{MP_max}	=	30,00%
Eignungskennwert	Q_{MP}	=	14,73%
minimale Toleranz	$TOL_{MIN\text{-}UMP}$	=	0,0196

With a capability characteristic value Q_{MP} of 14.73% for a capability limit Q_{MP_max} of 30%, the measurement process of the CMM for the measurement of the inside diameter of the measurement standard can be considered suitable.

4.2.8 VDA Example F5 - Measurement Process Capability of a Multiple-point Measuring Instrument

The measurement process capability must be verified and documented for a multiple-point measuring instrument with 3 identical measuring points.

In the first step, the measuring system is considered with the influencing factors of the resolution, calibration uncertainty of measurement standards, repeatability on the measurement standards, the bias and the probe/scanning is viewed as an additional component.

Specifications of Measuring System	
Nominal dimension	64.505 mm
Upper tolerance limit U	64.530 mm
Lower tolerance limit$L$	64.480 mm
Test equipment resolution RE (1 digit = 0.0001 mm)	0.1 µm
Calibration uncertainty U_{CAL}	1.8 µm
Coverage factor k_{CAL}	2
Linearity u_{LIN} (from previous examination)	0
Error limit due to probe/scanning	0.8 µm
Reference value for measurement standard 1 / measuring point 1	64.5042 mm
Reference value for measurement standard 1 / measuring point 2	64.5035 mm
Reference value for measurement standard 1 / measuring point 3	64.5016 mm
Reference value for measurement standard 2 / measuring point 1	64.5421 mm
Reference value for measurement standard 2 / measuring point 2	64.5449 mm
Reference value for measurement standard 2 / measuring point 3	64.5465 mm
Reference value for measurement standard 3 / measuring point 1	64.4604 mm
Reference value for measurement standard 3 / measuring point 2	64.4612 mm
Reference value for measurement standard 3 / measuring point 3	64.4596 mm

Specifications for Measurement Process	
Expansion coefficient α test object for steel	11.5 1/K · 10^{-6}/K
Expansion coefficient α measuring system for steel	11.5 1/K · 10^{-6}/K
Standard uncertainty of the thermal expansion coefficient from the test object $u_{\alpha OBJ}$ for steel	1.2 1/K · 10^{-6}/K
Standard uncertainty of the thermal expansion coefficient from the measuring system $u_{\alpha R}$ for steel	1.2 1/K · 10^{-6}/K
Extreme temperature (environment)	30°C
Display value of measuring system	64.505 mm
Error limit Diff. from temp. compensation	2.2 µm

To determine the standard uncertainties caused by the repeatability on the measurement standards and the bias, 10 repeat measurements each were carried out in a measuring test on the 3 measurements standards.

	Messstelle 1			Messstelle 2			Messstelle 3		
	Normal 1	Normal 2	Normal 3	Normal 1	Normal 2	Normal 3	Normal 1	Normal 2	Normal 3
Referenzwert	64,5042	64,5421	64,4604	64,5035	64,5449	64,4612	64,5016	64,5465	64,4596
Messung 1	64,5040	64,5430	64,4608	64,5029	64,5454	64,4616	64,5026	64,5485	64,4617
Messung 2	64,5040	64,5430	64,4607	64,5032	64,5455	64,4617	64,5025	64,5484	64,4616
Messung 3	64,5038	64,5430	64,4607	64,5031	64,5454	64,4614	64,5025	64,5485	64,4615
Messung 4	64,5039	64,5430	64,4608	64,5031	64,5454	64,4617	64,5026	64,5484	64,4616
Messung 5	64,5039	64,5430	64,4609	64,5032	64,5453	64,4613	64,5026	64,5486	64,4615
Messung 6	64,5038	64,5430	64,4608	64,5031	64,5452	64,4613	64,5026	64,5486	64,4617
Messung 7	64,5039	64,5431	64,4608	64,5031	64,5453	64,4616	64,5026	64,5485	64,4618
Messung 8	64,5039	64,5431	64,4608	64,5031	64,5454	64,4616	64,5026	64,5486	64,4618
Messung 9	64,5040	64,5431	64,4610	64,5031	64,5453	64,4619	64,5026	64,5485	64,4618
Messung 10	64,5039	64,5431	64,4609	64,5031	64,5453	64,4616	64,5026	64,5486	64,4619

The information on the measuring system and the measured values of the measuring test result in the following uncertainty budget and the result overview.

Einflussgrößen	Symbol	Typ	u	Rang
Auflösung der Anzeige	u_{RE}	B	0,0000289	5*
Kalibrierunsicherheit	u_{CAL}	B	0,000900	2
Wiederholbarkeit am Normal	u_{EVR}	A	0,000189	4
Linearität	u_{LIN}	B		
Bias	u_{BI}	A	0,00121	1
Taster / Antastung	u_{REST}	B	0,000462	3
Messsystem	u_{MS}		0,00159	

Toleranz	TOL	=	0,0500	
Auflösung	%RE	=	0,20%	0 5
Kombinierte Standardunsicherheit	u_{MS}	=	0,00159	
Erweiterte Messunsicherheit	U_{MS}	=	0,00317	
Eignungsgrenzwert	Q_{MS_max}	=	15,00%	
Eignungskennwert	Q_{MS}	=	12,69%	0 15
minimale Toleranz	$TOL_{MIN-UMS}$	=	0,0423	

With a percentage resolution %RE of 0.2% and a capability characteristic value of Q_{MS} of 12.69%, the measuring system of the multiple-point measuring instrument can be considered suitable.

In the second step, the entire measurement process is considered. Here the influencing factors of the repeatability on the test object, the comparability of the measuring points and their interactions are determined in a measuring test. In addition, the influence of the temperature is taken into account after the calculation without correction of the length expansion and a residual component from the temperature compensation. For determination of the residual component from the temperature compensation, a separate measuring test was carried out in a previous test (measured value in same position via a temperature curve/cool-down curve) and an error limit of 2.2 µm was established.

10 test objects were measured 2 times each in the measuring test for the measurement process. The measured values detected in the process are then evaluated with the ANOVA method.

	Messstelle 1		Messstelle 2		Messstelle 3	
	Messung 1	Messung 2	Messung 1	Messung 2	Messung 1	Messung 2
1	64,4959	64,4965	64,4955	64,4956	64,4980	64,4980
2	64,4976	64,4978	64,4973	64,4977	64,4992	64,4991
3	64,4957	64,4958	64,4957	64,4957	64,4975	64,4975
4	64,4945	64,4945	64,4942	64,4941	64,4961	64,4960
5	64,4866	64,4868	64,4865	64,4867	64,4886	64,4887
6	64,4994	64,4994	64,4989	64,4989	64,5011	64,5011
7	64,5019	64,5020	64,5005	64,5003	64,5029	64,5028
8	64,4996	64,4995	64,4990	64,4992	64,5012	64,5012
9	64,4974	64,4975	64,4971	64,4970	64,4989	64,4990
10	64,5001	64,5003	64,4998	64,4998	64,5017	64,5017

The information on the measuring system, the measurement process and the measured values of the measuring test result in the following uncertainty budget and the result overview.

Einflussgrößen	Symbol	Typ	u	Rang
Auflösung der Anzeige	u_{RE}	B	0,0000289	10*
Kalibrierunsicherheit	u_{CAL}	B	0,000900	5
Wiederholbarkeit am Normal	u_{EVR}	A	0,000189	8
Linearität	u_{LIN}	B		
Bias	u_{BI}	A	0,00121	3
Taster / Antastung	u_{REST}	B	0,000462	6
Messsystem	u_{MS}		0,00159	
Wiederholbarkeit am Prüfobjekt	u_{EVO}	A	0,000121	9*
Vergleichbarkeit Messstellen	u_{GV}	A	0,00107	4
Wechselwirkungen	u_{IAi}	A	0,000218	7
Temperatur	u_T	B	0,00126	2
Diff. aus Temp. Kompensation	u_{REST}	B	0,00127	1
Messprozess	u_{MP}		0,00263	

Kombinierte Standardunsicherheit	u_{MP}	=	0,00263	
Erweiterte Messunsicherheit	U_{MP}	=	0,00526	
Eignungsgrenzwert	Q_{MP_max}	=	30,00%	
Eignungskennwert	Q_{MP}	=	21,03%	0 30
minimale Toleranz	$TOL_{MIN-UMP}$	=	0,0351	

With a capability characteristic value Q_{MP} of 21.03% for a capability limit Q_{MP_max} of 30%, the measurement process of the multiple-point measuring instrument can be considered suitable.

4.2.9 VDA Example F7 - Temperature Compensation

Calculation of the standard uncertainty u_T without correction of different length expansion:

The nominal diameter of 85 mm is to be checked on a workpiece made of aluminum. This is to be carried out without complicated temperature compensation if possible. A steel adjusting ring is used for the comparison measurement. Temperatures up to 30°C can prevail at the workplace. No information is available on the exact expansion coefficient of the workpiece and adjusting ring.

Information on temperature influences	
Nominal dimension	85.00 mm
Length of measurement standard at 20°C (adjusting ring diameter) y_R	85.002 mm
Extreme temperature t_{MAX}	30°C
Expansion coefficient of test object α_{OBJ}	0.000024 1/K
Expansion coefficient of measurement standard α_R	0.0000115 1/K
Standard uncertainty of the thermal expansion coefficient from the test object $u_{\alpha OBJ}$	10% of α_{OBJ}
Standard uncertainty of the thermal expansion coefficient from the measurement standard $u_{\alpha R}$	10% of α_R

According to these specifications, the following measurement error results according to the formula B.6

$$\Delta y = 85{,}002 \cdot (30 - 20) \cdot (0{,}000024 - 0{,}0000115) = 0{,}0106\, mm\,.$$

Due to the uncertain expansion coefficient, the residual uncertainty according to B.5 is calculated for the temperature deviation of 10°C to the reference temperature to

$$u_{REST} = 85{,}002 \cdot \sqrt{10^2 \cdot 0{,}00000115^2 + 10^2 \cdot 0{,}0000024^2}$$
$$= 0{,}0023\, mm.$$

Both together therefore result according to B.7 in an error limit of

$$a = \left|0{,}0106\right| + 2 \cdot 0{,}0023 = 0{,}0152\, mm$$

and therefore according to B.8 a standard uncertainty due to temperature influences of

$$u_T = \frac{0{,}0152}{\sqrt{3}} = 0{,}0088\, mm\,.$$

In this case (assumption $u_{\alpha_{OBJ;R}} = 0{,}1 \times \alpha_{OBJ;R}$), the determination of the standard uncertainty would also be possible using table B.2. With the tabular value u_T = *10.3 µm* per *100 mm*, the same result is obtained with the exception of small curvature deviations:

$$u_T = 10{,}3 \times \frac{85{,}002}{100} = 8{,}76 \text{ µm.}$$

Calculation of the standard uncertainty u_T <u>with correction</u> of different length expansion:

In the uncertainty budget, the above uncertainty share proves to be too large so that a decision is made to reduce the uncertainty share to a reasonable level by correcting the measurement results. To detect the predominant temperatures during measuring, a temperature measuring instrument is used which does not exceed a maximum deviation of ± *0.5°C* according to the manufacturer's data.

With a measured workpiece temperature of *28.2°C* and a temperature of the adjusting ring of *26.7°C*, a differentiating measurement *d* = +0.014 *mm* results which then results in a measured value of *dia.* 85.016 *mm*. This measured value is corrected according to B.3 to:

$$y_{korr} = \frac{85{,}002 \times \left(1 + 0{,}0000115 \times (26{,}7 - 20)\right) + 0{,}014}{1 + 0{,}000024 \times (28{,}2 - 20)} = 85{,}0058\, mm.$$

With a standard uncertainty of the temperature measurements of $u_{\Delta T_{OBJ;R}} = 0{,}5 / \sqrt{3} = 0{,}2887$, a residual uncertainty remains according to B.5 which shows the now considerably smaller standard uncertainty through temperature influences:

$$u_T = 85{,}002 \times \sqrt{\begin{array}{l} 6{,}7^2 \times 0{,}00000115^2 + 8{,}2^2 \times 0{,}0000024^2 + \\ +0{,}0000115^2 \times 0{,}2887^2 + 0{,}000024^2 \times 0{,}2887^2 \end{array}}$$
$$= 0{,}0019\, mm.$$

Conclusion:
The advantage of not having to carry out complex temperature determinations and compensation calculations during the measurements is always bought with high extreme temperatures with a relatively large (usually too large) uncertainty share by the temperature influences. In many cases there is no way around the more complicated method of also determining and taking the predominant temperatures into account during the measurement. If possible, the use of modern-aided measuring instruments should already be considered during test planning, which relieves the user of a large part of the measuring and calculating work.

5 Appendices

Appendix A. Estimation of standard uncertainties due to temperature influences

As most substances change when subjected to temperature fluctuations, the standard uncertainty u_T as a consequence of temperature changes for all length measurements must be determined.

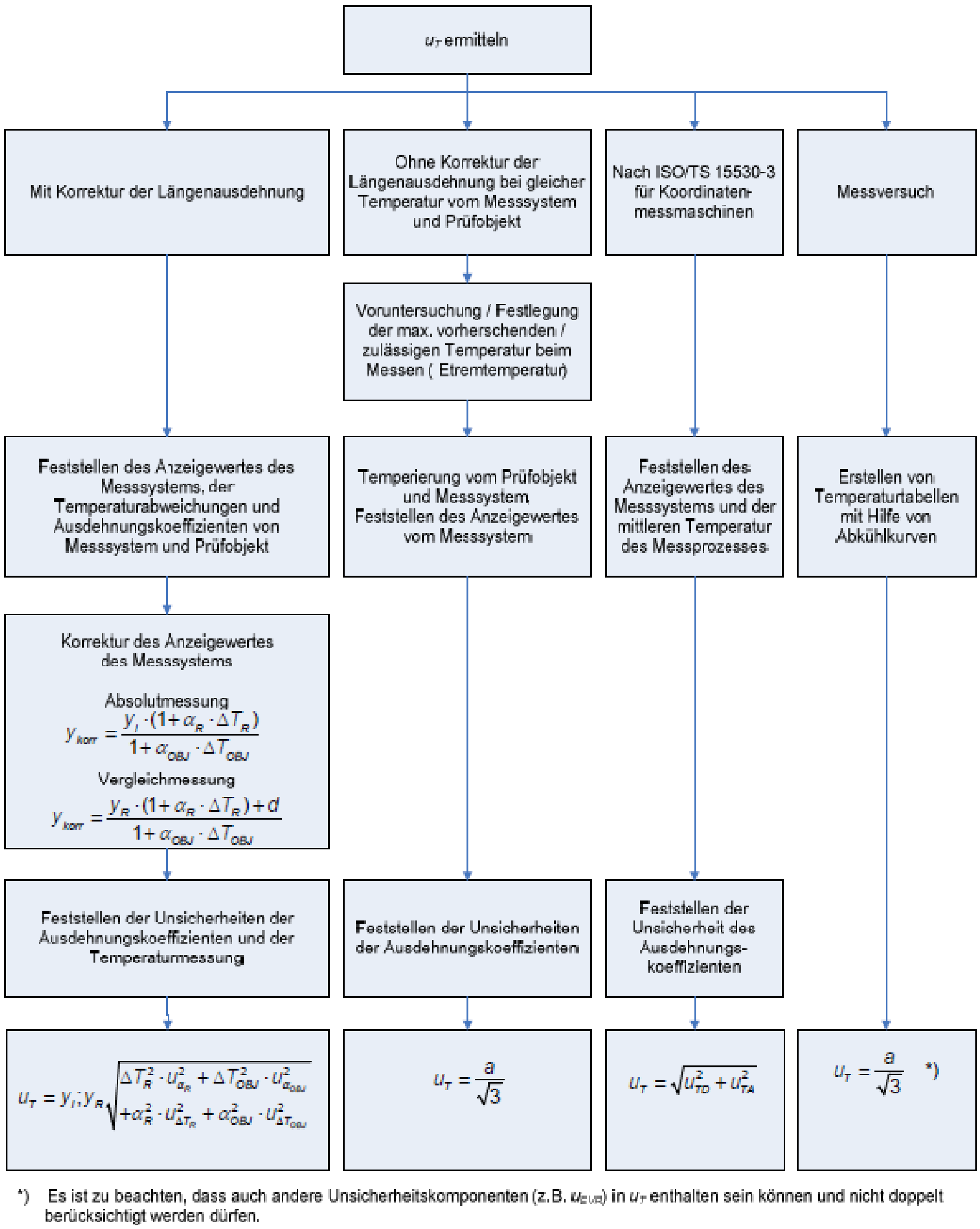


Figure 5-1: Procedures for determining standard uncertainty u_T

When comparing a test object (workpiece) with a measurement standard or standard, temperature influences only have no effects when both the test object and the measurement standard or standard are made of the same material and both have the same temperature. If this is not the case, the measurement result is subject to a deviation due to the different expansion. As deviations of this kind can in some cases be quite large, they should always be computationally corrected (temperature compensation).

1. Uncertainty with correction of different length expansion

The corrected measured value y_{korr} is calculated depending on the type of measurement as:

Absolute measurement

$$y_{korr} = \frac{y_i \cdot (1 + \alpha_R \cdot \Delta T_R)}{1 + \alpha_{OBJ} \cdot \Delta T_{OBJ}} \qquad \text{B.1}$$

with y_i = display value of measuring instrument
ΔT_{OBJ} = temperature deviation of test object of 20° C
ΔT_R = temperature deviation of measuring instrument scale of 20° C
α_{OBJ} = thermal expansion coefficient of test object
α_R = thermal expansion coefficient of measuring instrument scale (e.g. glass scale of an altimeter).

With a good proximity, the following also applies:

$$y_{korr} \approx y_i \cdot \left[1 - (\alpha_{OBJ} \cdot \Delta T_{OBJ} - \alpha_R \cdot \Delta T_R)\right] \qquad \text{B.2}$$

Comparison measurement

$$y_{korr} = \frac{y_R \cdot (1 + \alpha_R \cdot \Delta T_R) + d}{1 + \alpha_{OBJ} \cdot \Delta T_{OBJ}} \qquad \text{B.3}$$

with d = result of differentiation measurement (test object – measurement standard)
y_R = length of measurement standard at reference temperature 20° C
ΔT_R = temperature deviation of measurement standard of 20° C
α_R = thermal expansion coefficient of measurement standard

With a good proximity, the following also applies:

$$y_{korr} \approx y_R + d + y_R (\alpha_R \cdot \Delta T_R - \alpha_{OBJ} \cdot \Delta T_{OBJ}) \qquad \text{B.4}$$

Since not only the (measured) temperatures but also the thermal expansion coefficients used for the calculation are themselves subject to uncertainties, a residual uncertainty u_{REST} remains. Under the assumption that α_{OBJ}, α_R, ΔT_{OBJ} and ΔT_R are not correlated and the temperatures do not change during the measurement, the standard uncertainty due to the temperature influences are calculated as:

$$u_T = u_{REST} = y_i; y_R \sqrt{\Delta T_R^2 u_{\alpha_R}^2 + \Delta T_{OBJ}^2 u_{\alpha_{OBJ}}^2 + \alpha_R^2 u_{\Delta T_R}^2 + \alpha_{OBJ}^2 u_{\Delta T_{OBJ}}^2} \quad \text{B.5}$$

If no other data are available, 10% of the coefficient can usually be set for the uncertainties of the thermal expansion coefficients and 1 kelvin for the uncertainties of the temperatures. If temperature changes (drifts) are possible during the measurement, these influences may also have to be taken into account.

In Figure 5-2 the residual uncertainties are specified as an example which result for the measurement of objects made of different materials with various scales or measurement standards. For the examples, the assumption applies that the test object and measuring instrument have approximately the same temperature (temperature control of the test object), that the temperatures do not change during the measurement and, in addition, that $u_{\alpha_{OBJ;R}} = 0{,}1 \times \alpha_{OBJ;R}$ and $u_{\Delta T_{OBJ;R}} = 1$ kelvin.

Benchmark standard	**Material of test object**	**Residual uncertainty u_{REST} in µm per 100 mm with temperature deviation $\Delta T_{OBJ;R}$ of 20°C**						
		0 K	2.5 K	5 K	7.5 K	10 K	12.5 K	15 K
Steel	Aluminum $\alpha_{OBJ} = 24 \cdot 10^{-6}$ 1/K	2.7	2.7	3.0	3.3	3.8	4.3	4.8
	Brass $\alpha_{OBJ} = 18 \cdot 10^{-6}$ 1/K	2.1	2.2	2.4	2.7	3.0	3.4	3.9
	Steel $\alpha_{OBJ} = 11.5 \cdot 10^{-6}$ 1/K	1.6	1.7	1.8	2.0	2.3	2.6	2.9
	Gray cast iron $\alpha_{OBJ} = 10 \cdot 10^{-6}$ 1/K	1.5	1.6	1.7	1.9	2.2	2.4	2.7
Ceramic	Aluminum $\alpha_{OBJ} = 24 \cdot 10^{-6}$ 1/K	2.6	2.7	2.9	3.2	3.7	4.1	4.7
	Brass $\alpha_{OBJ} = 18 \cdot 10^{-6}$ 1/K	2.0	2.1	2.3	2.5	2.9	3.3	3.7
	Steel $\alpha_{OBJ} = 11.5 \cdot 10^{-6}$ 1/K	1.5	1.5	1.7	1.9	2.1	2.4	2.7
	Gray cast iron $\alpha_{OBJ} = 10 \cdot 10^{-6}$ 1/K	1.4	1.4	1.5	1.7	2.0	2.2	2.5

Bench-mark standard	**Material of test object**	**Residual uncertainty u_{REST} in µm per 100 mm with temperature deviation $\Delta T_{OBJ;R}$ of 20°C**						
		0 K	2.5 K	5 K	7.5 K	10 K	12.5 K	15 K
Glass	Aluminum $\alpha_{OBJ} = 24 \cdot 10^{-6}$ 1/K	2.5	2.6	2.8	3.2	3.6	4.0	4.6
	Brass $\alpha_{OBJ} = 18 \cdot 10^{-6}$ 1/K	2.0	2.0	2.2	2.5	2.8	3.2	3.6
	Steel $\alpha_{OBJ} = 11.5 \cdot 10^{-6}$ 1/K	1.4	1.4	1.6	1.8	2.0	2.2	2.5
	Gray cast iron $\alpha_{OBJ} = 10 \cdot 10^{-6}$ 1/K	1.3	1.3	1.4	1.6	1.8	2.1	2.3
System without expan. $\alpha_R \approx 0$ 1/K	Aluminum $\alpha_{OBJ} = 24 \cdot 10^{-6}$ 1/K	2.4	2.5	2.7	3.0	3.4	3.8	4.3
	Brass $\alpha_{OBJ} = 18 \cdot 10^{-6}$ 1/K	1.8	1.9	2.0	2.3	2.5	2.9	3.2
	Steel $\alpha_{OBJ} = 11.5 \cdot 10^{-6}$ 1/K	1.2	1.2	1.3	1.4	1.6	1.8	2.1
	Gray cast iron $\alpha_{OBJ} = 10 \cdot 10^{-6}$ 1/K	1.0	1.0	1.1	1.3	1.4	1.6	1.8

Figure 5-2: Standard uncertainties u_{REST} of test objects and measurement standards with temperature compensation

2. Uncertainty without correction of different length expansion

As in many cases the practice of a computational correction is not possible, the errors which occur due to differing length expansion at temperatures deviating from 20°C must also be taken into account.

The following method assumes that during the measurement both the test object and the measuring instrument have approximately the same temperature (temperature control of the test object) and that a maximum temperature deviating from 20° is not exceeded. The greatest possible measurement error at this extreme temperature t_{max} is considered to be the error limit *a* due to temperature influences.

Note 1: This approach especially also applies in temperature-controlled rooms (measuring centers) in which the currently prevailing temperature always periodically fluctuates between an upper and lower value around the reference temperature of 20°.

Note 2: If a high extreme temperature is permitted, then the resulting uncertainty share is usually the dominant share in the uncertainty budget and usually results in an unsatisfactorily large expanded uncertainty U_{MP}.

Through the different length expansion at the extreme temperature t_{max}, a measurement error Δy_i is calculated there with a close proximity to:

$$\Delta y \approx y_i;y_R \cdot (t_{\max} - 20°) \cdot (\alpha_{OBJ} - \alpha_R) \qquad \text{B.6}$$

This error results together with the errors due to deviating expansion coefficients α_R or α_{OBJ} (effective at t_{max}) in the error limit *a* (worst case) due to temperature influences:

$$a = \left|\Delta y_i\right| + 2u_{REST} \quad \text{with} \quad u_{REST} = y_i;y_R \cdot \sqrt{\Delta T_R^2 \cdot u_{\alpha_R}^2 + \Delta T_{OBJ}^2 \cdot u_{\alpha_{OBJ}}^2} \qquad \text{B.7}$$

In the process, u_{REST} is calculated in the same way as formula B.5, however without the uncertainty contributions from the temperature measurement not available here ($\alpha_R^2 \cdot u_{\Delta T_R}^2 = 0$ and $\alpha_{OBJ}^2 \cdot u_{\Delta T_{OBJ}}^2 = 0$).

As a result, due to temperature influences the standard uncertainty becomes:

$$u_T = \frac{a}{\sqrt{3}} \qquad \text{B.8}$$

In Figure 5-3 the uncertainties are specified as an example which result for the measurement of objects made of different materials with various scales or measurement standards if no computational correction of the differing length expansion is carried out. For the examples, the assumption applies that $u_{\alpha_{OBJ;R}} = 0{,}1 \cdot \alpha_{OBJ;R}$.

Note 1: Strictly speaking, the uncertainty determined according to the methods described only applies to rod-shaped test object with a homogeneous temperature distribution. For other and especially for asymmetrical test objects, the temperature-dependent length change and with it the uncertainty, is very difficult to estimate. However, it can always only be smaller than for the rod-shaped object, so that you are always on the "safe side".

Note 2: The tables show that different thermal expansion coefficients from the test object and the measurement standard or scale lead to large measurement uncertainties. As a result, measuring instruments with scales of very small thermal expansion coefficients lead to especially large measurement uncertainties if no temperature compensation is carried out. Therefore, the computational correction of the temperature influences should always be used for these kinds of measuring instruments.

Benchmark-measurement standard	Material of test object	Uncertainty u_T in µm per 100 mm with temperature deviation $(t_{max} - 20°C)$						
		0.5 K	1 K	2.5 K	5 K	7.5 K	10 K	15 K
Steel	Aluminum $\alpha_{OBJ} = 24 \cdot 10^{-6}$ 1/K	0.5	1.0	2.6	5.1	7.7	10.3	15.4
	Brass $\alpha_{OBJ} = 18 \cdot 10^{-6}$ 1/K	0.3	0.6	1.6	3.1	4.7	6.2	9.3
	Steel $\alpha_{OBJ} = 11.5 \cdot 10^{-6}$ 1/K	0.1	0.2	0.5	0.9	1.4	1.9	2.8
	Gray cast iron $\alpha_{OBJ} = 10 \cdot 10^{-6}$ 1/K	0.1	0.3	0.7	1.3	2.0	2.6	3.9
Ceramic	Aluminum $\alpha_{OBJ} = 24 \cdot 10^{-6}$ 1/K	0.6	1.1	2.8	5.7	8.5	11.4	17.0
	Brass $\alpha_{OBJ} = 18 \cdot 10^{-6}$ 1/K	0.4	0.7	1.8	3.6	5.4	7.3	10.9
	Steel $\alpha_{OBJ} = 11.5 \cdot 10^{-6}$ 1/K	0.1	0.3	0.7	1.4	2.2	2.9	4.3
	Gray cast iron $\alpha_{OBJ} = 10 \cdot 10^{-6}$ 1/K	0.1	0.2	0.5	0.9	1.4	1.9	2.8
Glass	Aluminum $\alpha_{OBJ} = 24 \cdot 10^{-6}$ 1/K	0.6	1.2	3.0	6.1	9.1	12.2	18.2
	Brass $\alpha_{OBJ} = 18 \cdot 10^{-6}$ 1/K	0.4	0.8	2.0	4.0	6.0	8.0	12.1
	Steel $\alpha_{OBJ} = 11.5 \cdot 10^{-6}$ 1/K	0.2	0.4	0.9	1.8	2.7	3.6	5.5
	Gray cast iron $\alpha_{OBJ} = 10 \cdot 10^{-6}$ 1/K	0.1	0.3	0.7	1.3	2.0	2.6	4.0
System without expan. αR ≈ 0 1/K	Aluminum $\alpha_{OBJ} = 24 \cdot 10^{-6}$ 1/K	0.8	1.7	4.2	8.3	12.5	16.6	24.9
	Brass α_{OBJ} = 18 · 10-6 1/K	0.6	1.2	3.1	6.2	9.4	12.5	18.7
	Steel $\alpha_{OBJ} = 11.5 \cdot 10^{-6}$ 1/K	0.4	0.8	2.0	4.0	6.0	8.0	12.0
	Gray cast iron $\alpha_{OBJ} = 10 \cdot 10^{-6}$ 1/K	0.3	0.7	1.7	3.5	5.2	6.9	10.4

Figure 5-3: Standard uncertainties u_T of test objects and measurement standards without temperature compensation

6 Abbreviations

α_{OBJ}	Thermal expansion coefficient of test object
α_R	Thermal expansion coefficient of measuring instrument scale or of measurement standard
$1-\alpha$	Confidence level
AV	Reproducibility (**A**ppraiser **V**ariation)
%AV	Reproducibility in % with reference to reference figure (RF)
a	Specification limit
b	Distribution factor
BI	Systematic measurement error
%Bi	Systematic measurement error (**Bi**as) in % with reference to the reference figure (RF)
BI_{max}	Maximum systematic measurement error for all measurement standards
C_g	Measuring system potential
C_{gk}	Capability index for measuring system
$C_{p;obs}$	Observed process potential
$C_{p;real}$	Actual process potential
d	Result of differentiation measurement test object – measurement standard
e_{nk}	Residues of k-th of K measurements of the n-th of N measurement standards
EV	Repeatability (**E**quipment **V**ariation) of the measuring system
%EV	Repeatability (**E**quipment **V**ariation) of the measuring system in % with reference to the reference figure (RF)
f	Number of degrees of freedom
GRR	Test system variation
%GRR	Test system variation in % with reference to the reference figure (RF)
k	Coverage factor
K	Number of repeat measurements (k = 1, ..., K) per measurement standard
LCL	Lower control limit
UCL	Upper control limit
MPE	Maximum permissible measurement error
N	Size of random sample
N	Number of measurement standards (n = 1, ..., N)
UIT	**U**pper **I**ntervention **T**hreshold
LIT	**L**ower **I**ntervention **T**hreshold
USL	**U**pper **S**pecification **L**imit
LSL	**L**ower **S**pecification **T**hreshold
P	Test result, characteristic value
Q_{MP}	Capability characteristic value (measurement process)

Q_{MP_max}	Capability limit (measurement process)
Q_{MS}	Capability characteristic value (measuring system)
Q_{MS_max}	Capability limit (measuring system)
r	Number of measured value series per tester
R&R	Repeatability & Reproducibility
%R&R	Repeatability and reproducibility in % with reference to the reference figure (RF)
RE	Resolution
%RE	Resolution) of the measuring system in %
RF	Reference Figure (e.g. process tolerance, process variation, tolerance)
s_g	Standard deviation of a repeat measurement
T	Temperature
TOL	Tolerance
T_{min}	Smallest testable tolerance
$TOL_{MIN-UMP}$	Minimum permissible measurement process tolerance
$TOL_{MIN-UMS}$	Minimum permissible measuring system tolerance
$u(x_i)$	Standard uncertainty
$u(y)$	Combined standard uncertainty
u_{AV}	Comparability of operators (operator influence)
u_{BI}	Systematic measurement error
u_{CAL}	Calibration of the measurement standard
u_{EV}	Measuring system: max $\{u_{EVR}, u_{RE}\}$
	Measurement process: max $\{u_{EVR}, u_{EVO}, u_{RE}\}$
u_{EVO}	Repeatability (on test object)
u_{EVR}	Repeatability (on measurement standard / on reference)
u_{GV}	Comparability of measuring devices (measuring points)
$u_{IAi)}$	Interaction(s)
u_{lin}	Linearity deviation
u_{MP}	Combined standard uncertainty (measurement process)
u_{MP}	Expanded measurement uncertainty (measurement process)
u_{MS}	Combined standard uncertainty (measuring system)
U_{MS}	Expanded measurement uncertainty (measuring system)
u_{MS_REST}	Further influences of measuring system
u_{OBJ}	Inhomogeneity of test object
u_{re}	Resolution of display / of readoff
u_{rest}	Further influences
u_{STAB}	Comparability to differing points in time
u_T	Temperature
x_i	Individual values of a measurement series

$\overline{x}$	Arithmetic mean of all correct values
$\overline{\overline{x}}$	Arithmetic mean from multiple mean values
x_m	Value of reference measurement standard
x_{ml}	Value of lower reference measurement standard
x_{mm}	Value of middle reference measurement standard
x_{mu}	Value of upper reference measurement standard
X_n	Correct value of the n-th measurement standard
Y	Measurement result (measured value y_i including the expanded uncertainty U_{MP})
y_i	Measured value
$\bar{y}$	Arithmetic mean of all measured values
y_{korr}	Corrected measured value
y_n	Measured value of the n-th measurement standard
y_{nk}	Value the of k-th of K measurements of the n-th of N measurement standards
y_R	Length of the measurement standard at a reference temperature of 20 °C
ΔT_{OBJ}	Temperature deviation of the test object from 20 °C
ΔT_R	Temperature deviation of measuring equipment scale or of measurement standard of 20 °C
β_0	y-axis section
β_1	Gradient of regression line
$\hat{\beta}_0$	Estimated y-axis section
$\hat{\beta}_1$	Estimated gradient of regression line
ε_{nk}	Deviation of the measured value of the k-th of K measurements of the n-th of N measurement standards from its expectation
ν_{eff}	Effective degrees of freedom
σ^2	Variance
$z_{1-\alpha/2}$	Quantile of the standard measurement standard distribution
$t_{f,1-\alpha/2}$	Quantile of the Student/t distribution with f degrees of freedom

7 Tables

Degree of freedom f	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	$\rightarrow \infty$
Values k (p = 95.45%)	13.97	4.53	3.31	2.87	2.65	2.52	2.43	2.37	2.32	2.28	2.25	2.23	2.21	2.20	2.0

Table 7-1: k values for 95.45% as a function of the degree of freedom

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9 Change History

Date	Version	Chapter	Change
2007-01-26	2007/1	All	Correction of spelling mistakes
2007-01-26	2007/1	1.6, 1.6.1, 1.6.2	Revision of content
2007-01-26	2007/1	2.14	Specification of length dimensions; Correction of individual sections
2007-01-26	2007/1	2.4, 2.9	Revision of definitions
2007-01-26	2007/1	3.1.3, 3.1.4	Calculation of %GRR and T_{min}
2007-01-26	2007/1	3.2.1	Revision
2007-01-26	2007/1	3.2.2	Specification of individual uncertainty components
2007-01-26	2007/1	3.2.4	Supplement to coverage factor
2007-01-26	2007/1	3.2.5	New section: "Capability of the Test Equipment"
2007-01-26	2007/1	3.4	New section: Procedure "Non-Capable Measurement Processes"
2007-01-26	2007/1	4.3.2	Additional uncertainty analysis case study
2007-01-26	2007/1	4.3.3	Additional uncertainty analysis case study
2007-01-26	2007/1	4.4	Stability monitoring case study
2007-01-26	2007/1	8	New section: "Change History"
2013-04-01	2013/1		Update of version number
2013-04-01	2013/1	All	Adjustment of terms Def. measuring system and measurement process
2013-04-01	2013/1	1	Updating of normative environment
2013-04-01	2013/1	1	Revision by new VDA5 and ISO 22514-7
2013-04-01	2013/1	2	Revision and addition of new terms
2013-04-01	2013/1	3	Revision of introduction
2013-04-01	2013/1	3.2	Compl. revision by new VDA5 and ISO 22514-7
2013-04-01	2013/1	3.3	Revision
2013-04-01	2013/1	4, 4.1	New software; notes on application: examples
2013-04-01	2013/1	4.2	Compl. revision; notes on application; examples
2013-04-01	2013/1	5	New appendix: Estimation of standard uncertainties due to temperature influences
2013-04-01	2013/1	6	Revision of abbreviations
2013-04-01	2013/1	8	Updating of literature

DAIMLER

Random Sample and Process Analysis,

Methods of Applied Statistics

Guideline LF 1236

Version 2013 / 1

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Table of Contents

A Introduction

A.1 Purpose of Guideline LF 1236

While guideline L 5 describes the process of verifying the capability of measurement processes, this guideline (LF 1236) describes the process of verifying the capability of production equipment and processes.
It also covers methods of analyzing, steering and optimizing production processes that can be applied in not only statistical process control (SPC), but also the Six Sigma methodology.

The document is divided into the following sections:

- Section A: Introduction
- Section B: Provisional Process Capability ("machine capability")
- Section C: Process Capability
- Section D: Methods of Applied Statistics (quality control chart, test, correlation, ANOVA, etc.)
- Section E: Terms and Abbreviations

The implementation of these methods with the help of the qs-STAT ® and destra® software is presented on a case-by-case basis.

A.2 General Information

The Q/P departments in Berlin, Hamburg and Untertürkheim are responsible for amendments to this guideline. Requests for modification can be included at any time.

The guideline is updated annually and with every qs-STAT software update.

This guideline is distributed internally over the intranet via the DocMaster® system and via a link in qs-STAT ("Tools" [Zusätze] menu). It is distributed externally via PPA.

Machine suppliers, for example, can download the currently applicable analysis strategy from the Internet: **http://www.q-das.de/en/service/download-center/evaluation-strategies/**

A.3 Product, Process, Characteristic

A **product** is the result of a **process**.

A **process** is a set of interdependent activities in which inputs are converted to results.

A **characteristic** is a distinguishing feature. It can be either inherent (e.g. hardness) or assigned (e.g. temperature of the curing oven) and is either **qualitative** (observations with or without a hierarchical relationship) or **quantitative** (continuous measured values and countable non-conformities).

A **process characteristic** is a characteristic of a process and a **product characteristic** is a characteristic of a product. A demonstrably strong **correlation** often exists between a process characteristic and a product characteristic that is generated by the process (e.g. oven temperature – hardness, cooling time of the melt – leakage rate of the casting).

A **quality characteristic** is a characteristic that relates to a requirement.

A **requirement** is a need that is defined and is normally presupposed or binding. A **quality requirement** is a requirement regarding the condition of a unit (product, process, system).

Quality is the degree to which a set of inherent characteristics fulfills requirements.

A **controlled process characteristic** is a process characteristic for which the distribution parameters of the characteristic values either practically do not change or change only in a known manner.

A **stable process** is a process for which the process characteristics that impact the quality of the process are controlled process characteristics. This term does not refer to the **quality capability** of the process with respect to its process characteristics, although it is often necessary to have stable process characteristics to be able to assess the quality capability of the process.

Controlled production is production in which the processes are controlled.

<u>Note regarding qualitative characteristics</u>

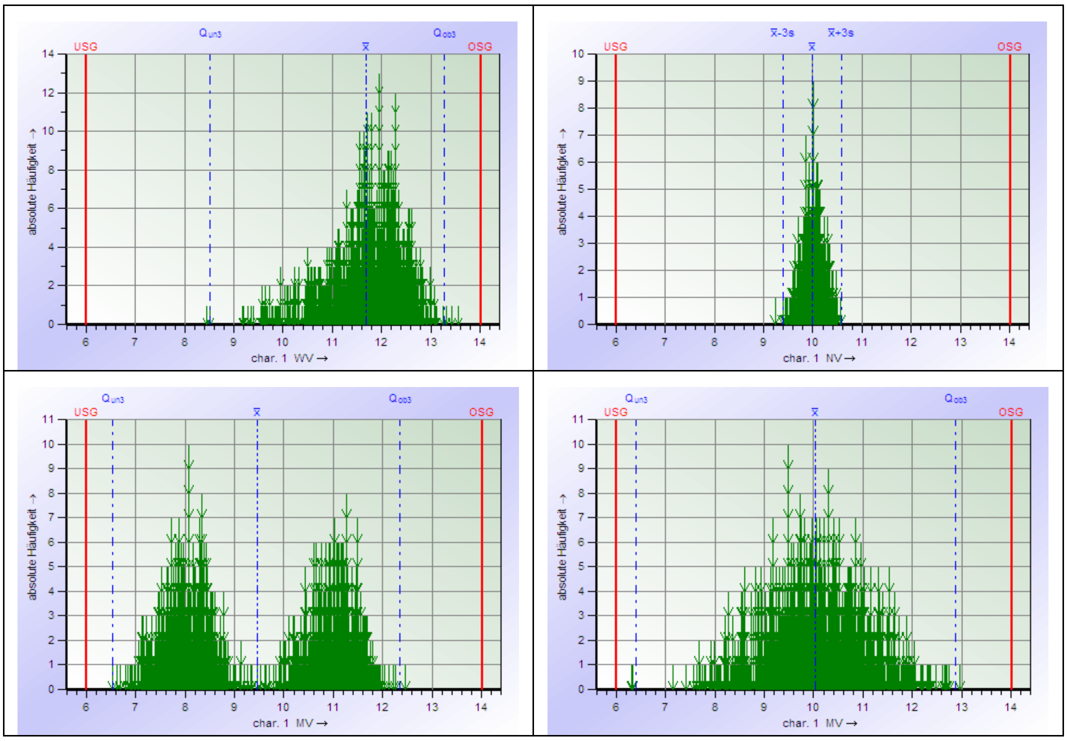
The categorization of characteristics as "Good (OK)" and "Bad (not OK)" is very undifferentiated. A result of "No errors found" is not sufficient for rating a process as capable.

A machine produces 1.000 units per shift. With severity of sampling (PS) 20, parts are removed and a characteristic is tested in terms of its attributes. If this random sample of n = 50 parts does not yield any defective parts, the non-conformance rate of the total population is, with 95% probability, somewhere between 0.0% and 7.1%.

If you now estimate with the help of a temporary 100% inspection that the non-conformance rate is 1% and you want to set the severity of sampling to a level at which a rise in the rate of defective items to 2% can be verified even during an attribute-related sampling inspection, around 1,200 items would have to be checked with a type 2 error of 10%. Even in a 100% inspection (PS 1), a doubling of the non-conformance rate would not be statistically significant throughout an entire production shift.

If a contractor agreement of 100 ppm (rate of defective items: 0.01%) has been concluded, it is 95% certain that no defective part will be found in a maximum random sample size of n = 512. Only in a random sample size of n = 513 or more does the upper random scattering limit of 0 (no defective part) increase to 1 (one defective part). If a defective part was found in a random sample size of n = 512 parts, however, the maximum non-conformance rate is with 95% probability 9,232 ppm (rate of defective items: approx. 0.92%).

The following diagram shows four random samples with several hundred measured values as a value flow in which no values were found outside the specification limits. In qualitative testing, these cases are indistinguishable. However, the representations of the quantitative measured values do show clear differences in process level, variation and form.



A.4 Data Quality and Outliers

Before measured data are used to assess the quality of machines, production equipment and processes, it must be ensured that the data themselves are of sufficiently high quality. All methods in Guideline 1236 are based on the following assumptions:

- The data are representative and free from outliers (incorrect measurements)
- The measuring system and measurement process are verifiably suitable (Guideline LF 5).
- At least five different measured values have been obtained so that a distribution time model can be specified.

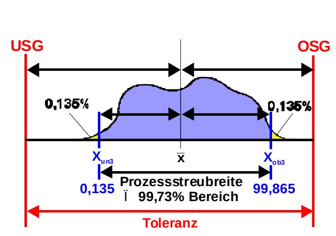
Specifically, it should be noted that the data reflect all the relevant influences. In particular, this means the following:

- in the "Preliminary process analysis", mostly all machine-related influences are contained and all other influences are virtually excluded
- in the "Process analysis" all influences of the 5 Ms (Machine, Man, Material, Method, Mother Nature) could act to the degree as is to be expected in the future for the usual process sequence.

qs-STAT identifies outliers according to different methods (see below) and highlights these in the data record prior to the first analysis.

All logs show whether and how many outliers were not taken into account when the statistical characteristic values were determined.
Users can identify outliers (e.g. in the value pattern diagram) by their dotted line and, if necessary, include them again in the analysis by choosing the appropriate buttons.

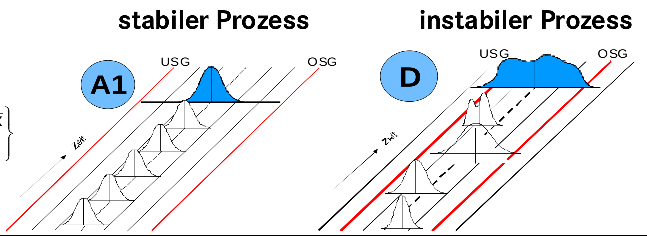
A.5 Requirements Regarding Quality Capability Statistics



$$C_p, P_p = \frac{OSG - USG}{X_{ob3} - X_{un3}}$$

$$C_{pk}, C_{mk} = \min\left\{\frac{\bar{x} - USG}{\bar{x} - X_{un3}}; \frac{OSG - \bar{x}}{X_{ob3} - \bar{x}}\right\}$$

$$X_{ob3} = X_{0,99875} \qquad X_{un3} = X_{0,00135}$$

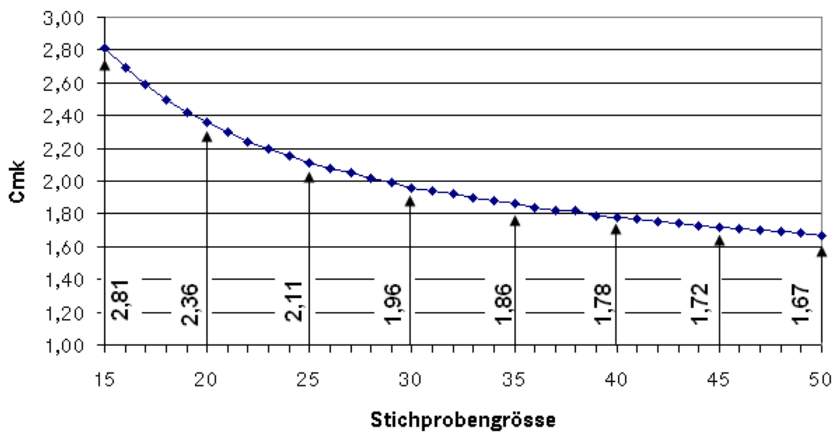


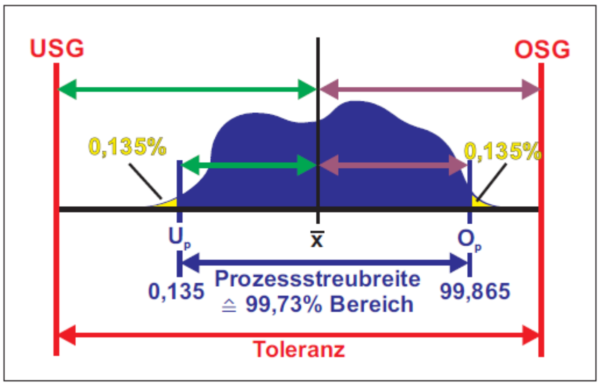
Module	Characteristic class	Stable		Unstable		Limit quantities
Preliminary process capability		C_m	C_{mk}	Unassigned		n = 50
	Critical	2.00	1.67			
	Significant	2.00	1.67			
	Important	2.00	1.67			
	Less important	1.67	1.33			
	Not critical	1.00	1.00			
Process capability		C_p	C_{pk}	P_p	P_{pk}	n = 125
	Critical	1.67	1.33	2.00	1.67	
	Significant	1.67	1.33	2.00	1.67	
	Important	1.67	1.33	2.00	1.67	
	Less important	1.33	1.00	1.67	1.33	
	Not critical	1.00	1.00	1.00	1.00	

Limit quantities are recommended effective random sample sizes. If the quantities are lower, qs-STAT® calculates dynamically adjusted requirements regarding the size of the capability index to be reached. However, it should be noted here the current random sample must not fall below a specific minimum size. In the "Provisional Process Capability" (vorläufige Prozessfähigkeit) module, the minimum size is n = 15; in the "Process Capability" (Prozessfähigkeit) module, it is n = 30.

During quality planning, characteristic classes for which different specification limits apply during process assessment must also be planned for quality characteristics. The "critical" and "significant" classes are assigned function-critical or process-critical characteristics. Unlike "significant," "critical" is used when the probability of detection is low.

Adapted requirements when the limi
in the module for preliminary proces
of the characteristic classes critical,





$$C_m, C_p, P_p = \frac{OSG - USG}{O_p - U_p}$$

$$C_{mk}, C_{pk}, P_{pk} = \min\left\{\frac{\bar{x} - USG}{\bar{x} - U_p}; \frac{OSG - \bar{x}}{O_p - \bar{x}}\right\}$$

d in the production control plan

d / tolerance ≤ 3 / 5 (60%)

ed in the production control plan:

d / tolerance ≤ 3 / 4 (75%)

e above requirements are increased by 5%

A.6 "Benchmark Graphic" (Benchmarkgrafik) Methods Sheet

Methodenblatt Stand: 28.01.2008

Quartalsweise Darstellung der Prozessfähigkeiten (Benchmarkgrafik)

Bearbeiter: Schmidt/Jungk, QM, Tel:60420

2 Vorwort

Um die Effektivität einer Produktion zu beurteilen, werden für die Qualitätsmerkmale der Produkte laufend Fähigkeitskennwerte berechnet.

Die Management-Berichterstattung über die Fähigkeiten erfordert eine geeignete Verdichtung der vorhandenen Einzelanalysen auf Centerebene bzw. Produktionsbereiche.

3 Ziel/Zielgruppe

Dieses Methodenblatt soll bei der Auswahl von Merkmalen die relevant sind für die Berichterstattung der Prozessfähigkeiten auf Managementebene eine Hilfestellung geben.

Führungskräfte QM, Prüfplaner QM, QM-Verantwortliche für Managementberichte

5 Methodische Grundlagen

5.1 Qualitätsmerkmale

Die Beurteilung eines Produktes erfolgt anhand seiner Merkmale. Merkmale, die die Qualität des Produktes betreffen, nennt man Qualitätsmerkmale (Vorbearbeitungsmaße sind demnach keine Qualitätsmerkmale).

Analog zum Produkt gibt es so genannte Prozessmerkmale, die Auskunft über das Prozessverhalten geben. Häufig besteht eine Korrelation zwischen einem Prozess- und einem Produktmerkmal, das durch einen Prozess erzeugt wird (z.B.: Produktmerkmal Härte ⇔ Prozessmerkmal Ofentemperatur). Im Zweifelsfall muss eine vermutete Korrelation durch eine Korrelationsanalyse (mit qs-STAT) nachgewiesen werden.

In der Regel unterscheiden sich die Anforderungen an ein Prozessmerkmal von denen an ein Produktmerkmal. Bedingt durch die Qualitätsanforderungen an das Produkt lassen sich aber oftmals die Anforderungen an die Prozessmerkmale ableiten.

Um sowohl Produkte als auch kontinuierlich ablaufende Prozesse beurteilen und überwachen zu können, sind die entsprechenden Qualitätsmerkmale festzulegen und diese zu beurteilen.

5.2 Auswahl von Qualitätsmerkmalen

Prinzipiell wird zwischen qualitativen (attributiven) und quantitativen (kontinuierlichen) Qualitätsmerkmalen unterschieden.

Um einen Prozess bestmöglich zu beurteilen, sollten die quantitativen Qualitätsmerkmale „gemessen" und die gewonnenen Merkmalswerte ausgewertet werden.

Qualitätsmerkmale für deren Überwachung ein Messautomat (100%-Prüfung, Sortierprüfung), wie z.B. bei Drehmomentgesteuerten Verschraubungen, eingesetzt wird, dürfen nur in begründeten Ausnahmefällen bei der Erstellung von Benchmarkgrafiken berücksichtigt werden. Die fehlerhaften Einheiten werden in diesen Fällen direkt erkannt und erfasst (Ausschuss-Nacharbeitserfassung und Berichterstattung).
Eine statistische Schätzung des Anteils fehlerhafter Einheiten mit Hilfe von Fahigkeitsindizes ist hier demnach nicht sinnvoll.

In der Quartalsweisen Darstellung der Prozessfähigkeiten (Benchmarkgrafik) eines Produkt(ions) – Bereiches werden grundsätzlich nur quantitative Qualitätsmerkmale berücksichtigt.

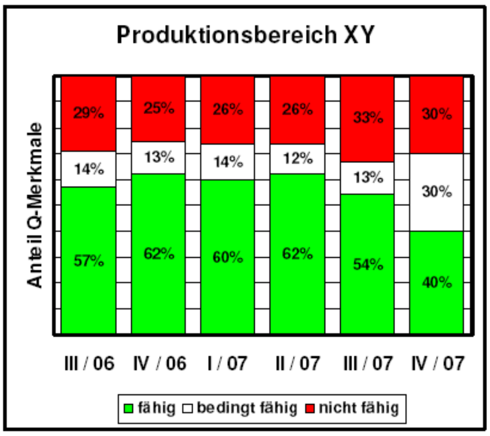
Die Festlegung derjenigen Merkmale, die in einer Benchmarkgrafik berücksichtigt werden sollen, obliegt der QM des Produktionsbereiches! Dabei wird der Anwender durch folgende Auswahloptionen unterstützt.

1. Merkmale denen von der Qualitätsplanung die Merkmalsklasse „unkritisch" zugeordnet wurde, werden in der Benchmarkgrafik nicht berücksichtigt.
2. Merkmale, deren Werte in Prüfplänen erfasst sind, deren Vorgangsbezeichnung nicht eindeutig auf eine Serienmessung hindeutet, werden nicht berücksichtigt.
   Diese Eindeutigkeit (z.B.: Vorgangsbezeichnung in QDA enthält „Serie") wird in jeder einzelnen QDA-Datenbank individuell hergestellt.
3. Sollte 1. und 2. für die korrekte Auswahl der Qualitätsmerkmale nicht ausreichend sein, kann über ein Zusatzfeld im Prüfplankopf selektiert werden (z.B.: Zusatzfeld3 „Benchmark").

Im Falle von Parallelbearbeitungen darf ein erkanntes Qualitätsmerkmal nicht nach Entstehungsort (Linie, Maschine, ...) getrennt betrachtet werden, da für die Benchmarkgrafik die „Kundensicht" ausschlaggebend ist.
Natürlich werden solche Merkmale für die interne Prozessoptimierung (KVP) nach Entstehungsorten getrennt ausgewertet.

7 Darstellung im Managementbericht

Die im QDA (qs-STAT Statistik-Server) ermittelten Fähigkeiten werden je Quartalssäule in 3 Klassen aufgeteilt.



fähig: Cpk ≥ 1,33
bedingt fähig: 1,00 ≤ Cpk < 1,33
nicht fähig: Cpk < 1,00

B Provisional Process Capability

B.1 General Machine Acceptance Procedure

B.1.1 Shipping Acceptance at the Contractor's Site and Following Installation in the Plant

Are all the relevant areas represented in the acceptance team? Training in qs-STAT (incl. analysis strategy) provided? Software available? Acceptance modalities (test plan in particular) agreed upon? Test equipment/process suitable? Certified interface? Measuring programs agreed upon and available? Drawings available? Sufficient quantity of parts/tools marked and available? Documentation type and scope clarified?

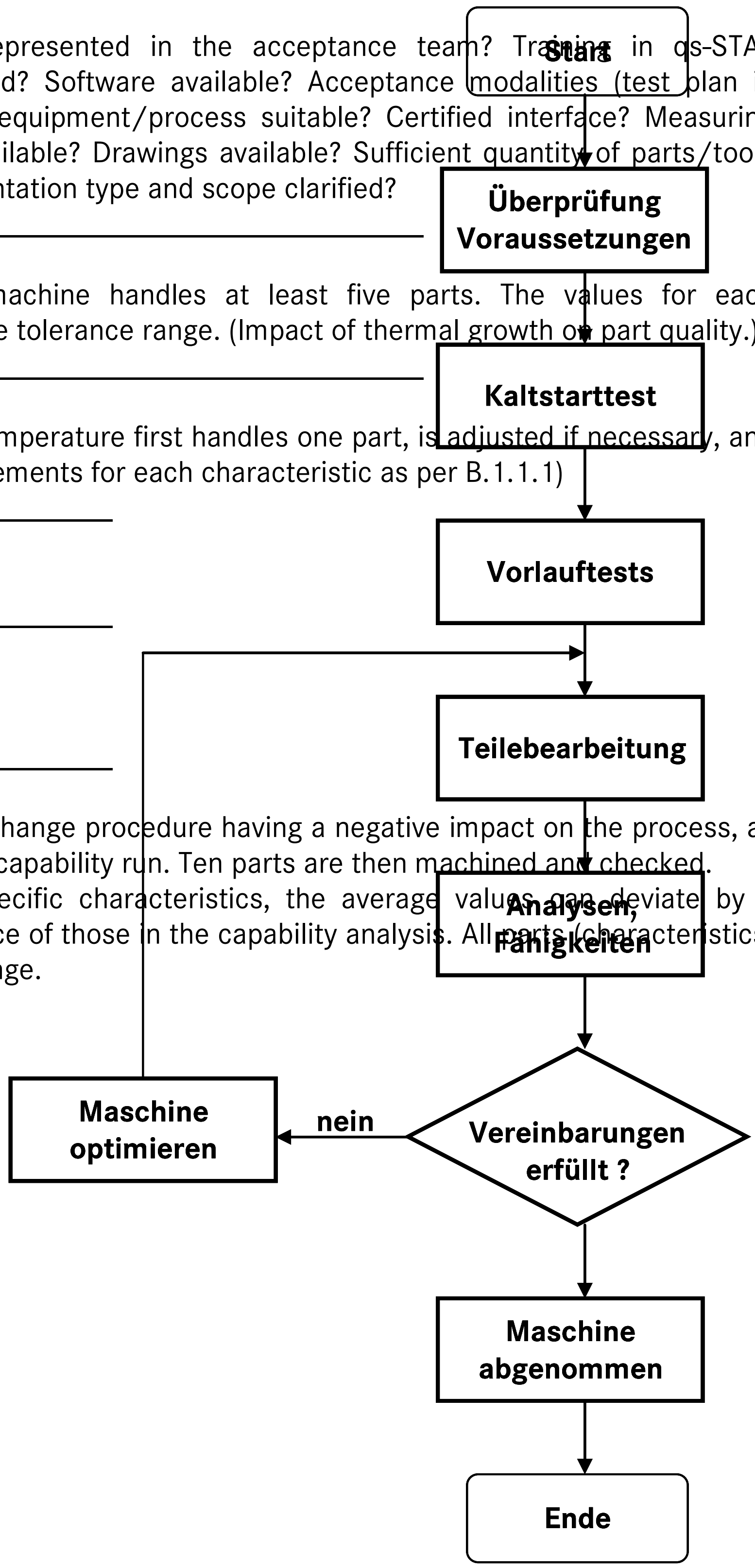
Following a cold start, the machine handles at least five parts. The values for each characteristic must lie within the tolerance range. (Impact of thermal growth on part quality.)

Machine at regular operating temperature first handles one part, is adjusted if necessary, and then handles five parts. (Requirements for each characteristic as per B.1.1.1)

(See B.1.1.2)

(See B.1.1.3)

To exclude the risk of the tool change procedure having a negative impact on the process, all the tools are changed after the capability run. Ten parts are then machined and checked.
For the acceptance of tool-specific characteristics, the average values can deviate by a maximum of 25% of the tolerance of those in the capability analysis. All parts (characteristics) must lie within the tolerance range.



B.1.1.1 Requirements for the Preliminary Tests

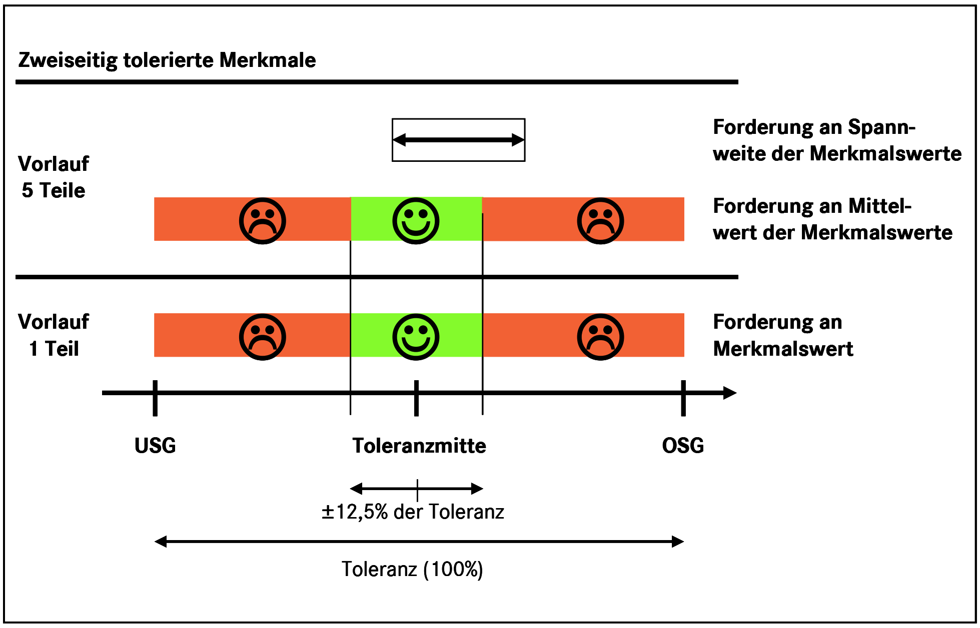
For each agreed-upon, acceptance-relevant characteristic as per the test plan, the following applies:

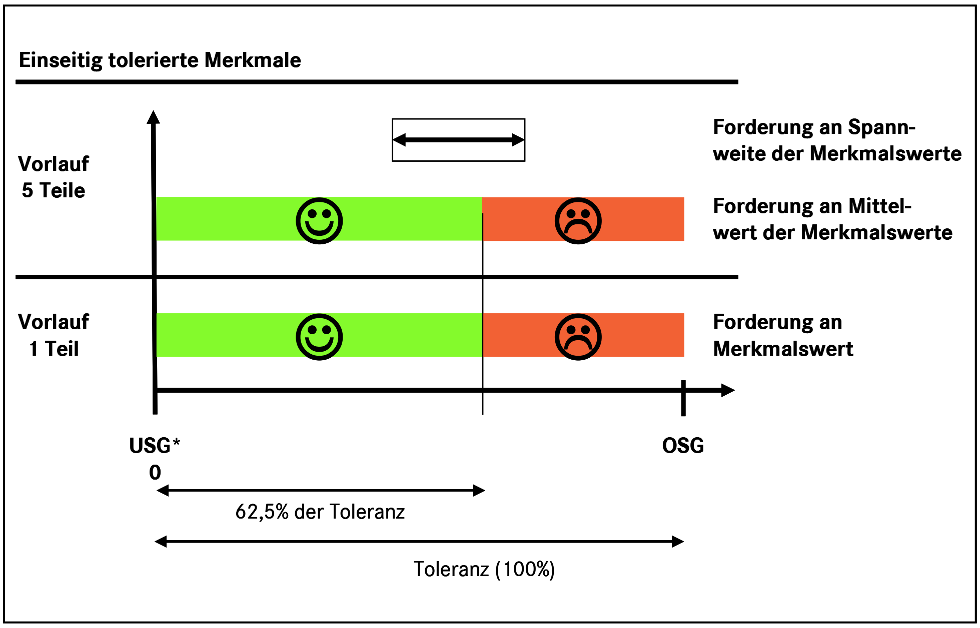
- Preliminary test with 1 part: For characteristics with tolerance on two sides:
  The mean value lies within the interval ±12.5% of the tolerance around the tolerance mean.

  For characteristics with tolerance on one side and a natural limit:
  The characteristic value lies within 62.5% of the tolerance.

- Preliminary test with 5 parts: For characteristics with tolerance on two sides:
  The characteristic value lies within the interval ±12.5% of the tolerance around the tolerance mean.
  The range is less than 25% of the tolerance.

  For characteristics with tolerance on one side and a natural limit:
  The mean value lies within 62.5% of the tolerance.
  The range is less than 25% of the tolerance.





B.1.1.2 Parts Machining

Before the actual process of machining the parts can begin, all prerequisites must be fulfilled and all tests successfully completed.

The parts are machined on a machine that is working at its regular operating temperature and has been set to its specified parameters. The parts to be machined must be clearly identified and their machining sequence recorded.

The whole process should be uninterrupted. If an error occurs, the test can either be continued or restarted, depending on the type of error. Nevertheless, the problem responsible for the fault must be identified, rectified and noted.

In the case of machines with a number of identical stations, each station is to be treated as a discrete machine. The strategies described in Section B.2 must be applied in this situation.

The parts must be labeled in such a way that the machine, clamping point and boring spindle can be clearly identified in both the shipping acceptance and in-plant acceptance process. For machines with pallet transportation, a larger number of parts can be taken as a random sample from a small number of pallets; from the remaining pallets, a smaller number of parts can then be taken as a random sample. The decisions made at this stage have an impact both on the number of parts to be machined and the test objects that are chosen.

Subject to these conditions, at least 50 parts are produced in succession during acceptance at the manufacturer of the equipment and at the installation location. The parts must be taken from the process under normal production conditions.

They are then measured in accordance with the specifications contained in the test plan.

When the measured values for the quality characteristics are entered, the correlating process characteristics must also be entered.

To assess the stability, the individual values can be combined in random samples or in the form of "pseudo random samples" (floating characteristic values).

If the expected variation based not on time but on other factors, other random sampling strategies can be used. The random sampling strategies should be agreed upon during acceptance planning. For machines with pallet transportation, for example, random samples could be collected by pallets.

B.1.1.3 Analysis of the Measurement Results

For the efficient analysis of the measurement results with qs-STAT, the data should, if possible, be supplied in Q-DAS ASCII transfer format.

To ensure that suppliers of computerized measuring and test equipment can correctly supply their data in Q-DAS ASCII transfer format, each one should be able to produce certification of the data format.

A specification limit for the quality capability variable can be defined for individual characteristics and does not have to be the same as generally defined limits (see Section A.5).

qs-STAT performs an automatic analysis in accordance with this guideline.

If a characteristic does not reach the predefined specification limits, it must be analyzed in detail using the value pattern, histogram and probability grid (also "probability plot") as well as statistical characteristic values.

When the data are being analyzed, it should first be checked whether the measured value series exhibit any anomalies (e.g. outliers) or identifiable trends.

If outliers exist, the parts may need to be measured again to exclude the possibility of incorrect measurements.

Furthermore, the probability grid must be used to check whether the proposed distribution model is applicable or whether a model needs to be assigned manually to a characteristic. Only when a data record is correctly described by means of a distribution model is the calculated capability characteristic value applicable.

The agreed-upon quality characteristics are relevant for the acceptance. In addition, however, all the quality characteristics that have been assigned nominal values and specifications have to be analyzed.

The acceptance criteria should be agreed upon on a case-by-case basis for the use of modified machines with existing product designs. This applies, for example, to tolerances of an existing design, the criteria for which cannot be fulfilled with the current technology. In this case, either the tolerances or the requirements have to be changed in line with the specification limits. In cases where the criteria are not fulfilled, the contractor is responsible for taking the necessary steps to resolve the problem.

The aforementioned criteria should not be seen as absolute. The process owner makes the final decision regarding whether or not the process (shipping acceptance / in-plant acceptance) is acceptable.

When the data are being analyzed, you can see whether certain measurements should be performed again or that certain variation influences were present. Under the precondition that verifiable causes can be identified and action plans for rectifying problems are in place, machines can undergo provisional acceptance.

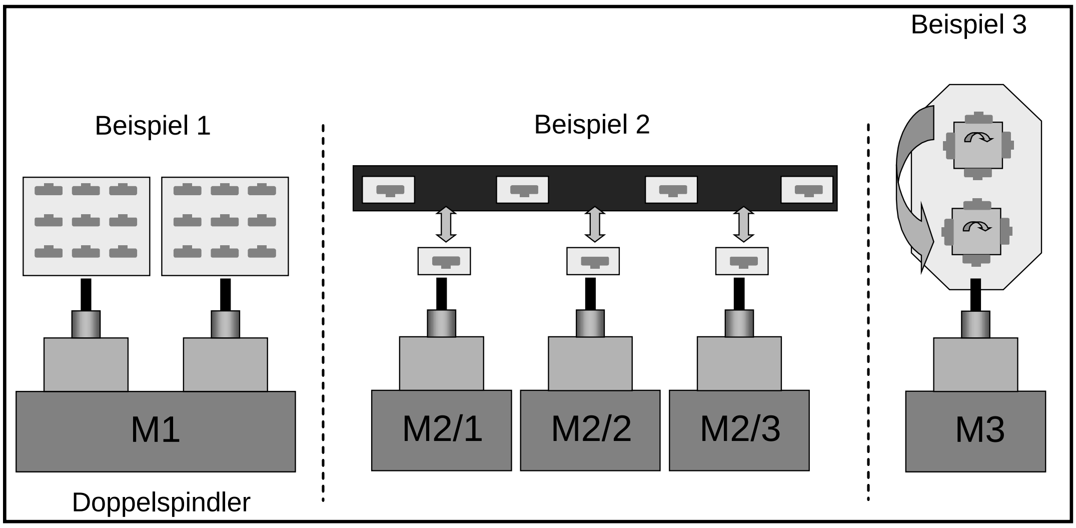
B.2 Acceptance of Machining Centers

B.2.1 Use Case

In production processes, machining centers with workpiece carriers or pallets are often used for increasing flexibility.

In practice, the following scenarios can occur:

- A machine uses one or two spindles and per spindle it machines one workpiece carrier, which can hold several workpieces (example 1).
- Several machines each handle one workpiece at the same time on a pallet. Here, the pallets are randomly assigned to the machine and this assignment can change with each machining cycle (example 2).
- One machine handles one workpiece, which is secured on a swivel table (workpiece carrier). Here, one workpiece is always in the machining position and the other in the change position (example 3).



In the standard acceptance process (as described in Section B.1), 50 components per clamping point would have to be machined and analyzed. If you consider the number of potential combinations, it becomes clear that an acceptance in this form is not possible.
In example 2, one machining operation is carried out on three identical machines and seven pallets. This means that 3*7*50 = 1,050 parts would have to be machined and analyzed for the acceptance. For this reason, a shortened acceptance procedure is proposed.

B.2.2 Prerequisite

For subsequent operation, it must be ensured that all combinations that can take a workpiece through a system are analyzed. In preparation, the contractor must therefore ensure that all combinations are statistically comparable to each other. This means that a component from pallet 1 produced on machine A is comparable with a component from pallet 2 produced on machine B. This is a basic requirement for a shortened acceptance procedure.
Part of this comparison takes place as part of the geometrical analysis of the machine.

B.2.3 Defining the Test Scope

The first step in defining the testing scope is to determine the number of combinations that a workpiece can take through the system.
The number of combinations for each operation is calculated as follows: <number of components per pallet/workpiece carrier> * <number of pallets/workpiece carriers> * <spindles per machine> * <number of machines in operation>.
For each combination, at least five components should be tested so that a well-founded conclusion can be reached. Furthermore, the testing scope for each combination should be defined such that a total of at least 50 components are tested for each operation.
In coordination between PPA, the production center and Q, certain combinations do not need to be tested if it has been verified that they are "geometrically identical."

B.2.4 Machining and Testing

The workpieces should be labeled in a manner that makes it possible to trace the combination of:

- Position on the pallet/workpiece carrier
- Pallet/workpiece carrier
- Spindle
- Machine

When the components are measured, the measured values are to be entered such that a reference to the combination exists. For the subsequent analysis, it is recommended to measure the components sorted by combination in the machining chains.

B.2.5 Analysis

The combinations should not play a role for the analysis. All measurement results are analyzed together. If the analysis shows that values deviate significantly from the collective, the relevant combination can be determined by classifying the measurement results.
For analysis with reference to a combination, qs-STAT allows you to select the values according to a combination (process parameter) so that the mean value and variation can be analyzed. Alternatively, you can open the qs-STAT process capability analysis for troubleshooting purposes. The testing scope for each combination should be entered as the random sample size. The mean value and variation are then calculated automatically for each combination.
Depending on the plant setup, it may be sufficient to rectify the deviation within the combination. Other combinations are sometimes also affected by changes, which is why it is recommended to repeat the acceptance procedure in full following correction.

B.2.6 Other

<u>Shape and position analyses</u>
The explanations relate to coordinates/positions. (i.e. characteristics dependent on the geometry of the machine and pallets/workpiece carriers). Characteristics such as roundness are primarily dependent on the system rigidity, spindle concentricity and machining process.
A total of 50 components, equally distributed across all spindles, should be measured here.
The same applies to surface characteristics.

Further potential
If they are used, it is often possible to measure pallets/workpiece carriers (e.g. mounting/fixing points). A representative selection of pallets/workpiece carriers, distributed uniformly across the tolerance, can then be made. This makes it possible to perform acceptance with a lower number of pallets/workpiece carriers, which means that the number of combinations can be further reduced.

To check the pallets/workpiece carriers that are not part of the machine capability examination, five components per pallet/workpiece carrier and mounting point should be produced and measured. If machining can be performed on more than one machine, it is recommended that the machining processes be equally distributed across the machines. The components must be clearly labeled here too.

B.3 Introduction to qs-STAT®, solara® and destra®

With the introduction of version ME10 of the software package, the previous modular structure for various application areas has been replaced by individual programs. solara® is to be used for measurement process analyses, qs-STAT® is to be used for verification of capability of production equipment and processes, and destra® is to be used for regression and variance analyses.

When a data record is created or loaded, a menu tailored specifically to the characteristic type is displayed along with a tool bar that changes based on the window that is open. This tool bar is divided into various tabs to separate the buttons by subject. The working window is located below the tool bar. The status bar containing information about the data record that has been loaded as well as the active part and characteristic can be found at the bottom of the screen.

Once a data record has been loaded, qs-STAT performs an analysis according to the current analysis configuration. Following this, all the results are available and can be accessed as required. However, users can also manually intervene in the analysis.

If nominal values for capability characteristics are not fulfilled, for example, it is important to know why this is. Statistical tools, methods and processes support cause analysis and thus make it easier to implement improvement measures. qs-STAT offers a range of graphical and numeric functions for this purpose, the most important of which are described below.

B.3.1 Data Entry

- If you want to create a new file, choose FILE/NEW FILE (DATEI/DATEI NEU). You can then define characteristics along with their type and default value.
- If you want to change an existing data record, choose FILE/OPEN (DATEI/ÖFFNEN) and open the data entry forms by choosing FILE / CHANGE/ ADD (DATEI / ÄNDERN/ HINZUFÜGEN).
- The following forms are available for entering data:
    - Part form (information describing the part under analysis)
    - Characteristic form (information describing the characteristic under analysis)
    - Value form (measured values and additional data such as time, date, tester, etc.)
    - Part/characteristic list (view of data structure and additional functions via the context menu)

  The forms are also generally filled out and used in this order.
- The comprehensive input of data regarding the machine and process capability analysis of course requires more information, particularly regarding the course of the process, process parameters and any events or measures. This information must also be available for selections.

  qs-STAT offers the following additional data fields with/without catalog support:

  With: Event, cavity, tester, machine, test equipment, process parameters

Without: Date/time (automatic), batch number, order number, text, attribute (validity of the values)

Data can be entered from catalog fields only if catalogs have been loaded.

Load standard catalog: OPTIONS / SYSTEM SETTINGS / CATALOGS
CATALOG DATA FROM FILE / CATALOGS.DFD

To enter additional data, you first have to select the data in the value form via the context menu (right-click).

- The easiest way to enter data is to use the clipboard (copy and paste). For this, the data must be available in Excel in columns for each individual characteristic.

B.3.2 Analyzing the Input Data

Value pattern

The value pattern shows the following: outliers, jumps in the process results curve, trends, fluctuations/periodicities, transient behavior

Other functions (initiate, set and execute function in each case):

- Zoom (Enlarge part of value pattern)
  Via "Zoom" button (magnifying glass)
- Select (Select value ranges for analysis)
  Before selecting value ranges, right-click selected areas.
- Value axis (Change view of x-axis)
  Via "Value axis" (Werteachse) button
- Display (Values displayed separated by random samples)
  Via "Special" (Spezial) button
- Information (Detailed information about individual values)
  Via "Special" (Spezial) button
- Split (split value pattern by cavities, for example)
  Via "Special" (Spezial) button

- **Value flow (also "value plot")**

The value flow shows the measured properties of a characteristic. This can be used to identify the resolution of the measuring equipment. Requirement:
At least 20 potential properties within the tolerance (resolution ≤ 5% tolerance)

- **Histogram**

The histogram is created by forming classes in the value flow. The value flow can be displayed in the histogram via the "Special" (Spezial) button.

The histogram shows the distribution shape, the position of the distribution in relation to the specification thresholds and the process spread, thereby enabling
you to estimate the capability index..

The question "For which tolerance and for which specification limits does a particular capability index result?" can be answered with the C value function. When the histogram is open, choose the "C value function" (C-Wert-Funktion) button.

- **Probability grid (also "plot") and cumulative curve (also "line")**

The empirical distribution function (also known as the "cumulative frequency function" or "cumulative curve") is formed from the columns in the histogram. This is also the basis for the probability grid.

A range of interesting characteristic values can be identified in the probability grid (the table is exact only for normal or symmetrical distributions):

P on ordinate	↔	Char. value on abscissa
99.865%	→	$\bar{x}$ + 3s (Q_{ob3})
84.135%	→	$\bar{x}$ + 1s
50%	→	$\bar{x}$
15.865%	→	$\bar{x}$ - 1s
0.135%	→	$\bar{x}$ - 3s (Q_{un3})
LSL	←	Undershoot component
USL	←	1-overshoot component

The numerically selected model distribution can be confirmed with the probability grid. It is advisable here to show the confidence interval (choose "Special" [Spezial]).
You may then have to choose a different model distribution with the functions NUMERICS / DISTRIBUTIONS (NUMERIK / VERTEILUNGEN) and NUMERICS / DISTRIBUTION SELECTION (NUMERIK / VERTEILUNGSAUSWAHL).

- **Box plot**

The box plot [OVERVIEW / BOX-PLOT (ÜBERSICHT / BOX-PLOT)] includes all of the relevant characteristic values of a characteristic:
Specification limits, Quantile Q_{ob3}/Q_{un3} ("Process variation" between), largest/smallest value ("Span" between), median and mean value.

To be able to compare characteristics with widely differing value ranges, the characteristic values are standardized by default (i.e. the specification thresholds are set to +1 or -1).

In the box plot, you can select a characteristic and display the associated value pattern. To do so, first position the two windows next to each other ("Window" [Fenster] menu). To display the relevant value pattern, click the required box and drag it (with the mouse button held down) to the "Value pattern for individual values" (Werteverlauf Einzelwerte) window.

Setting options:
Value axis (with/without scale, different labeling)
(Non-) standardized view
95%, 99%, 99.9% confidence intervals
Filter (by characteristic classes, for example) and sort
Quantiles (e.g. 99.73% limits for relevant distribution)
Box plot type (Q-DAS, EDA, DGQ)

Box plot types:

Q-DAS
The height of the box specifies the range in which (based on a selected distribution model) 50% of the values lie. The average value (continuous line) and median value (dotted line) are also entered in the box. The width of the box is proportional to the random sample size. The biggest and smallest value are highlighted by a cross. The whiskers each depend on the quantiles.

EDA
The height of the box specifies the range in which 50% of the values lie. In addition, the average value (continuous line) and median value (dotted line) are entered in the box. A whisker that is 1.5 times the height of the box is connected with the box to link the smallest and biggest value. Values outside this range are drawn in separately with a cross.

DGQ
The height of the box is limited by the 25% and 75% quantile. which means that the box contains the average 50% of the values. The average value (continuous line) and median value (dotted line) are also entered in the box. The smallest and biggest value are connected with the box by a line whisker, although the maximum length of the lines is 1.5 times the length of the box. If the smallest and/or biggest value is outside this range, they are drawn in separately with a cross.

C values

Graph (OVERVIEW / C VALUES [ÜBERSICHT / C-WERTE]) for displaying capability indices across multiple characteristics or parts.

For a rapid overview:
Open an individual value graph (e.g. value pattern) and overview graph (e.g. C values). Right-click a C value column and drag the pointer to the individual value graph.

- **Correlation**

The correlation matrix also offers a similar comparative overview
(OVERVIEW / CORRELATION [ÜBERSICHT / KORRELATION]).
Here you can see immediately whether characteristics correlate with each other (i.e. whether your values are interdependent). A dependency exists if r tends toward +1 or –1. If r tends toward zero, no dependency can be identified.

- **F/t test**

As with the correlation, the comparative F and t tests can also be displayed for all characteristics in a matrix. (OVERVIEW / F/t-test
Wherever the result H1 appears, you can assume that variations (F test) or average values (t test) are significantly different.

ATTENTION: These tests are based on the assumption of normal distribution. If it is clear that the distribution is not normal, these tests are useful only to a limited extent.

B.3.3 Numerical Output

The aggregate characteristic values can also be displayed as numerical results in many different ways.

For characteristic-specific outputs, choose e.g. NUMERICS / FORMS / FORM3 (NUMERIK / FORMBLÄTTER / FORM3).

Wie ist dieses Formblatt zu lesen? In den Spalten sind jeweils Zeichnungswerte, gemessene Werte und statistisch ermittelte Werte aufgelistet, die zeilenweise verglichen werden können. So steht in der dritten Zeile und ersten Spalte die Toleranz, in der zweiten Spalte die Spannweite der in der Stichprobe vorgefundenen Werte und in der dritten Spalte die daraus abgeleitete statistische Prozessstreubreite, die z. B. zur Ermittlung der Fähigkeitsindex herangezogen wird.

Teilnr.	9	Teilebez.		Drehteil (Bsp. 9)	
Merkm.Nr.	9.1	Merkm.Bez.		Durchmesser (Bsp. 9.1)	
Zeichnungswerte		Gemessene Werte		Statistische Werte	
T_m	20,00			$\bar{x}$	20,0880
USG	19,70	x_{min}	20,02	X_{un3}	20,0018
OSG	20,30	x_{max}	20,14	X_{ob3}	20,1592
T	0,60	R	0,12	X_{ob3}-X_{un3}	0,1574
		$n_{<T>}$	50	$p_{<T>}$	100,00000 %
		$n_{>OSG}$	0	$p_{>OSG}$	0,00000%
		$n_{<USG}$	0	$p_{<USG}$	0,00000%
		n_{ges}	50	n_{eff}	50
Merkmalklasse		signifikant			
Modell-Verteilung		Johnson-Transformation (NV)			
Berechnungsart		$M4_1$ Percentil (0,135%-$\bar{x}$-99,865%)			
potentieller Fähigkeitsindex	C_m	3,06 ≤ **3,81** ≤ 4,56	0 … 2		
kritischer Fähigkeitsindex	C_{mk}	2,38 ≤ **2,98** ≤ 3,57	0 … 1,67		
Die Anforderungen sind erfüllt (C_m,C_{mk})					
Forderung potentieller Fähigkeitsindex	$C_{m\,soll}$	=	2,00		
Forderung kritischer Fähigkeitsindex	$C_{mk\,soll}$	=	1,67		

Es bedeuten:

T_m Toleranzmitte
USG Untere Spezifikationsgrenze
OSG Obere Spezifikationsgrenze
T Toleranz(breite)

Es bedeuten:

x_{min} kleinster gemessener Wert
x_{max} größter gemessener Wert
R Spannweite
$n_{<T>}$ Anzahl Werte innerhalb T
$n_{>OSG}$ Anzahl Werte über OSG
$n_{<USG}$ Anzahl Werte unter USG
n_{eff} Anz. der ausgewerteten Werte
n_{ges} Anzahl der gemessenen Werte

Es bedeuten:

$\bar{x}$ Prozesslage (arithm. Mittelwert)
X_{un3} Untere Prozessstreugrenze
X_{ob3} Obere Prozessstreugrenze
X_{ob3} - X_{un3} Prozessstreubreite
$p_{<T>}$ erwarteter Anteil innerhalb T
$p_{>OSG}$ erwarteter Anteil über OSG
$p_{<USG}$ erwarteter Anteil unter USG

<u>Special case: Normal distribution</u>:

$X_{un3} = \bar{x} - 3s,$

$X_{ob3} = \bar{x} + 3s,$

$X_{ob3} - X_{un3} = 6s$

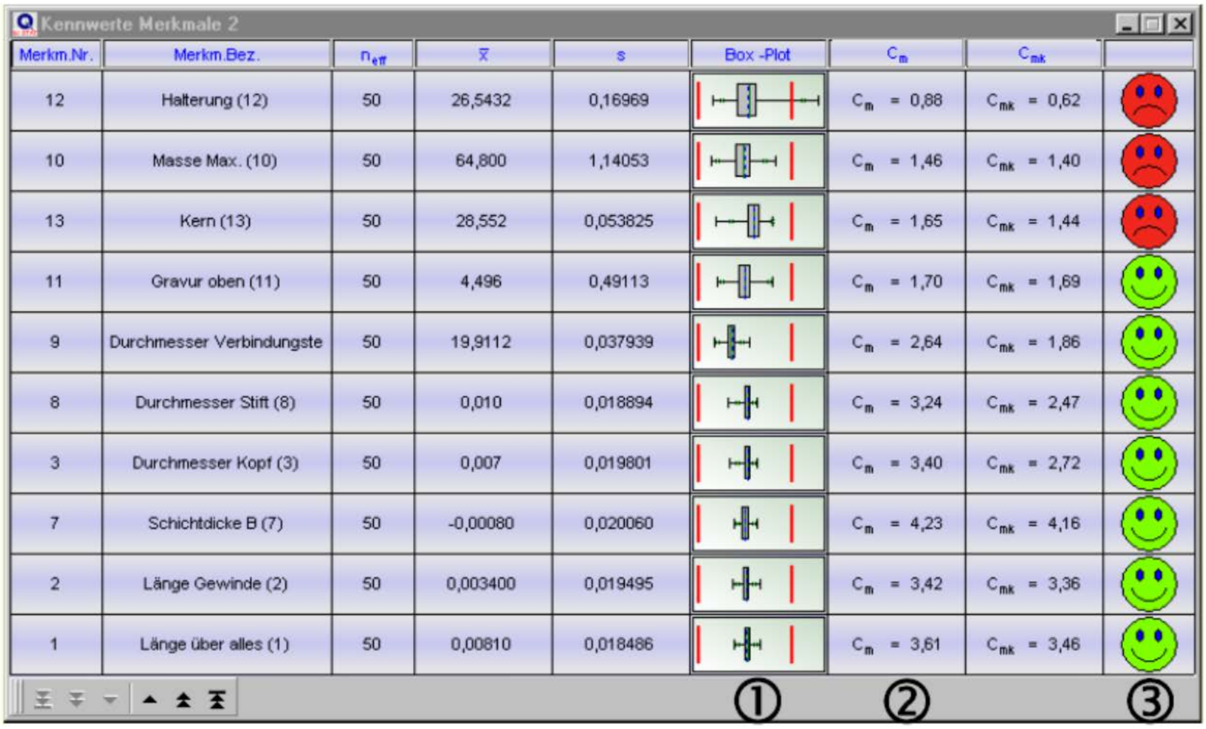
Merkmalklasse		signifikant	
Model-Verteilung		Johnson-Transformation	
Berechnungsart		$M4_1$ Percentil (0,135%-$\bar{x}$-99,865%)	
potentieller Fähigkeitsindex	C_p	1,09 ≤ **1,21** ≤ 1,33	0 … 1,67
kritischer Fähigkeitsindex	C_{pk}	0,83 ≤ **0,93** ≤ 1,03	0 … 1,33
Die Anforderungen sind nicht erfüllt (C_p,C_{pk})			
Forderung potentieller Fähigkeitsindex	$C_{p\,soll}$	1,67	
Forderung kritischer Fähigkeitsindex	$C_{pk\,soll}$	1,33	
DaimlerChrysler (04/2005)			

Angabe der
- Merkmalsklasse (aus Merkmalsmaske, beeinflusst den Grenzwert),
- genutzten Modellverteilung,
- Berechnungsmethode für C-Werte,
- Berechnete Fähigkeitsindizes mit Vertrauensbereichen
- Beurteilung (mit Anforderungen)
- Sollwerte lt. Auswertekonfiguration
- zu Grunde liegenden Auswertekonfiguration.

Die Darstellungen können je nach Versionsstand und Konfiguration abweichen. Wurde die automatische Auswertung nochmals manuell überarbeitet, so wird an den Zusätzen zur Auswertekonfiguration deutlich gemacht, an welchen Punkten eingegriffen wurde. Details dazu entnehmen Sie der Hilfe zu qs-STAT®.

(DaimlerChrysler (04/2005)[S,D,Q])

For cross-characteristic outputs, choose e.g. OVERVIEW / CHARACTERISTIC VALUES (ÜBERSICHT / KENNWERTE).



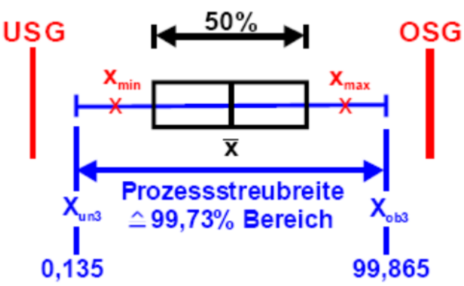
Kennwerte Merkmale 2

Merkm.Nr.	Merkm.Bez.	n_{eff}	$\bar{x}$	s	Box -Plot	C_m	C_{mk}	
12	Halterung (12)	50	26,5432	0,16969		C_m = 0,88	C_{mk} = 0,62	
10	Masse Max. (10)	50	64,800	1,14053		C_m = 1,46	C_{mk} = 1,40	
13	Kern (13)	50	28,552	0,053825		C_m = 1,65	C_{mk} = 1,44	
11	Gravur oben (11)	50	4,496	0,49113		C_m = 1,70	C_{mk} = 1,69	
9	Durchmesser Verbindungste	50	19,9112	0,037939		C_m = 2,64	C_{mk} = 1,86	
8	Durchmesser Stift (8)	50	0,010	0,018894		C_m = 3,24	C_{mk} = 2,47	
3	Durchmesser Kopf (3)	50	0,007	0,019801		C_m = 3,40	C_{mk} = 2,72	
7	Schichtdicke B (7)	50	-0,00080	0,020060		C_m = 4,23	C_{mk} = 4,16	
2	Länge Gewinde (2)	50	0,003400	0,019495		C_m = 3,42	C_{mk} = 3,36	
1	Länge über alles (1)	50	0,00810	0,018486		C_m = 3,61	C_{mk} = 3,46	

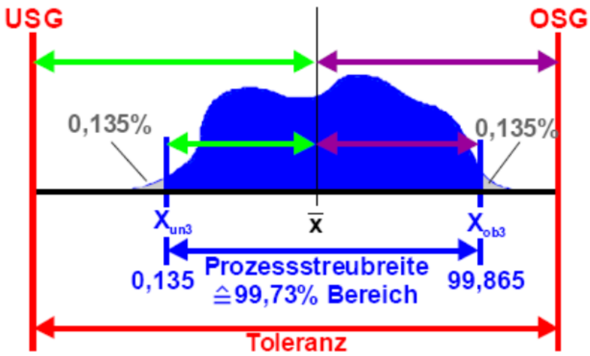
① ② ③

③ Ein Doppelklick in die Spalten sortiert die Ergebnisse auf- oder absteigend der Größe nach.

① Box-Plot



②



$$C_p, C_m = \frac{OSG - USG}{X_{ob3} - X_{un3}}$$

$$C_{pk}, C_{mk} = \min\left\{\frac{\bar{x} - USG}{\bar{x} - X_{un3}}; \frac{OSG - \bar{x}}{X_{ob3} - \bar{x}}\right\}$$

$$X_{ob3} = X_{0,99875} \qquad X_{un3} = X_{0,00135}$$

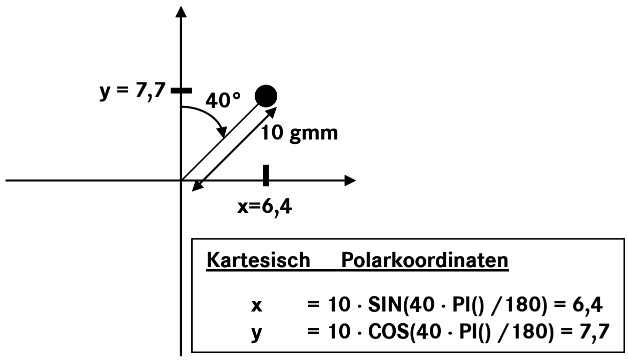
The "Part report" (Teileprotokoll) view (OVERVIEW / PART REPORT [ÜBERSICHT / TEILEPROTOKOLL]) takes a slightly different approach. Here, all the measured characteristics for a single measured part are shown in an overview.

B.4 Case Study: Balancer

This section describes by way of example the acceptance procedure for **balancers**.

Balancers are devices used for both **measuring** and **balancing** (e.g. by drilling or grinding) imbalances. This balancing takes place on the basis of the previously measured imbalances.

The **vectorial** quantity "imbalance" here is **two-dimensional**. To specify imbalance, either the scalar quantities "imbalance value" and "imbalance direction" (polar coordinates) or "imbalance horizontal component" and "imbalance vertical component" (Cartesian coordinates) are used.



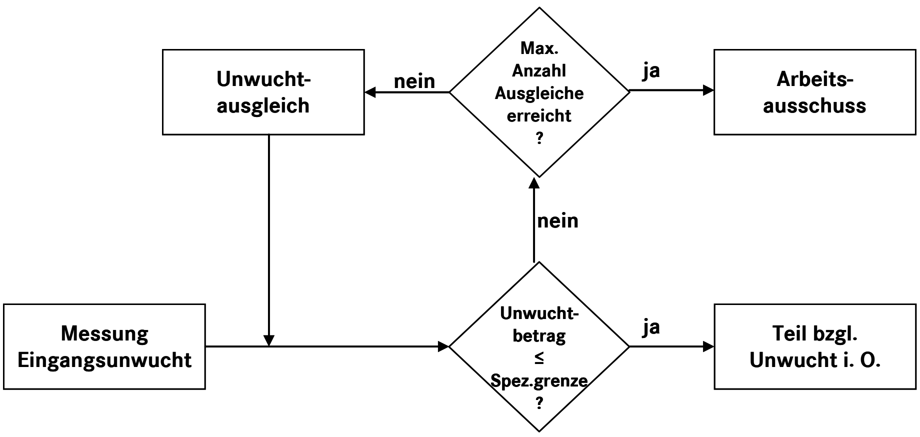
Regardless of the "imbalance" quantity under analysis here, the methods used can also be applied if the "multi-dimensionality" is the result not of a vectorial measurand, but for example **multiple coordinates** of a position.

Imbalance is the result of unequal mass distribution in relation to a given axis of rotation. The centrifugal forces and oscillations caused by imbalance can reach magnitudes that place considerable stress on not only the rotors (crankshafts, brake disks, articulated shafts, articulated flange, turbocharger basic units, etc.), but also their bearings or at least give rise to noise complaints.

The **acceptance** procedure for balancers (imbalance measuring equipment **combined** with a device for balancing imbalance) involves **two steps**:

1. Verification of capability of the measurement process $\mathbf{C_g/C_{gk}}$ (measure imbalance)
2. Verification of capability of the production process $\mathbf{C_m/C_{mk}}$ (balance imbalance)

If the requirements regarding C_m/C_{mk} are not fulfilled, but the capability of the measurement process C_g/C_{gk} has been verified, this is not particularly critical because the aforementioned combination (i.e. de facto **100% check of residual imbalances**) is sufficient to ensure that no defective parts will be installed. Of course, this does not rule out the possibility that, in this case, the ppm rates for waste from work processes will be very high.



The following **distinctions** (variants) must always be taken into account:

1. A rotor can have **several** measurement **planes**, sensor planes, tolerance planes and balancing planes. As a rule, however, the imbalances output by the measuring equipment relate to the tolerance planes. If this is not the case, the fundamental theorem of proportionality must be used for conversion.

   In this section, it is assumed that in each case **only one of these planes** exists and that the measured values relate to the tolerance plane.

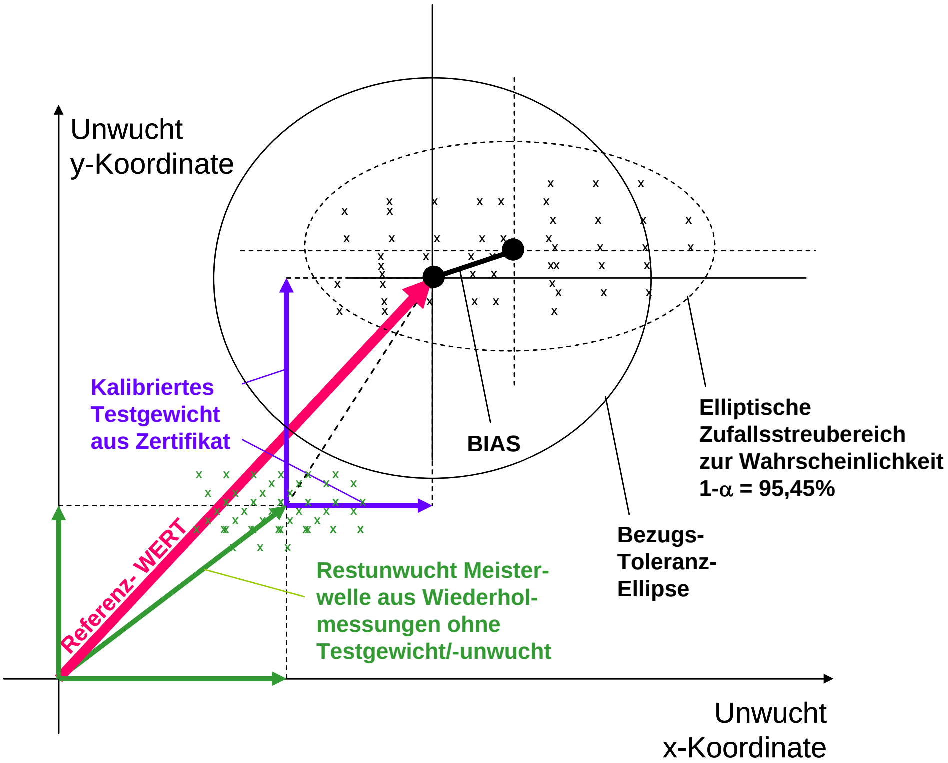
2. If a rotor (e.g. a brake disk) does not have **its own angle reference system** and if no corresponding reference is created (e.g. with the magnetic marking of an angular position), the C_m/C_{mk} values are calculated using the imbalance value only (i.e. one-dimensionally).

3. Degree of detail of the information via the actual, **reference value of the measurement standard**:

   a) **Actual value** is **0** in both Cartesian coordinates (theoretical only)
   b) **Actual value** is **unknown** in both Cartesian coordinates
   c) **Actual value** is **known, ≠ 0** in both Cartesian coordinates (normal)

   This value is entered in the appropriate field in the qs-STAT characteristic form.
   In case b), the field is left empty. However, this means that only one C_g value and no C_{gk} value can be calculated. The following example illustrates case c).

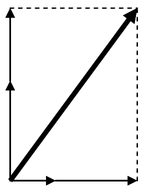
Visualization of the reference value in the C_g/C_{gk} calculation



The actual/reference value is thus the **sum** of the residual imbalance of the master shaft and the attached test imbalance. The test imbalance here is the **product** of the test weight mass and its center of gravity radius.

Determining the reference value in the C_g/C_{gk} calculation

1. **Mean** from repeated measurements of the measurement standard (without test imbalance)
2. **Transformation** of the mean from polar to Cartesian coordinates (residual imbalance)
3. Coordinate-by-coordinate **addition** of the test imbalance as per the calibration report
   (This is straightforward if the test weight acts horizontally or vertically only, i.e. the angular position of the test imbalance is a multiple of 90°.)



Required data and calculations

	1. Richtiger Wert		2. Cg/Cgk (zweidimensional)				3. Cm/Cmk (eindimensional)
	20 Wiederholmessungen **ohne** Testunwucht		20 Wiederholmessungen **mit** Testunwucht				50 Restunwuchtbeträge aus dem Wuchtprozess
	Betrag	**Richtung**	**Betrag**	**Richtung**	**X**	**Y**	**Betrag**
	27,9	88	324	3	**17,0**	**323,6**	**50**
	31,2	89	326	3	**17,1**	**325,6**	**197**
	39,4	83	328	4	**22,9**	**327,2**	**15**
	29,4	87	326	4	**22,7**	**325,2**	**237**
	23,5	85	326	4	**22,7**	**325,2**	**53**
	40,4	83	324	4	**22,6**	**323,2**	**180**
	39,4	84	324	4	**22,6**	**323,2**	**232**
	26,6	89	325	3	**17,0**	**324,6**	**157**
	25,1	87	324	3	**17,0**	**323,6**	**266**
	27,5	89	325	3	**17,0**	**324,6**	**289**
	26,4	83	324	4	**22,6**	**323,2**	**187**
	28,6	86	325	4	**22,7**	**324,2**	**26**
	26,3	87	326	4	**22,7**	**325,2**	**134**
	28,4	84	324	4	**22,6**	**323,2**	**205**
	32,4	84	326	3	**17,1**	**325,6**	**219**
	33,8	87	328	4	**22,9**	**327,2**	**234**
	30,1	82	322	4	**22,5**	**321,2**	**29**
	27,8	88	325	4	**22,7**	**324,2**	**185**
	27,7	86	324	4	**22,6**	**323,2**	**50**
	30,2	87	323	4	**22,5**	**322,2**	**14**
							34
Mittel (polar)	**30,1**	**86**					**152**
Mittel (kart.)	**30,0**	**2,1**					**71**
							110
Restunwucht	**30,0**	**2,1**					**99**
Testunwucht	0,0	299,0					**69**
ISTWERTE	**30,0**	**301,1**					**43**
							290

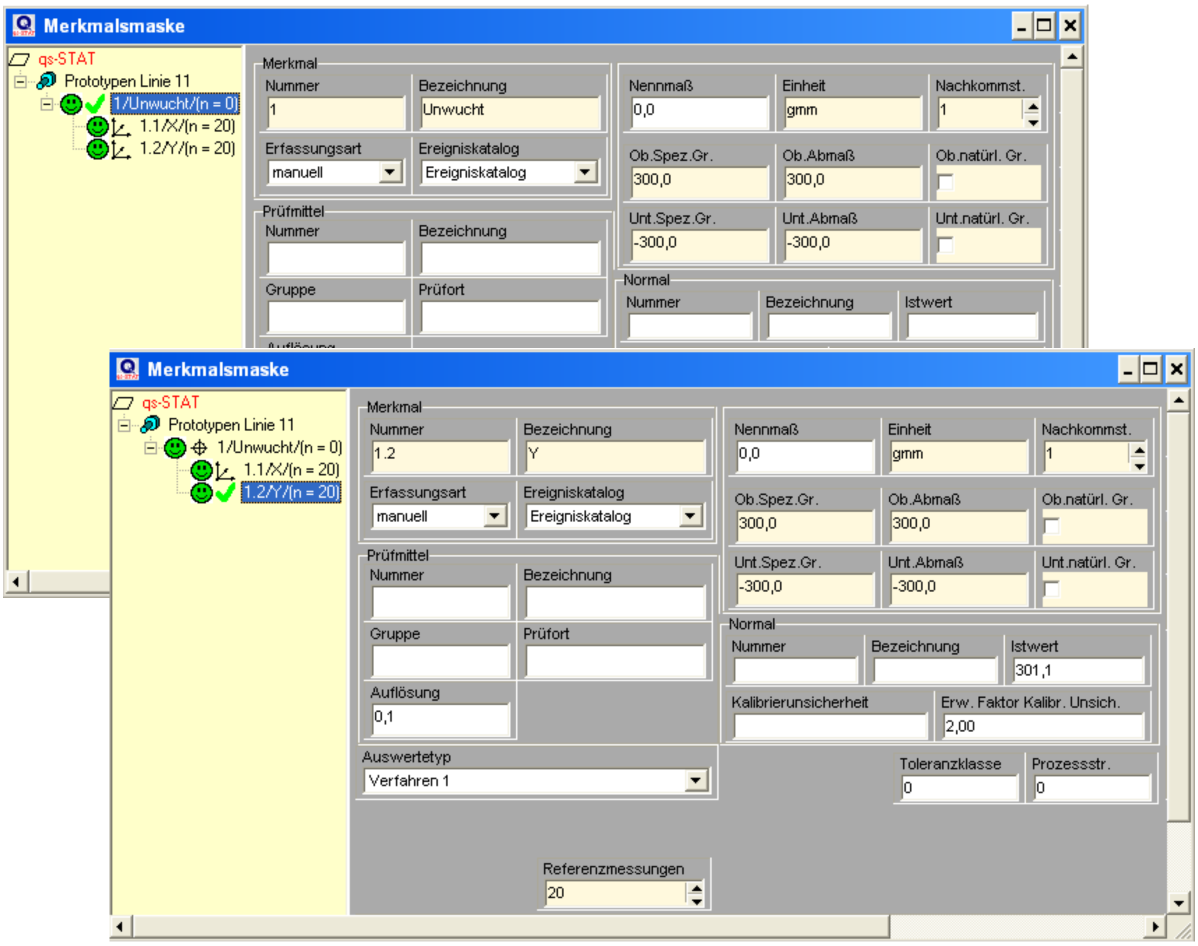
See information on determining the reference value

22 values not shown!

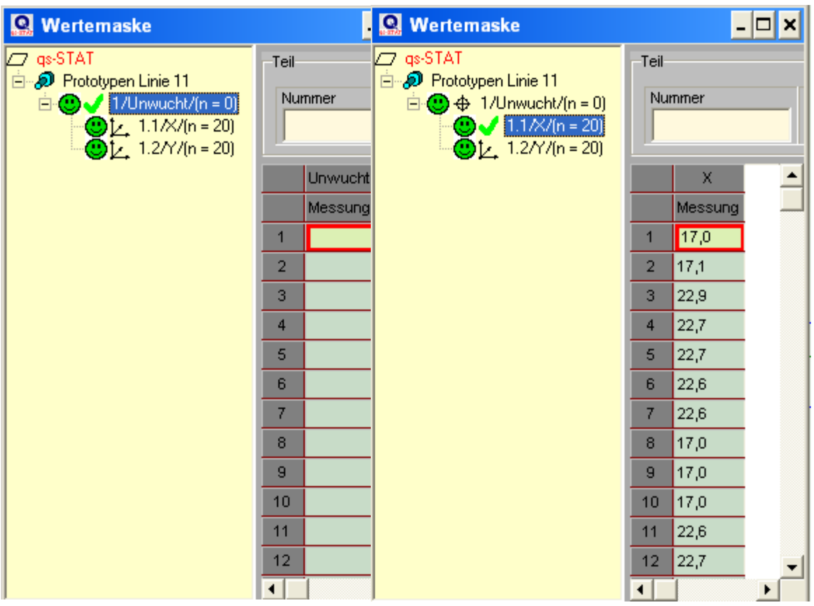
Analysis with qs-STAT

- Open qs-STAT, "Measuring system capability" (Messsystemfähigkeit) module, new file, 1 position tolerance
- Presettings: "Coordinates" (Koordinaten) measurand, nominal size, dimensions, unit, digits after decimal point, no. of reference measurements
- Fill out the part form and characteristic form(s).
- Copy the measured values (Cartesian) to the value form (e.g. from Excel) or enter them.
- Save the file; analyze the data.
- x-y plot position tolerances (specification limits hidden) and numerics form 3.

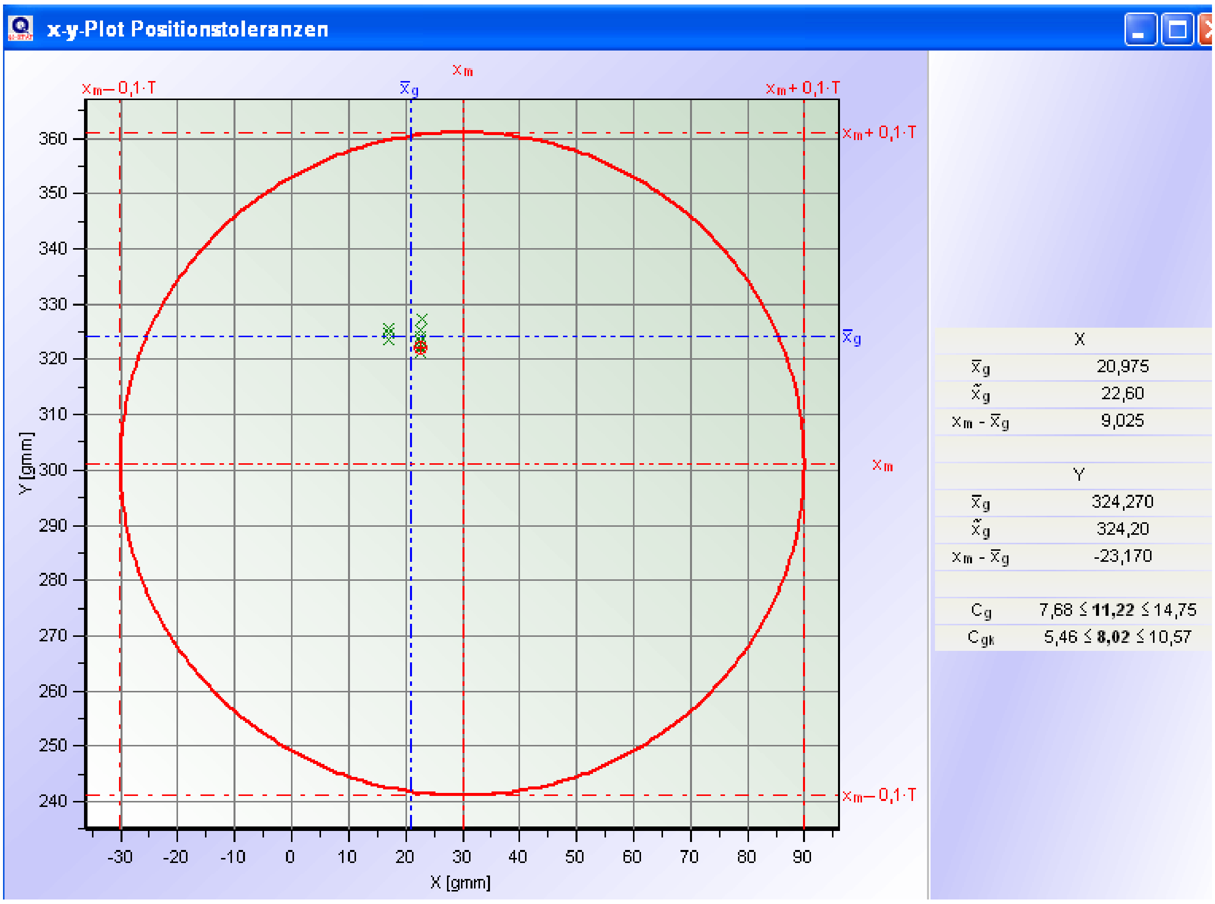
Characteristic forms:



Value forms:



Individual measurement errors shown in x-y plot:

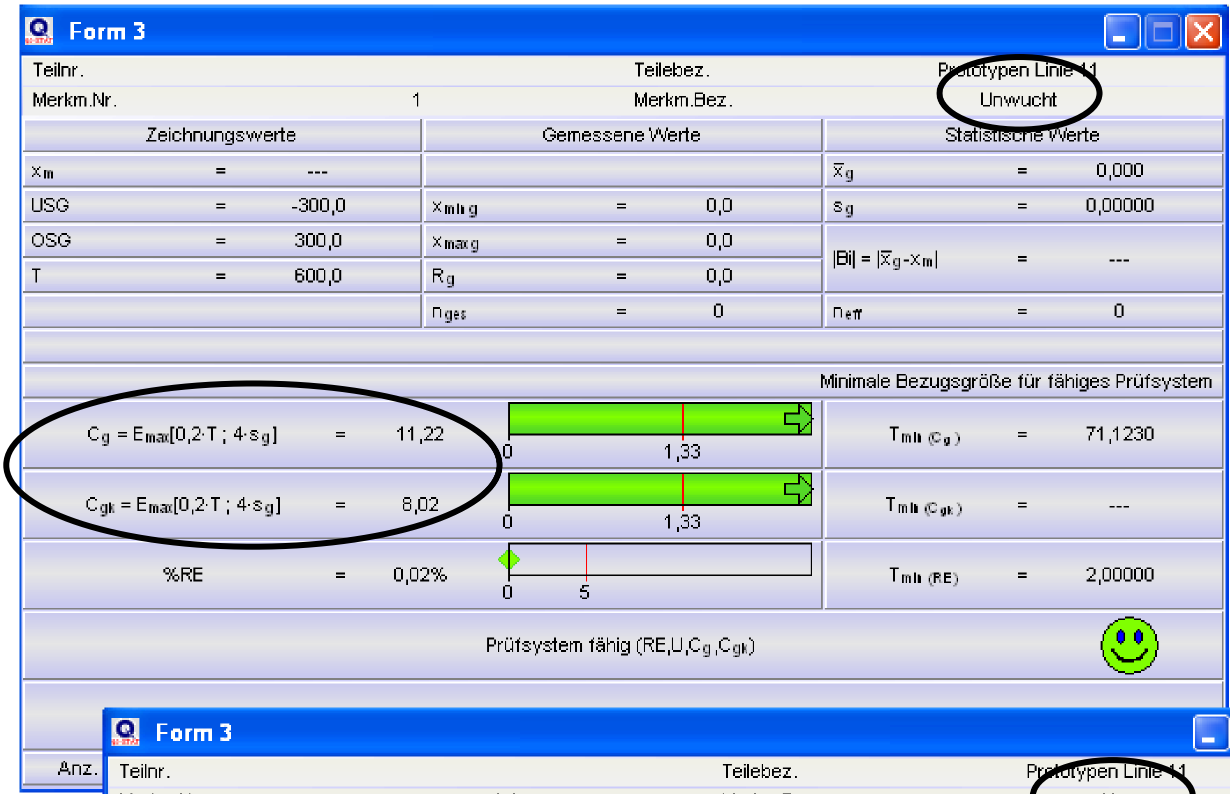


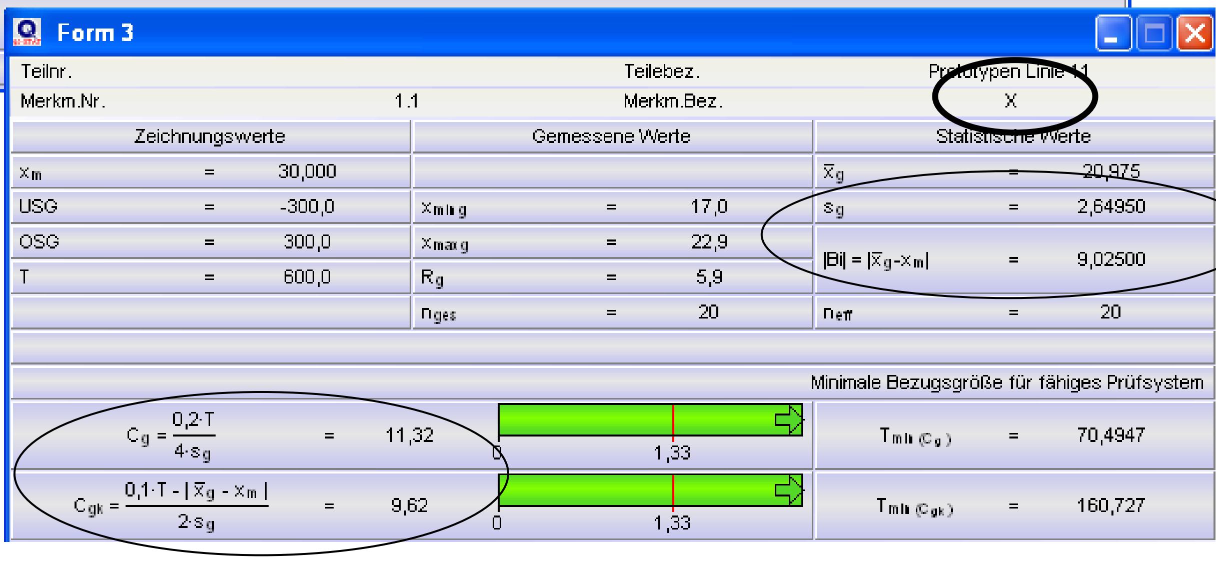
Remark:

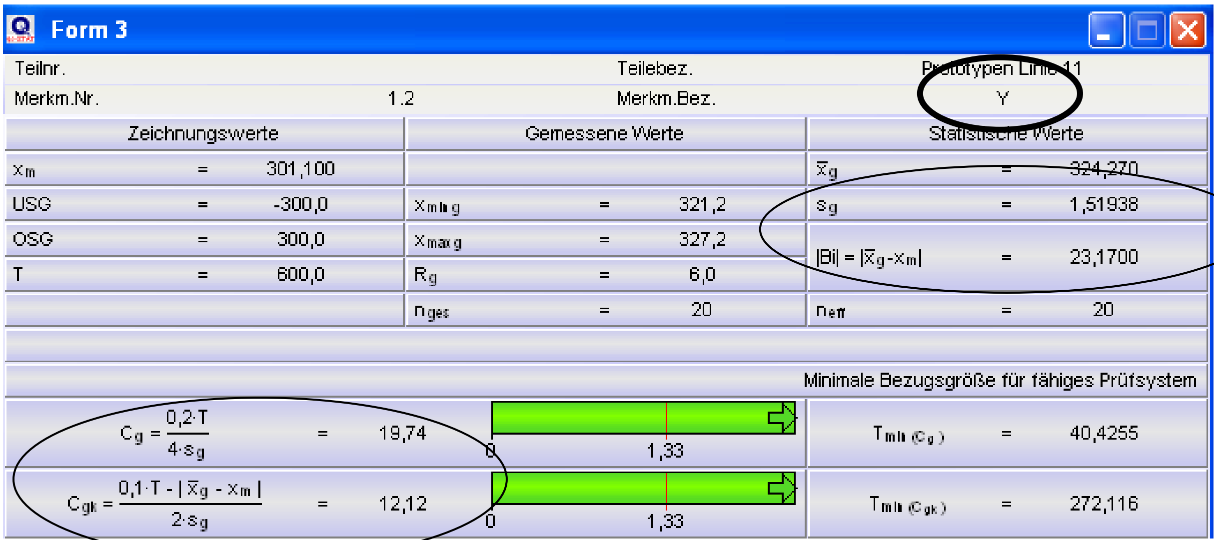
In the method described for determining the C_g/C_{gk} values, the master rotor (measurement standard) is not re-clamped between the individual repeated measurements.

To estimate the non-conformity attributable to the jig, method 3 (one-dimensional, amounts only) or method 1 (two-dimensional) with repeated clamping/unclamping of the rotor can be performed in addition to method 1 (two-dimensional).

Method 1 using qs-STAT: C_g/C_{gk}, bias Bi and variation s_g for both components







Effect of measurement uncertainty on manufacturing tolerance

Regardless of whether or not measuring system capability was verified, the predefined manufacturing tolerance must theoretically always be limited by the measurement uncertainty that has been determined.

According to VDA Volume 5, the uncertainty is calculated as follows:

$$U_{MS} = 2 \cdot \sqrt{s_g^2 + (\frac{1}{\sqrt{3}} Bias)^2}$$

Values s_g and $Bias$ are specified separately in form 3 for the horizontal (x) and vertical (y) components. In each case, the larger of the two values must be used.

In this example, the following new production tolerance for the amount of imbalance would be obtained:

$$300gmm - 2 \cdot \sqrt{(2.65gmm)^2 + \left(\frac{1}{\sqrt{3}} \cdot 23.17gmm\right)^2} = 273gmm$$

Remarks:

- Restricting the production tolerance increases the average number of balancing steps (takt time) and leads to more waste.
- Experience shows that centering the process and, in turn, minimizing the bias and also increasing C_{gk} to the level of C_g is much easier than reducing the variation.
- Key variables include:

  Tolerances of the calibration weights (mass and radius), specification and monitoring of the balancing speed, quality of the cooling lubricant, design of the balancing unit, conditions at the installation location, etc.
- Relationship between measurement process capability and manufacturing process capability:

	Actual C value of the process at...				
Observed C value	**Q_{MP} = 10%**	**Q_{MP} = 20%**	**Q_{MP} = 30%**	**Q_{MP} = 40%**	**Q_{MP} = 50%**
0.67	0.67	0.68	0.70	0.73	0.77
1.00	1.01	1.05	1.12	1.25	1.51
1.33	1.36	1.45	1.66	2.21	18.82
1.67	1.72	1.93	2.53		
2.00	2.10	2.50	4.59		

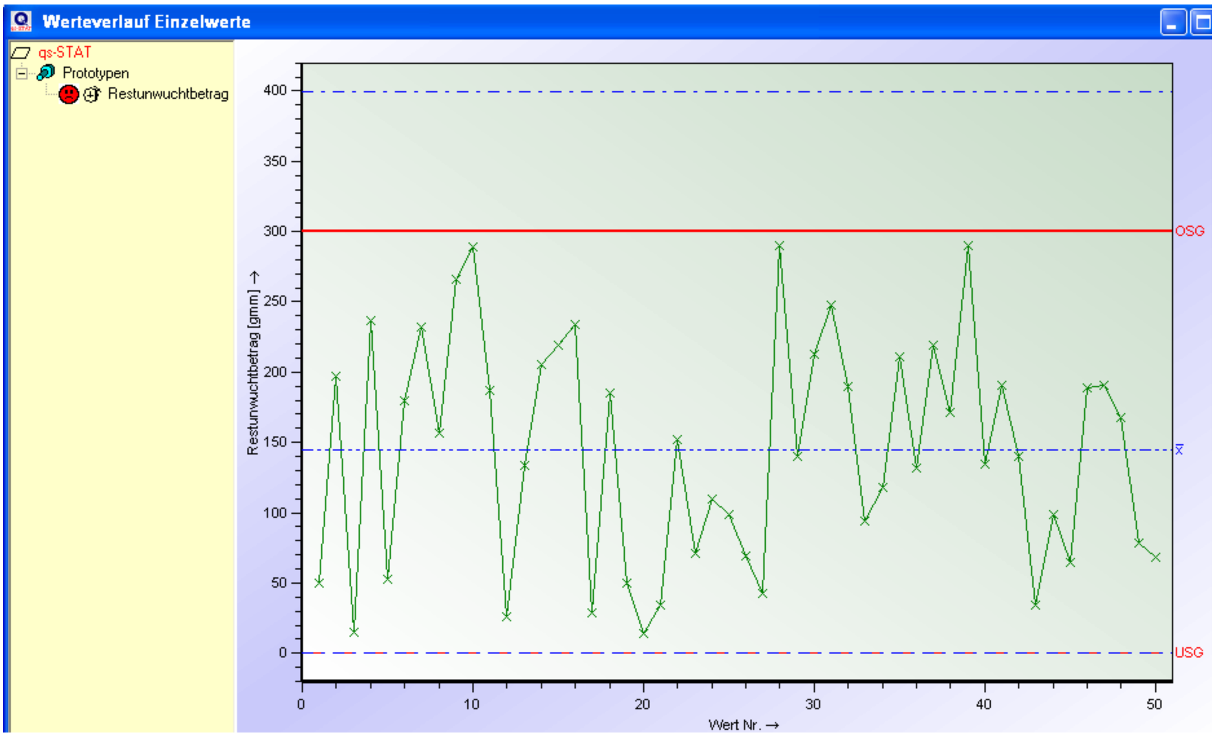
At an actual process potential of 2.21 and a capability characteristic value of the measurement process of 40%, only a potential of 1.33 can be observed.

Capability of the balancing process (one-dimensional)

- Open qs-STAT, module prel. Process capability, New file, 1 characteristic,
- Presettings: "Imbalance" (Unwucht) measurand, nominal size, dimensions, unit, digits after decimal point, characteristic class "non-critical" (unkritisch)
- Fill out the part form and characteristic form(s).
- Copy the measured values (amounts of imbalance) to the value form.
- Save the file; analyze the data.
- Value patterns and numerics form 3.

Characteristic form:

Value pattern:



Analysis:

Form 3

Teilnr.	Teilebez.	Prototypen
Merkm.Nr.	Merkm.Bez.	Restunwuchtbetrag

Zeichnungswerte		Gemessene Werte		Statistische Werte	
T_m	150			$\bar{x}$	144,22
USG*	0	x_{min}	14	Q_{u3}	0,55
OSG	300	x_{max}	290	Q_{ob3}	399,71
T*	300	R	276	$Q_{ob3}-Q_{u3}$	399,16
		$n_{<T>}$	50	$p_{<T>}$	96,75825 %
		$n_{>OSG}$	0	$p_{>OSG}$	3,24175%
		$n_{<USG}$	---	$p_{<USG}$	---
		n_{ges}	50	n_{eff}	50

Merkmalklasse	unkritisch
Modell-Verteilung	Betragsverteilung 1. Art (Faltung <> 0)
Berechnungsart	M4 $_1$ Percentil (0,135%-$\bar{x}$-99,865%)

potentieller Fähigkeitsindex	C_m	--- 915	0
kritischer Fähigkeitsindex	C_{mk}	0,46 ≤ **0,61** ≤ 0,76	0 1

Die Anforderungen sind nicht erfüllt (C_m,C_{mk})

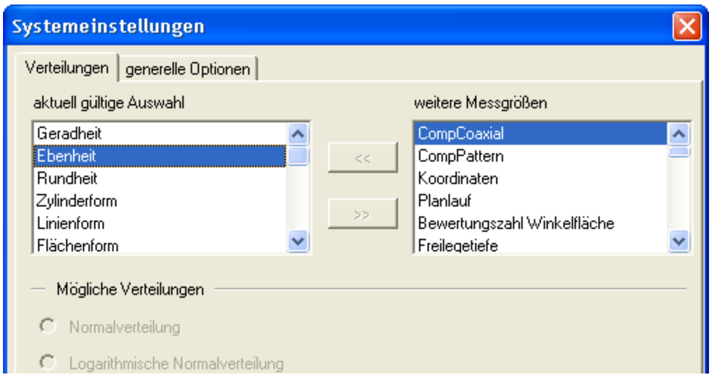
Forderung potentieller Fähigkeitsindex	$C_{m\,soll}$	=	--- 915
Forderung kritischer Fähigkeitsindex	$C_{mk\,soll}$	=	1,00

B.5 Special Cases

B.5.1 Characteristics Limited on One Side

A relationship fundamentally exists between the physical properties of a characteristic and the associated theoretical distribution model.

For example, the type 1 amount distribution is the theoretical distribution model of the form tolerances "straightness," "flatness," "roundness," "cylindricity," "line shape" and "area shape" as well as the dimensional location tolerances "parallelism," "perpendicularity," "gradient," "symmetry," "roundness" and "axial runout." A full list can be found in qs-STAT:



Whether the relevant distribution model is applicable, however, must be determined on a case-by-case basis (e.g. using the probability grid). The measurands of the characteristics must be preset in qs-STAT in the characteristic form so that the physically correct distribution is found and the "best fit" is used without needing to check the expected distribution.

In the case of unilateral limited characteristics, only the critical capability index (C_{mk}) is generally calculated. This then relates to the critical tolerance limit.

If the characteristic is a zero-limited characteristic, the tolerance is automatically known and can be taken into account when the potential capability index (C_m) is calculated. Note that the potential capability characteristic value may in this case be smaller than the critical capability characteristic value.

Due to various influences, even zero-limited characteristics are subject to fluctuations. These manifest themselves in that, unlike in the best-case scenario, the characteristic may be distributed.

B.5.1.1 Example

Typical applications for unilateral limited characteristics are all form and position dimensions, whose physical limit is zero (i.e. all values should ideally tend toward the zero point). Values less than zero cannot occur.

B.5.2 Systematic and Random Fluctuations

If only a few parts are manufactured on a continuous basis under identical conditions and the characteristics are measured, it is generally not possible to detect any significant systematic or random fluctuations.

If the precondition of identical conditions is not in place, it may be possible to detect signs of wear or abrasion on the tools.

Batch and tool changes as well as any changes to the ambient conditions can cause the process to be subject to random fluctuations.

A similar situation exists when identical characteristics (e.g. diameter) are produced with different tools. This raises the question of whether or not you must compensate for (i.e. mathematically correct) the recorded measured values for the analysis. The machine vendor, for example, always prefers the data to be "scrubbed" due to tool wear, because the product is a supplied product over which the vendor has little or no influence. The customer, however, would argue that he/she is interested only in having a properly functioning end product (manufactured parts) under real-life production conditions (i.e. under the action of the specified influences).
The data should therefore first be analyzed and evaluated in unchanged form. If the required specification limits are complied with during acceptance, any further discussion is unnecessary anyway. If any specification limits are undershot, however, the causes must be analyzed in more detail. In this way, for example, tools can be analyzed individually or the tool service life must be shortened as appropriate.

Note: Compensating a trend or misalignment is ultimately nothing more than a cosmetic procedure, the outcome of which does not exist in reality. This means that one obtains only a hypothetical statement regarding the capability that could be reached if the influencing factor did not exist or its impact is not noticeable.

The calculation at a particular specification limit is often useful in trend processes or for fixed tools. In particular, tools with expected wear (e.g. awls) are deliberately manufactured with a nominal value offset in order to achieve the longest possible service life. The specification limit in the direction of which the trend and/or wear is tending toward is entered as a critical limit for calculating the C_{mk} value. If the tendency is toward the lower specification limit, the upper specification limit must be entered in the characteristic form in qs-STAT as the natural limit. The C_{mk} value is then automatically calculated for the lower specification limit.

B.5.3 Equipment with Measurement Control

Pre-process measurement controllers measure, for example, the machining allowance of the workpiece prior to machining and forward the result to the machine controller.

In-process measurement controllers supply cyclical or continuous measured values while machining is taking place, which are then processed further by the machine controller.

A typical example of in-process automatic measurement instruments are screwdriver controllers. The current tightening torque and, with most controllers, the rotational angle while the screw is being tightened are monitored here. If a particular tightening torque and/or rotational angle is reached, the controller outputs a signal indicating that the nominal value has been reached.

Pre-process and in-process measurement controllers are also included in the capability analysis, which means that the measurement controller is active during the acceptance procedure.

Post-process measurement controllers measure characteristics after machining. The results of the measurements are used either as input quantities for further machining (post-process as pre-process) or for assessing the quality.

Post-process measurement controllers are only also included in the capability analysis if they are used as pre-process measurement controllers for the follow-up process.

B.5.4 Two-Dimensional Position Tolerances

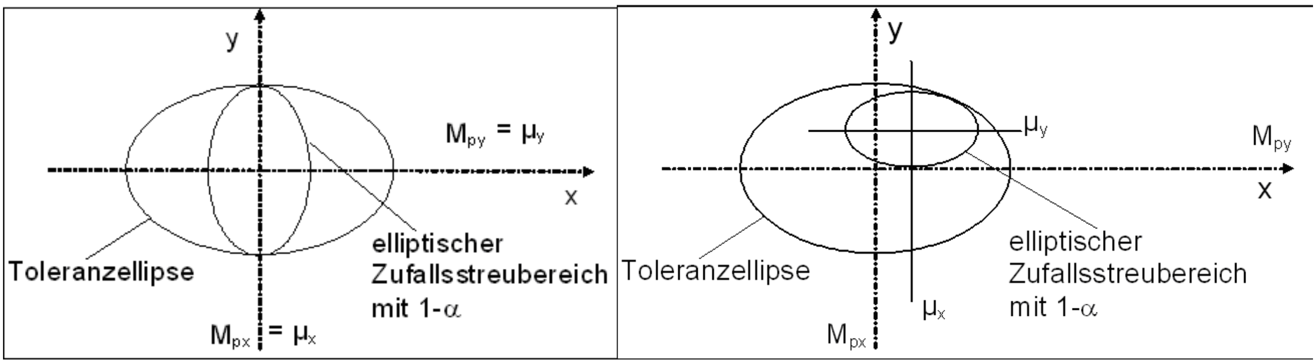
To determine the quality characteristics in the case of bivariate normal distribution, the error bands are analyzed – analogously to one-dimensional normal distribution – as a function of a predefined probability 1-α (e.g. 99.73%). The following table shows an example of the relationship between the error bands, the multiples of the standard deviations and the resulting capability indices.

Probability 1-α	Standard deviations	Capability index
99.73%	$\pm 3\ \sigma$	1.00
99.9937%	$\pm 4\ \sigma$	1.33
99.99994%	$\pm 5\ \sigma$	1.67
99.9999998%	$\pm 6\ \sigma$	2.00

In the bivariate scenario, the predefined probability 1-α yields an error band that can be drawn into the x-y plot in the form of a probability ellipse. If the requirement for a particular capability is fulfilled, this band may not cut through the tolerance ellipse.

<u>Potential capability index c_p</u>
When the elliptical error band and, in turn, capability is determined, the center point of the ellipse is placed onto the center point of the tolerance. The elliptical error band that just touches the tolerance ellipse is then determined. The probability associated with this band is used for determining the capability potential Po.

<u>Critical capability index c_{pk}</u>
To determine the capability C_{pk}, the elliptical error band that just touches the tolerance ellipse is determined. The estimated values for bivariate normal distribution are assumed when the center point of the ellipse is determined. The probability associated with this elliptical error band determines the capability index C_{pk}. If the estimated values are outside the tolerance ellipse, no capability index C_{pk} is specified.



B.5.4.1 Example

The center point of a drilled hole on a workpiece is measured. The nominal sizes here are 80 mm in the X direction and -116.5 mm in the Y direction.

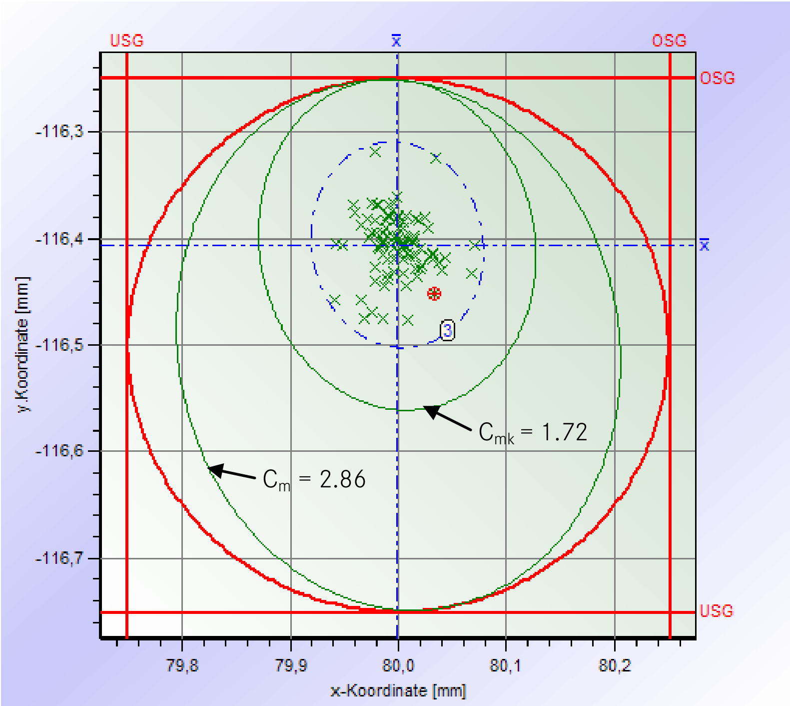
No. of measured parts n = 100

Specification limits: X-coordinate LSL = 79.750 USL = 80.250
Y-coordinate LSL = -116.750 USL = -116.250

Individual values:

No.	X-coord.	Y-coord.	No.	X-coord.	Y-coord.	No.	X-coord.	Y-coord.
1	79.976	-116.470	36	79.995	-116.410	71	79.986	-116.394
2	79.993	-116.406	37	80.002	-116.403	72	80.016	-116.429
3	80.031	-116.420	38	80.027	-116.390	73	79.995	-116.431
4	79.968	-116.475	39	79.995	-116.520	74	79.975	-116.395
5	79.973	-116.399	40	80.010	-116.416	75	79.965	-116.387
6	79.983	-116.410	41	80.005	-116.390	76	79.971	-116.382
7	80.008	-116.401	42	80.004	-116.419	77	79.978	-116.383
8	80.014	-116.415	43	79.966	-116.457	78	79.999	-116.382
9	80.020	-116.428	44	80.013	-116.404	79	80.008	-116.477
10	79.979	-116.427	45	80.021	-116.425	80	80.005	-116.406
11	79.978	-116.440	46	79.989	-116.383	81	80.007	-116.444
12	80.016	-116.416	47	79.988	-116.390	82	80.032	-116.413
13	79.990	-116.434	48	79.987	-116.445	83	79.958	-116.368
14	79.992	-116.380	49	80.012	-116.400	84	79.990	-116.378
15	79.999	-116.397	50	80.017	-116.435	85	79.994	-116.374
16	80.016	-116.382	51	80.000	-116.401	86	80.029	-116.416
17	80.038	-116.423	52	79.995	-116.399	87	80.000	-116.390
18	80.018	-116.383	53	79.999	-116.361	88	80.010	-116.417
19	80.005	-116.384	54	80.002	-116.414	89	80.000	-116.379
20	80.071	-116.406	55	80.068	-116.433	90	79.992	-116.369
21	79.941	-116.458	56	79.990	-116.397	91	79.992	-116.378
22	79.984	-116.404	57	80.035	-116.325	92	79.990	-116.439
23	79.986	-116.475	58	79.980	-116.395	93	79.999	-116.402
24	80.043	-116.418	59	79.978	-116.319	94	79.986	-116.415
25	80.027	-116.538	60	80.000	-116.401	95	79.986	-116.404
26	80.031	-116.415	61	79.995	-116.420	96	80.020	-116.410
27	80.005	-116.403	62	79.996	-116.367	97	79.984	-116.406
28	80.024	-116.380	63	80.000	-116.412	98	79.980	-116.369
29	80.040	-116.430	64	79.948	-116.406	99	79.981	-116.369
30	80.006	-116.406	65	80.015	-116.400	100	80.033	-116.452
31	79.986	-116.402	66	79.990	-116.420			
32	79.982	-116.408	67	80.009	-116.413			
33	79.942	-116.405	68	80.004	-116.433			
34	79.975	-116.367	69	79.960	-116.376			
35	80.014	-116.398	70	80.007	-116.379			

View in x-y plot:



x-Koordinate	
$\bar{x}$	79,99917
$\tilde{x}$	79,9990
$T_m - \bar{x}$	0,00083
y.Koordinate	
$\bar{x}$	-116,40572
$\tilde{x}$	-116,4045
$T_m - \bar{x}$	-0,09428
C_m	2,46 ≤ **2,86** ≤ 3,26
C_{mk}	1,47 ≤ **1,72** ≤ 1,98

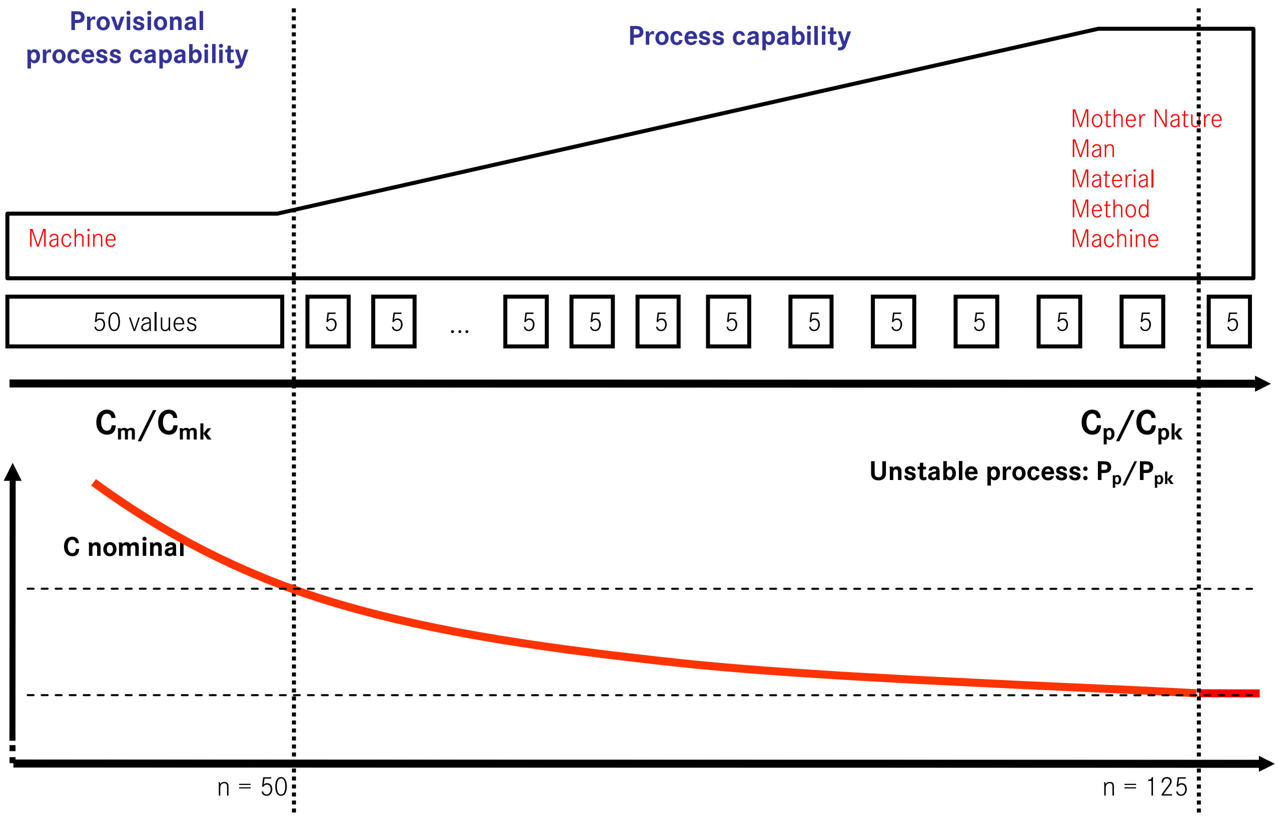
Teilnr.	FBSP2 DC1236	Teilebez.		Fallbeispiel 2	
Merkm.Nr.	1	Merkm.Bez.		td	
Zeichnungswerte		Gemessene Werte		Statistische Werte	
T_m	0,125			$\bar{x}$	0,09746
USG*	0,000	x_{min}	0,024	X_{un3}	0,00148
OSG	0,250	x_{max}	0,182	X_{ob3}	0,19621
T*	0,250	R	0,158	$X_{ob3}-X_{un3}$	0,19472
		$n_{<T>}$	98	$p_{<T>}$	99,99411 %
		$n_{>OSG}$	0	$p_{>OSG}$	0,00589%
		$n_{<USG}$	---	$p_{<USG}$	---
		n_{ges}	100	n_{eff}	98
Merkmalklasse			signifikant		
Modell-Verteilung			Johnson-Transformation		
Berechnungsart			MPo2 max. Wahrscheinlichkeitsellipse		
potentieller Fähigkeitsindex	C_m	2,46 ≤ **2,86** ≤ 3,26	0 2		
kritischer Fähigkeitsindex	C_{mk}	1,47 ≤ **1,72** ≤ 1,98	0 1,67		
Die Anforderungen sind erfüllt (C_m,C_{mk})					
Forderung potentieller Fähigkeitsindex			$C_{m\,soll}$	=	2,00
Forderung kritischer Fähigkeitsindex			$C_{mk\,soll}$	=	1,67

C Process Capability

The difference between provisional process capability and process capability is analogous to that between an analysis with drastically reduced influencing factors and one in which all the expected influencing factors in the process are visible in the recorded data. The influencing factors can be described symbolically with the traditional "5Ms":

- Machine
- Man
- Material
- Method
- Mother Nature

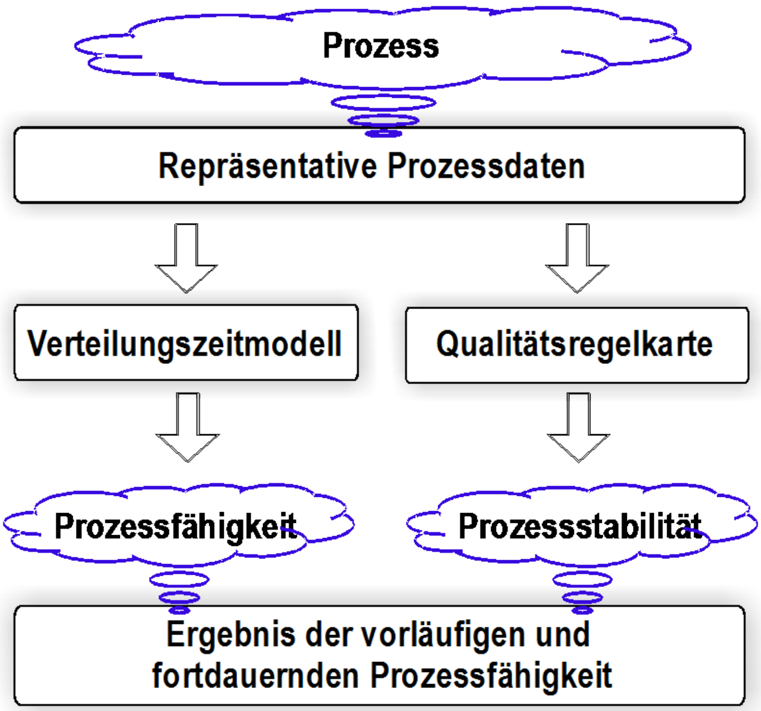
Provisional process capability primarily involves "machine" influences, otherwise only unavoidable influences resulting from the remaining four Ms. This means that influences arising from the operator, environment, tool and so on must be excluded as far as possible.
In the process analysis, however, it should be assumed that all the relevant influencing factors can have their usual impact during the course of the process. This means above all that the process owner must schedule a longer analysis period that is process-specific and representative. Since capability characteristic values are estimated from random samples, a minimum number of measured values is defined in order to limit the size of the confidence intervals.



C.1 General Procedure

Both during machine acceptance (module B) and process qualification (module C), representative parts or random samples are taken from the "process" and evaluated by means of a capable measurement process. The capability of the measurement process is verified using guideline LF 5 and/or VDA 5.

The key elements of process qualification:



For the "distribution time model" and "quality control chart" elements, see Sections C2 and C3.

To assess the various quality characteristics, the results (continuous characteristic values) should be determined and stored by means of measurement and test equipment. The gage test is not suitable for assessing the process.

The uncertainty of the measuring method should be known for each result of the assessment of a quality characteristic. The constancy of the measurement uncertainty must be verified on an ongoing basis across the period of use of a measurement process.

The acceptance-relevant characteristics should already be defined in the design or by means of an FMEA and noted in the drawing. The acceptance-relevant characteristics are a subset of all characteristics.

C.1.1 Planning the Capability Analysis

The following points must be taken into account:

- Does the approval team (these are generally Production, QA and measuring technology) a cross-divisional staff? Do other departments have to be involved?
- Is the ongoing process from which the random samples are taken stabilized?
- Has the personnel tasked with performing statistical activities received sufficient training in the proper use of the current qs-STAT release?

Notes regarding random sampling (frequency and size):

- To assess a process on an ongoing basis, either all the parts (100% inspection) or random samples must be taken from the process. Their quality-relevant characteristics are then measured and analyzed.
- A distinction must in principle be made here between series production with high quantities and series production with recurring processes and low quantities.
- While random samples are taken at long intervals in continuous series production, it may be the case with small lot sizes that each individual part needs to be measured.
- With small lot sizes, however, it is not initially possible to specify a quality characteristic. The few values that are obtained should nonetheless be entered and displayed graphically, which makes it easier to identify changes. If such processes recur, the data from previous processes must also be used. This means that a greater quantity of values is obtained only over a very long period. This enlarged data record can be used for calculating capability characteristic values.
- When the characteristic values are entered, the process parameters (date/time, machine, operator, material, tool, speed, feed rate, temperature, position of the part, jig used, etc.) must also always be recorded. Without these process parameters, it is generally not possible to control or improve a process at a later stage.
- If little or nothing is known about a process, the provisional process capability is used as a basis and parts are taken from the process at specific intervals (e.g. one connecting rod at the start, in the middle and at the end of each shift).

  Normally, $k = 25$ lots with a random sample size of $n = 5$ parts are checked. If possible, n should be ≥ 3 and $n \cdot k$ should be ≥ 125 (also see C.1.2).
- In principle, the random sample frequency and size depend on the length of time that a process is capable. The greater the capability and the less this changes, the less the random sample frequency and size can be.

  The following factors can lead to a greater frequency and size:

- Unstable processes and/or low process capability parameters
- Function-/process-critical characteristics
- New production technology
- Non-availability of empirical values
- Short tool service life
- Few time-intensive and cost-intensive checks
- Demand for high statistical confidence coefficient
- Requirement for rapid response to ensure parts access with a low lead time in the plant for screening inspection in "not OK" case (traceability)

Depending on the process type, further graduations are possible. The temporal offset (morning/afternoon/shift change, etc.) must always be noted.

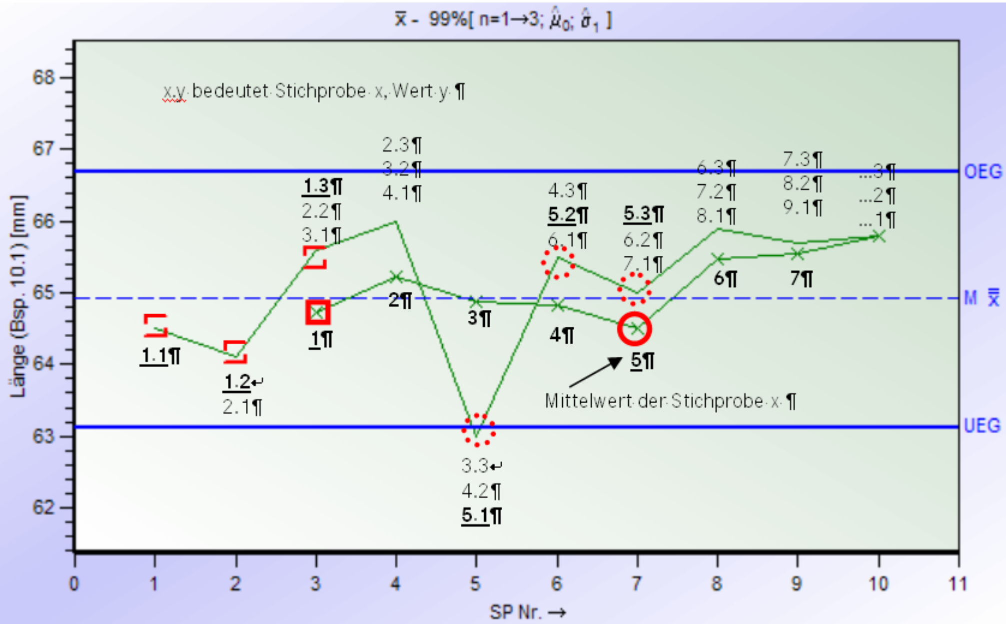
If, in exceptional cases, the minimum requirement of, for example, 25 random samples, associated with a minimum number of parts (at least 125), is not fulfilled for economic or technical reasons, the confidence intervals of the capability characteristic values increase along with the requirements regarding these characteristic values.

C.1.2 Sliding Random Samples

In certain processes, the random sample size is, for various reasons, n = 1. Typical examples include destructive testing and parameter monitoring as well as checks that are high-cost and involve small lot sizes.

To monitor these processes, individual value charts or control charts with sliding characteristic values can be used. With the sliding mean chart, for example, two, three or more consecutive values are combined to form one mean. These represent a random sample with a size of n = 2, 3, 4, etc. Based on these "pseudo" random samples, a variation exists that is used for calculating the intervention thresholds of the quality control charts. The variation chart is also calculated from the variation of the combined random samples and represented as an s or R chart.

Creation of a Shewhart chart with sliding means (pseudo random sample: n = 3):



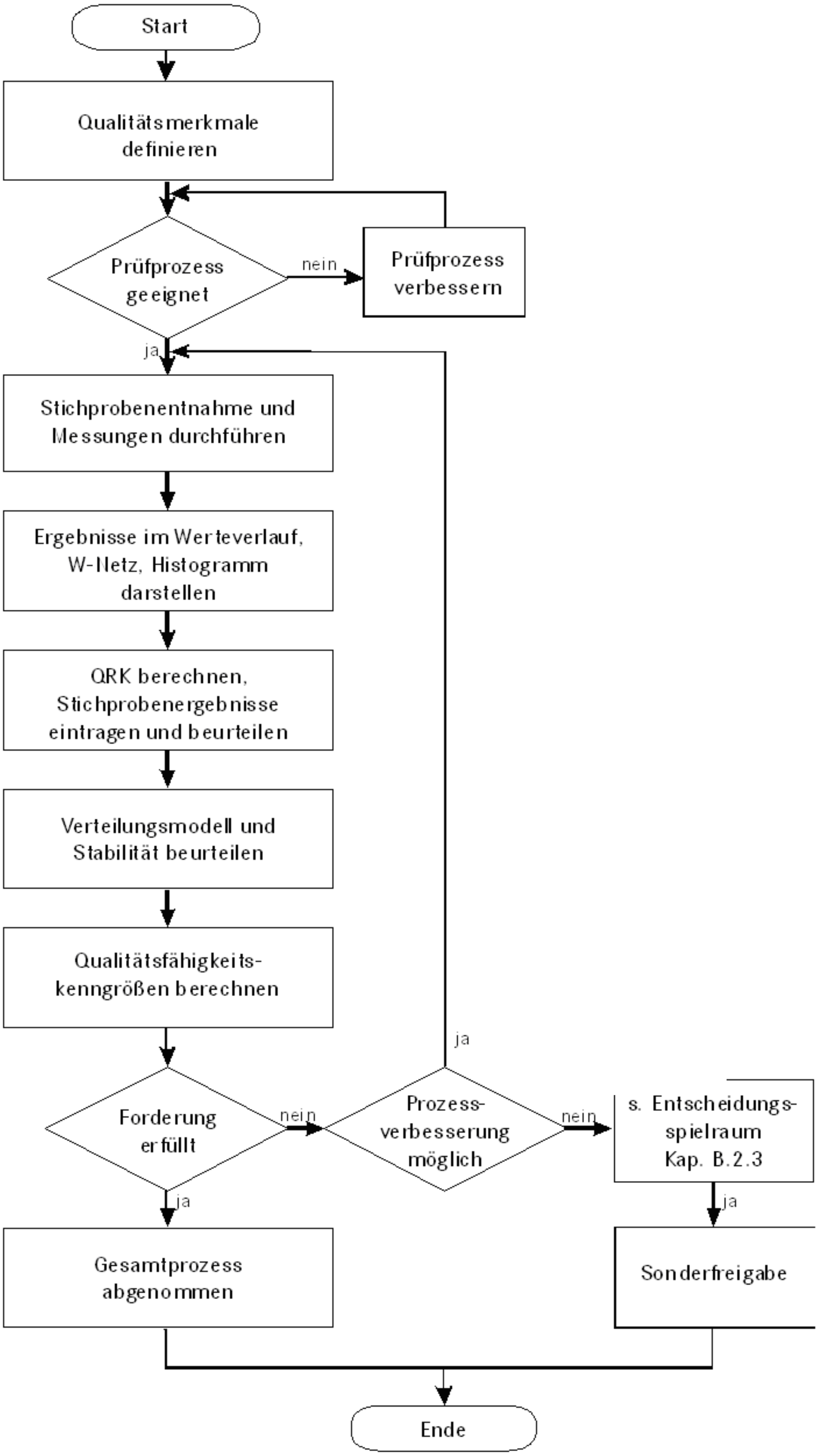
C.1.3 Performing Capability Analysis

Element
quality planning:

As per guideline LF 5:

Simultaneous input of sequence

With probability grid and quality



Decision-making scope:

None of the criteria may be considered absolute. The final decision regarding whether or not a process is acceptable lies with the process owner. If specification limits are not realistic, they should undergo a critical check.

C.2 Distribution Time Models

Real-life processes can be theoretically mapped (modeled) by means of statistical methods. "Distribution time models" are relevant in this context.

Distribution time models are the result of combining multiple current random samples. The sometimes differing behavior of the current random samples leads to different distribution time models.

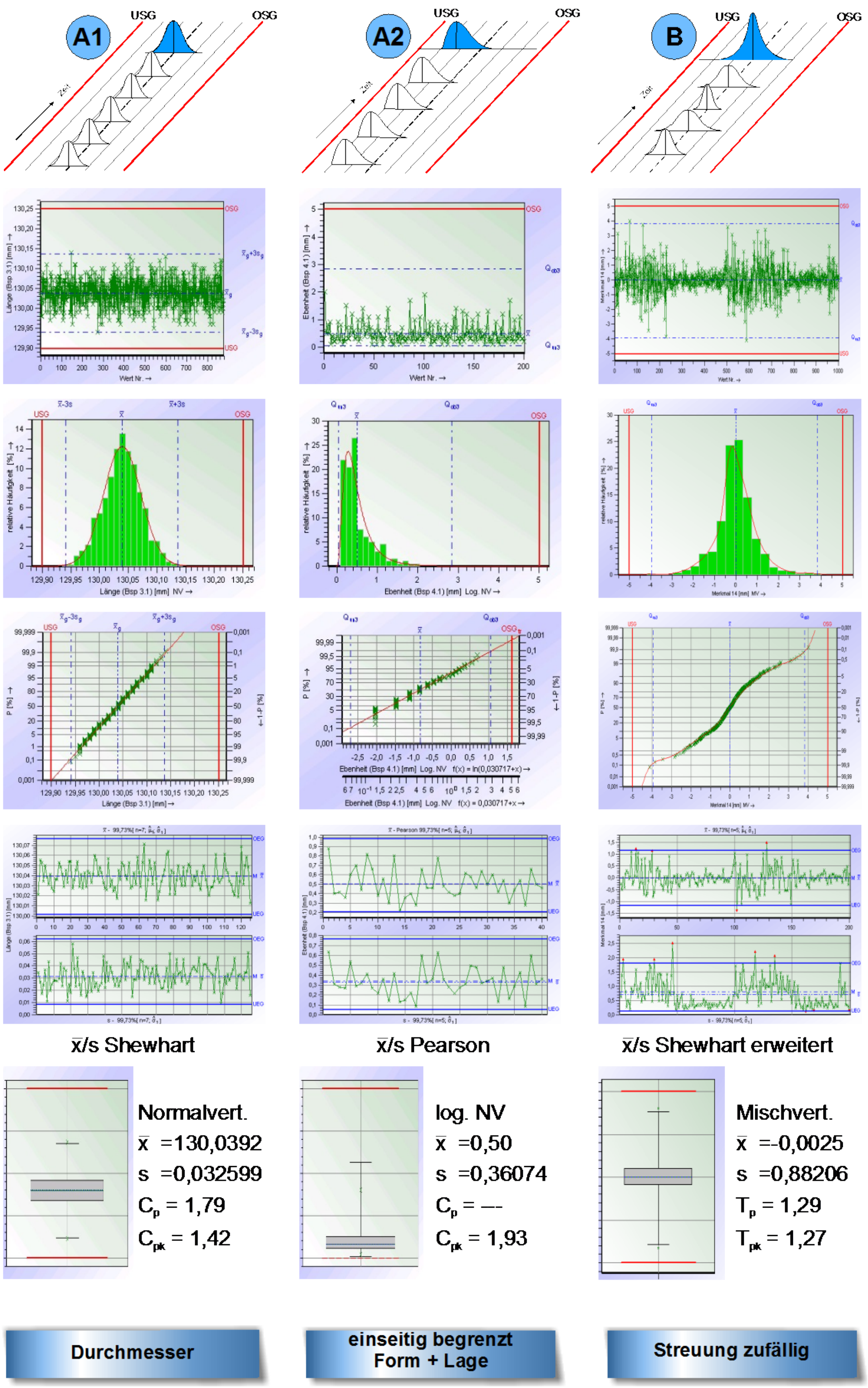
To find the distribution time model that is right for the process, different statistical test methods and quality criteria are needed for the assessment. The better the distribution time model represents the process in question, the more accurate the calculated quality capability statistics.

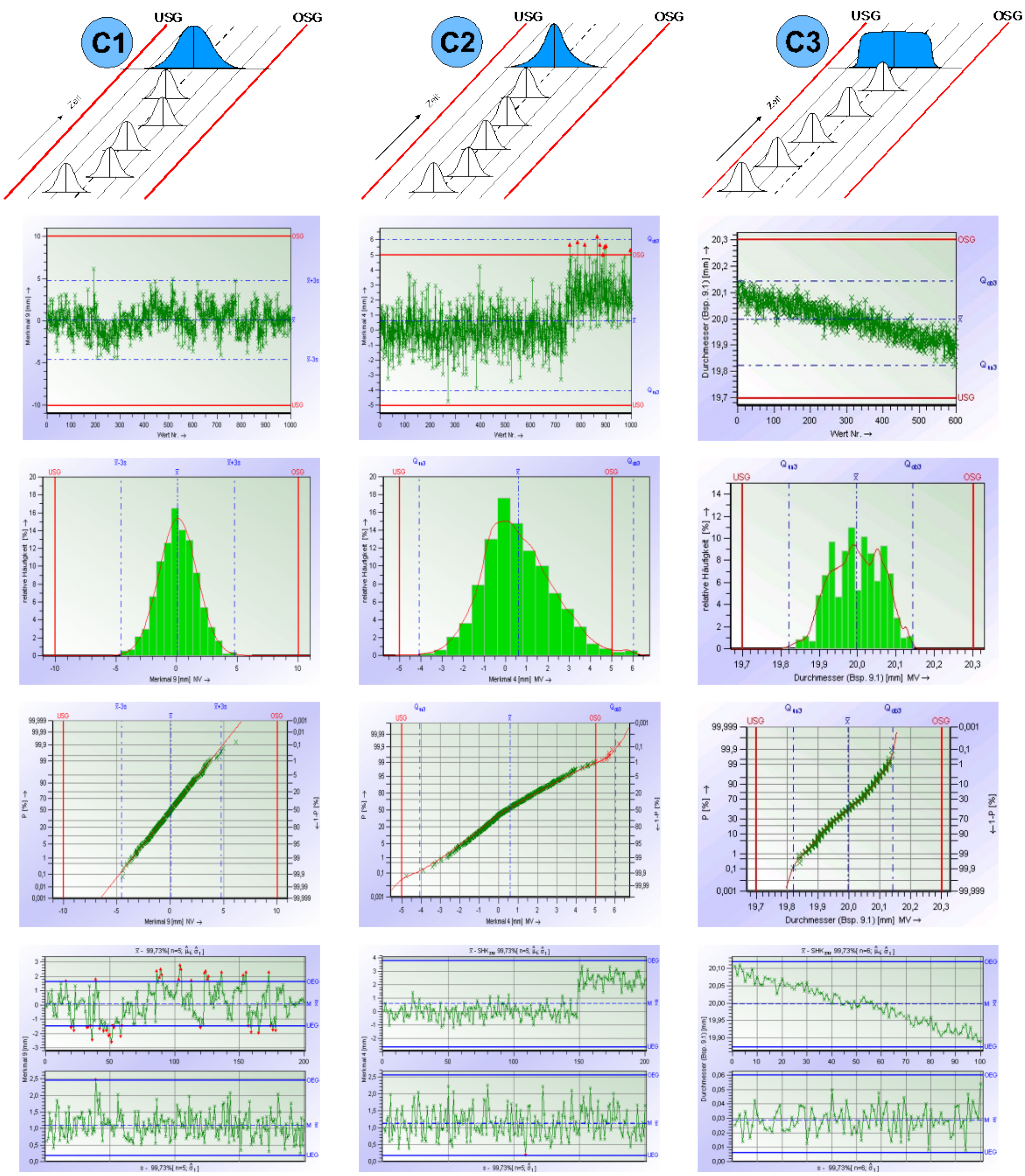
Typical distribution time models are described in DIN ISO 21747. An overview can be found on the following pages. Furthermore, this procedure is implemented in qs-STAT and can be followed for each concrete analysis as a "red path" under OPTIONS / CONFIGURATION OF ANALYSIS (OPTIONEN / KONFIGURATION AUSWERTUNG).

Distribution time model	Quality control chart	Distribution
A1	Shewhart	Normal distribution
A2	Pearson	1st/2nd type amount distribution Weibull distribution Logarithmic normal distribution
B, C1-C4, D	Shewhart (expanded)	Mixed distribution

An appropriate quality control chart is typically assigned to each distribution time model. Once the distribution time model has been assigned, the quality control chart and quality capability statistics are also known.

The identification of the distribution time model is an important step toward implementing systematic process improvements.

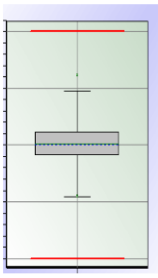

A1
A2
B
USG
OSG
Zeit
x̄/s Shewhart
x̄/s Pearson
x̄/s Shewhart erweitert
Normalvert.
x̄ =130,0392
s =0,032599
C_p = 1,79
C_{pk} = 1,42
log. NV
x̄ =0,50
s =0,36074
C_p = ---
C_{pk} = 1,93
Mischvert.
x̄ =-0,0025
s =0,88206
T_p = 1,29
T_{pk} = 1,27
Durchmesser
einseitig begrenzt
Form + Lage
Streuung zufällig



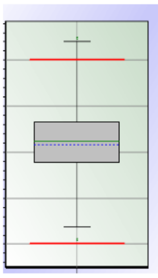
$\bar{x}$/s Shewhart erweitert

$\bar{x}$/s Shewhart erweitert

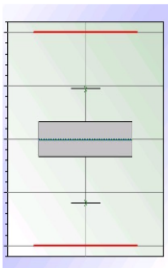
$\bar{x}$/s Shewhart erweitert



Normalvert.
$\bar{x}$ =0,0885
s =1,55818
T_p = 2,14
T_{pk} = 2,12



Mischvert.
$\bar{x}$ =0,9842
s =1,65321
T_p = 0,84
T_{pk} = 0,61

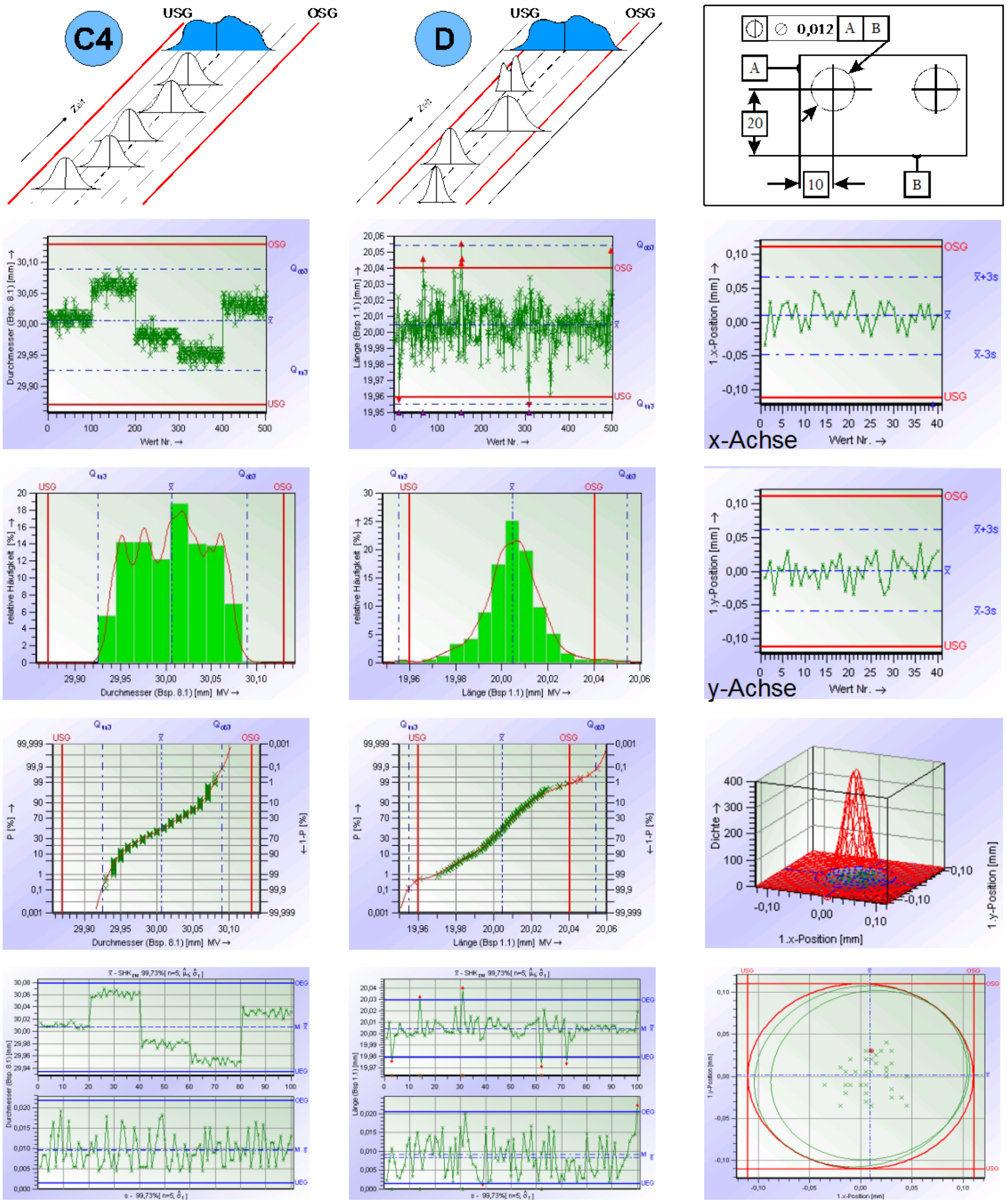


Mischvert.
$\bar{x}$ =19,9973
s =0,063738
C_p = 1,87
C_{pk} = 1,69

Lage zufällig (normalverteilt)

Lage zufällig

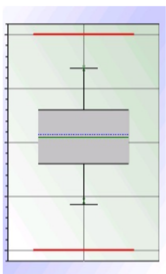
syst. Änderungen Verschleiß



x̄/s Shewhart erweitert

x̄/s Shewhart erweitert

x-y Plot



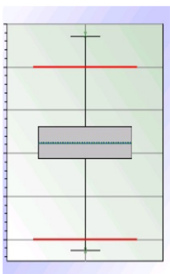
Mischvert.

$\bar{x}$ =30,00668

s =0,039701

C_p = 1,58

C_{pk} = 1,48



Mischvert.

$\bar{x}$ =20,00453

s =0,012554

T_p = 0,81

T_{pk} = 0,71

P_o = 3,24

P_{ok} = 3,15

Δx = 0,00775

Δy = 0,00887

zufällige Änderungen voreingestellte Werkzeuge

gestörter Prozess

Positionstoleranzen

C.3 Quality Control Charts

C.3.1 Process Stability

To assess the stability of a process, an (analysis) quality control chart is used. A distinction is made here between the following:

- Shewhart charts
- Pearson charts
- Shewhart charts with sliding characteristic values
- Shewhart charts with expanded limits.

For the assignment of the distribution time model and control chart, see C2. Shewhart charts with sliding characteristic values are used only in exceptional cases (destructive testing and parameter monitoring as well as checks that are high-cost and involve small lot sizes) (also see C.1.2). The assumption quality control chart can also be used.

The intervention thresholds are calculated specifically for each control chart. In principle, a non-intervention probability of $1-\alpha = 99\%$ is used for determining the intervention thresholds.

If the intervention thresholds for both the position and variation chart have not been violated, the process is considered to be stable. In the case of processes with a larger random sample size, a defined number of stability violations are permissible depending on the non-intervention probability.

How many are permitted? This question is answered with the help of the following definition of stability:

The number of intervention threshold violations on a position chart must not exceed the bilateral error band of a binomial distribution. The number of intervention threshold violations on a variation chart must not exceed the unilateral error band of a binomial distribution.

This definition applies for all position and variation charts as well as for quality control charts with sliding characteristic values. The following table contains, for various random sample sizes, the number of permissible violations on a $\bar{x}/s$ quality control chart with a non-intervention probability of 99%, separated by position and variation chart.

k random samples of size n	k = 100	k = 500	k = 1,000	k = 2,000	k = 5,000	k = 10,000	k = 100,000	k = 1,000,000
Max. no. of violations in position chart	2	4	6	10	19	32	237	2,116
Max. no. of violations in variation chart	1	3	4	6	12	19	127	1,082

If the maximum number of intervention threshold violations is exceeded, the process is considered to be unstable.

Even if the process is unstable, quality capability statistics can be calculated based on the values entered. With instability, however, this should be described not with C_p/C_{pk} as is usually the case, but with P_p/P_{pk} (performed automatically in qs-STAT). The requirements regarding the capability characteristic values should also be increased.

During continuous process monitoring, special attention should be paid to a change from "C" to "P." If this takes place frequently, appropriate measures must be taken.

C.3.2 Creating Quality Control Charts

In line with the aim, a process must be assessed with respect to position and variation. This can take place with the help of a quality control chart, which shows both parameters in the form of a "position plot" or "variation plot."

Typical parameters for the position include individual values, means and medians, while typical parameters for the variation include standard deviation and range. Combinations are also possible.

Nowadays, $\overline{x}/s$ charts with a random sample size of n = 5 are generally used.

Formulas for calculating the intervention thresholds of a mean and variation chart in accordance with Shewhart for a 99% non-intervention probability and n = 5 and for process model A1:

$$OEG_{\overline{x}} = \hat{\mu} + u_{1-\frac{\alpha}{2}} \cdot \frac{\hat{\sigma}}{\sqrt{n}} = \hat{\mu} + 2.578 \cdot \frac{\hat{\sigma}}{\sqrt{n}} \qquad OEG_s = \sqrt{\frac{\chi^2_{4;1-\frac{\alpha}{2}}}{4}} \cdot \hat{\sigma} = 1.927 \cdot \hat{\sigma}$$

$$UEG_{\overline{x}} = \hat{\mu} + u_{\frac{\alpha}{2}} \cdot \frac{\hat{\sigma}}{\sqrt{n}} = \hat{\mu} - 2.578 \cdot \frac{\hat{\sigma}}{\sqrt{n}} \qquad UEG_s = \sqrt{\frac{\chi^2_{4;\frac{\alpha}{2}}}{4}} \cdot \hat{\sigma} = 0.227 \cdot \hat{\sigma}$$

Examples of figures for calculating the estimated values for process level and variation:

k·n = 8·5 = 40 Messwerte	i = 1	i = 2	i = 3	i = 4	i = 5	i = 6	i = 7	i = 8 = k	Mittelwert über k Stichproben	Schätz-werte
j = 1	-0,35	0,30	-0,10	0,15	0,45	0,05	-0,15	0,25		
j = 2	0,30	0,05	0,45	-0,05	0,05	0,30	0,05	0,05		
j = 3	-0,20	0,25	0,25	0,15	-0,15	0,10	-0,20	0,25		
j = 4	0,25	-0,15	0,05	0,05	0,10	0,30	0,10	-0,10		
j = 5 = n	0,25	0,05	0,15	0,25	-0,20	0,20	0,00	0,10		
Mittelwert	0,05	0,10	0,16	0,11	0,05	0,19	-0,04	0,11	0,09	0,09
Varianz	0,09	0,03	0,04	0,01	0,07	0,01	0,02	0,02	0,04	
Stand.Abw.										0,19

$$OEG_{\overline{x}} = 0.09 + 2.578 \cdot \frac{0.19}{\sqrt{5}} = 0.31 \qquad OEG_s = 1.927 \cdot 0.19 = 0.37$$

$$UEG_{\overline{x}} = 0.09 - 2.578 \cdot \frac{0,19}{\sqrt{5}} = -0.13 \qquad UEG_s = 0.227 \cdot 0.19 = 0.04$$

C.3.3 Creating Quality Control Charts with Expanded Limits

Different studies have shown that most processes change over time due to a range of influencing factors (batch influence, tool wear, different machines and tools, machines with multiple spindles or workpiece carriers, etc.).

In the calculation method shown in Section C.3.2 for the intervention thresholds on the quality control chart, only the internal variation is taken into account. The aforementioned cases, however, also exhibit additional fluctuations (external variation) that are not taken into account in the calculation. This indicates that the intervention thresholds have been violated and, in turn, that the process is unstable. The process would have to be improved. This is frequently either not possible or not necessary simply for economic and, in some cases, technical reasons. For this reason, quality control charts with expanded limits were introduced. These take into account the change in mean values across the time axis.

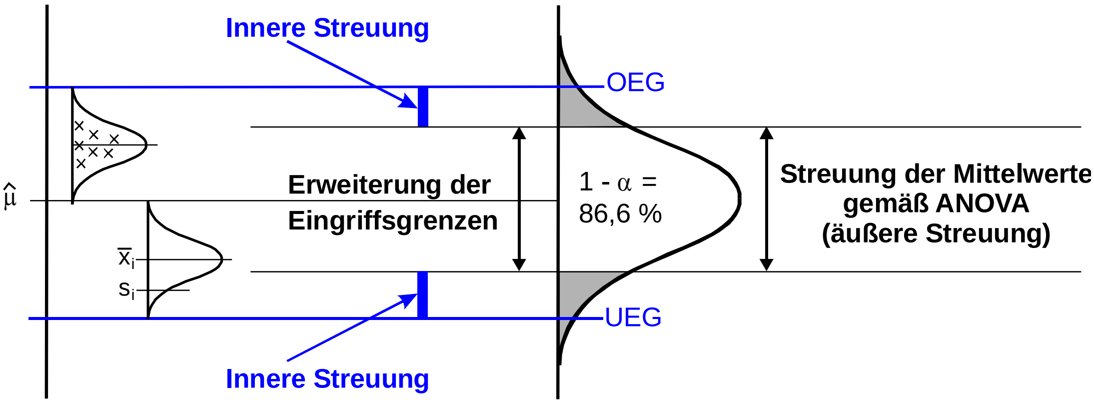
The calculation of the intervention thresholds involves two components:

- Internal variation (random sample variation; similar to C.3.2)
- External variation (variation of the mean values between the random samples)

The intervention thresholds are then calculated using the following formula:

$$\mathrm{OEG}_{\bar{x}} = \hat{\mu} + \left(2.578 \cdot \frac{\hat{\sigma}}{\sqrt{n}} + 1.5 \cdot \hat{\sigma}_A \right) \quad \mathrm{UEG}_{\bar{x}} = \hat{\mu} - \left(2.578 \cdot \frac{\hat{\sigma}}{\sqrt{n}} + 1.5 \cdot \hat{\sigma}_A \right)$$

with $\hat{\sigma}_A$ the standard deviation between the random samples calculated by means of variance analysis



C.3.4 Creating Quality Control Charts with Sliding Characteristic Values

To create a $\bar{x}$/s Shewhart chart with a random sample size of n = 1, two, three or more consecutive values are combined to form a "pseudo" random sample (n*). For this random sample, $\bar{x}$ and s can be calculated and shown in the quality control chart. This chart can also be used for monitoring process characteristics.

The intervention thresholds are calculated in a similar manner to the Shewhart chart (see C.3.2).

C.3.5 Creating Quality Control Charts with Predefined C Values

C.3.5.1 Normally Distributed Processes (Distribution Models A1 and C1)

If no data are yet available for a process, the intervention thresholds for a quality control chart cannot be calculated. In such cases, the intervention thresholds from the requirements regarding quality capability can be calculated. This procedure is possible with process models A1 and C1 only.

To calculate an estimated process variation value, the following formula is used:

$$\hat{\sigma} = \frac{\text{Tolerance}}{\text{Factor}_{\text{Cp}} \cdot \text{R}\mathit{equirement}\,\text{Cp}}$$

C_p requirement	C_p factor
1.00	6
1.33	8
1.67	10
2.00	12

The intervention thresholds are then calculated using the following formula (T_M = tolerance mean):

$$\text{OEG}_{\bar{x}} = \text{T}_M + 2.578 \cdot \frac{\hat{\sigma}}{\sqrt{\text{n}}} \qquad \text{UEG}_{\bar{x}} = \text{T}_M - 2.578 \cdot \frac{\hat{\sigma}}{\sqrt{\text{n}}}$$

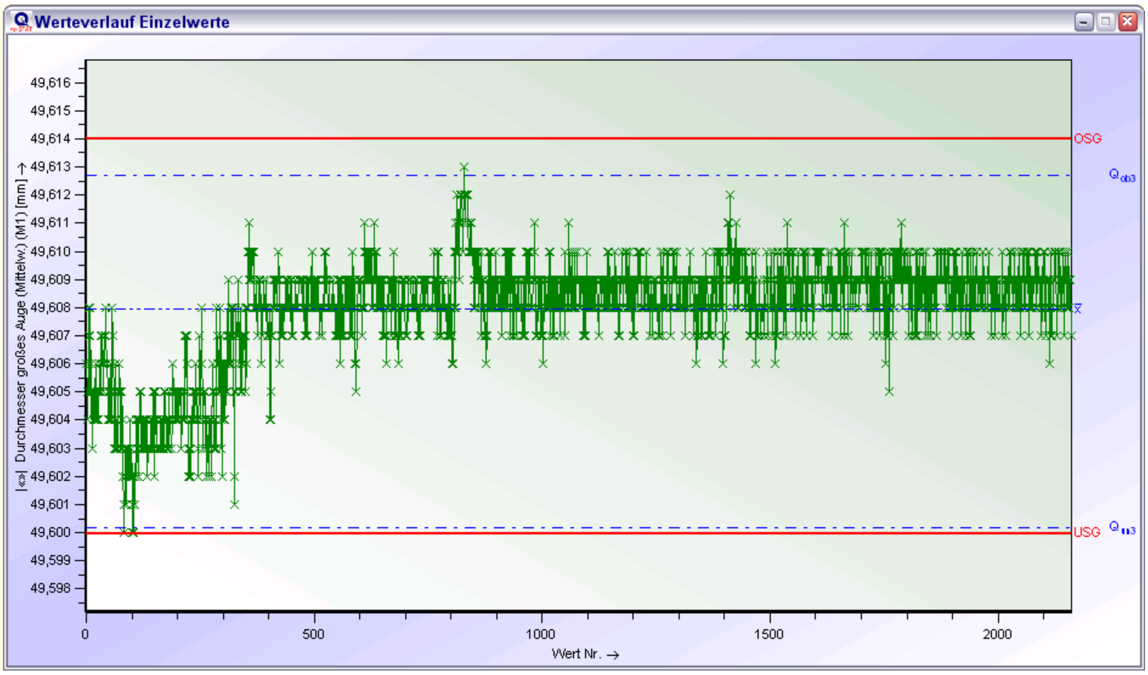
C.3.5.2 Processes with Mixed Distribution (Distribution Models C3 and C4)

For these distribution time models, the Shewhart chart with expanded limits is used as the quality control chart. It is characterized by the expression $\hat{\mu}_{zus}$, which takes into account the mean value fluctuations of the random samples.

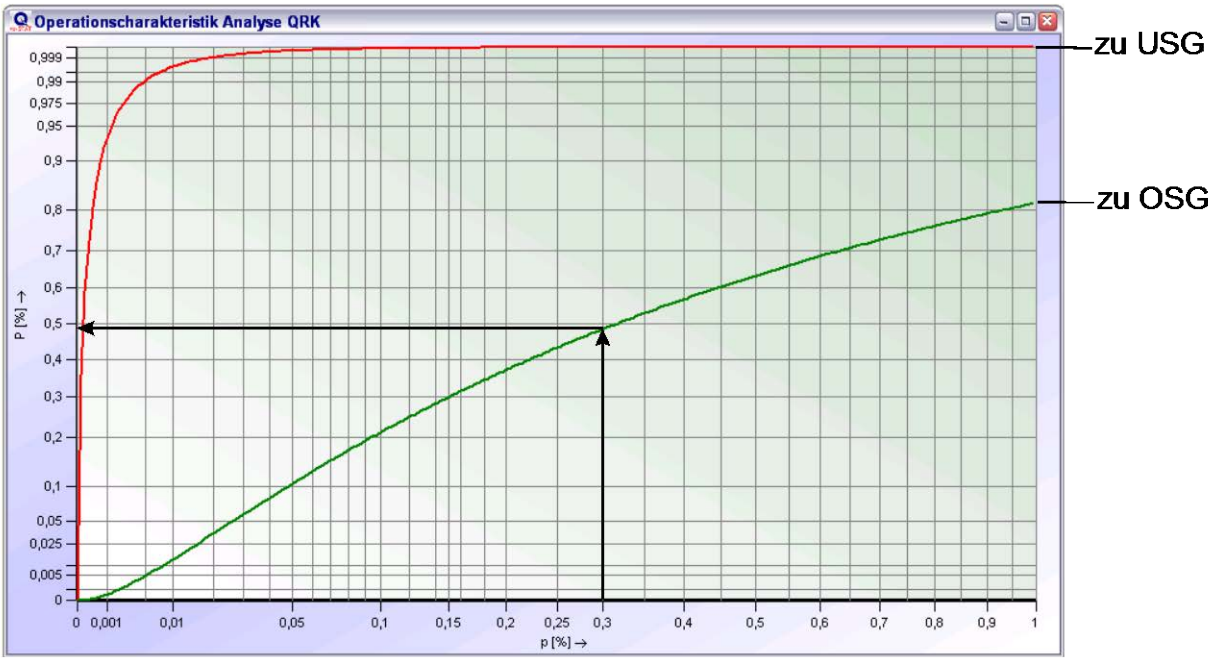
If, in contrast to the process analysis, a different C_{pk} value is to be used for a process such as this, the selected C_{pk} value can be used to calculate the $\hat{\mu}_{zus}$ and determine the new intervention thresholds.

C.3.6 Assessing Quality Control Charts

The sensitivity of a quality control chart may be assessed on the basis of the "operating characteristic curve." The following diagrams show the value pattern, quality control chart and the associated OC for a characteristic.



Note:
The s chart exhibits no variation (s = 0) with multiple random samples. This is improbable with a random sample size of n = 5, which means it can be assumed that incorrect measurements were made.



The sensitivity is a quality criterion for the use of a quality control chart and can be assessed using an operating characteristic curve (OC). Here, the error percentage is entered on the x-axis and the intervention probability on the y-axis.

If the process mean is not identical to the tolerance mean, this results in one operating characteristic curve for the upper and lower specification limit. The intervention probability for a specified error percentage may be read off on the y-axis. The question concerning the probability of discovering this item percentage with the existing quality control chart may therefore be answered. The objective shall therefore be to determine intervention thresholds which lead to the steepest possible operating characteristic curve. High sensitivity is therefore guaranteed.

The sensitivity also depends on the random sample size. This tool can be used, for example, to assess whether random sample sizes can be reduced and, if so, to what extent.

Notes regarding interpretation:

It can be seen from the aforementioned OC that, with reference to the USL (e.g. 0.3%), the probability of discovering non-conformities in the first random sample is P = 0.5%. This means that at least two random samples are required.

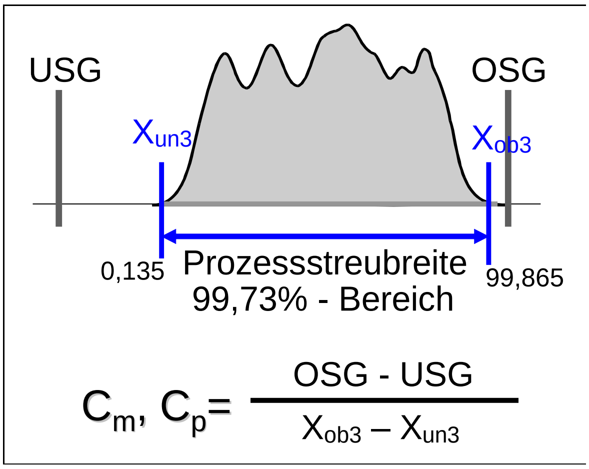
C.4 Quality Capability Statistics

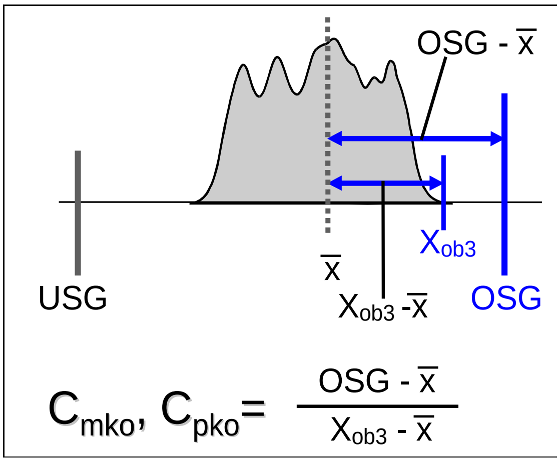
C.4.1 Quality Capability Statistics with Stability – C_p / C_{pk}

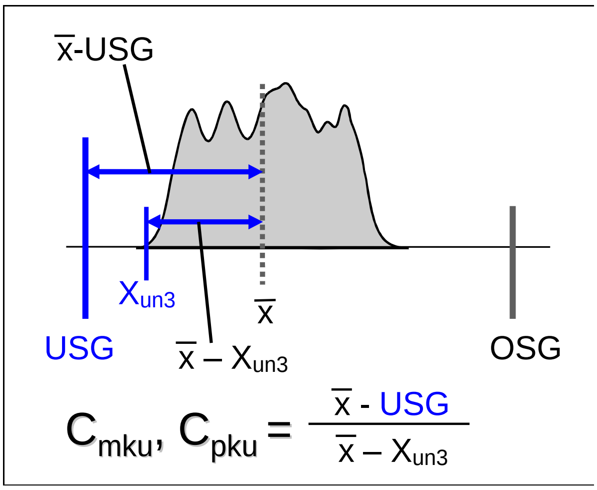
Capability indices are used for assessing quality. However, it must always be checked whether it is sensible to assign capability indices to measured characteristics.

In MBC, a distinction is made between C_m/C_{mk} (provisional process capability) and C_p/C_{pk} (process capability). The C_m (C_{mk} value) is only relevant if the machine underwent a short-term analysis (of a random sample) only. Otherwise, one talks of "process capability." The capability indices C_m/C_{mk} and C_p/C_{pk} are also used for assessing the capability of two-dimensional and three-dimensional quality characteristics (e.g. position assessment of bores and amounts of imbalance).

To assess capability, the spread is set in proportion with the tolerance width (Figure B 14). The spread is defined as the area in which 99.73% of the values are expected to lie. The capability is specified using the characteristic values based on the expected distribution time model. The 99.73% area is calculated for the relevant distribution time model. If "normal distribution" is used as the distribution time model, the 99.73% range equates to six times the standard deviation. The same formulas are used for unstable processes, although the indices are named P_p and P_{pk}. The better the theoretical distribution model describes the real-life situation, the better the capability index reflects the process behavior.







$$C_{mk}, C_{pk} = Min \{C_{pku}, C_{pko}\}$$

C.4.2 Quality Capability Statistics with Instability – P_p / P_{pk}

If the quality control chart shows no stability, a quality capability statistic can still be calculated.

This case is particularly relevant if the process is narrow in relation to the tolerance width (i.e. high key figures), but the characteristics originally forming the basis of the quality control chart calculation are no longer, or never were, present. The letter P introduced for C here shows that this process is unchanged, but the current process parameter is still calculated. This procedure is important if processes are still sufficiently capable (i.e. greater than the nominal value), but have already changed systematically due to the stability criterion not being met. The calculation is performed in the same way as for C_p/C_{pk}.

D Methods of Applied Statistics

The following pages contain an overview of the functions available in the destra® program.
<u>Note:</u>
With the introduction of the new ME10 software package, the modular structure within qs-STAT® is replaced by individual programs. The destra® program replaces the previous "Variance/Regression Analysis" module.

D.1 Hypothesis Test

Overview of the tests implemented in destra®:

	Anzahl Stich-proben	Verteilung Annahme	Test über ...		Realisierter Test	Nullhypothese	Bemerkung
diskret (Fehler)	1	Poisson Binomial	... den Erwartungs-wert		p-Test	Erwartungswert der Grundgesamtheit ist = oder = oder = einem vorgegebenen Wert	Fallzahlen-planung
	2	Poisson Binomial			p-Test	Erwartungswert der Grundgesamtheit 1 ist = oder = oder = EW der GG 2	
	>2	Poisson Binomial			Chi^2-Test	Erwartungswerte der Grundgesamtheiten sind gleich	
stetig (Messwerte)	1	normal	die Lage	Varianz bekannt	u-Test	Erwartungswert der Grundgesamtheit ist = oder = oder = einem vorgegebenen Wert	Fallzahlen-planung
				Varianz unbekannt	t-Test	Erwartungswert der Grundgesamtheit ist = oder = oder = einem vorgegebenen Wert	Fallzahlen-planung
			die Streuung		Chi^2-Test	Varianz der Grundgesamtheit ist = oder = oder = einem vorgegebenen Wert	Fallzahlen-planung
		nicht normal	die Lage		Wilcoxon	Median der Grundgesamtheit ist = oder = oder = einem vorgegebenen Wert	
	2	normal	die Lage	Stichproben verbunden	t-Test	Erwartungswert der Differenzen ist = oder = oder = 0	Fallzahlen-planung
				Varianz bekannt	u-Test	Erwartungswert der Grundgesamtheit 1 ist = oder = oder = EW der GG 2	Fallzahlen-planung
				Varianz unbekannt	t-Test	Erwartungswert der Grundgesamtheit 1 ist = oder = oder = EW der GG 2	Fallzahlen-planung
			die Streuung		F-Test	Varianz der Grundgesamtheit 1 ist = oder = oder = Varianz der GG 2	Fallzahlen-planung
		nicht normal	die Lage	Stichproben verbunden	NN	Median der Differenzen ist = oder = oder = 0	
				Stichproben unabhängig	U-Test	Median der Grundgesamtheit 1 ist = oder = oder = Median der GG 2	
			die Streuung		Rang-Dispersion	Streuung der Grundgesamtheit 1 ist = oder = oder = Streuung der GG 2	
	>2	normal	die Lage		einf ANOVA	Erwartungswerte der Grundgesamtheiten sind gleich	
			die Streuung		Bartlett	Varianzen der Grundgesamtheiten sind gleich	
		nicht normal	die Lage		H Kruskal Wallis	Lageparameter der Grundgesamtheiten sind gleich	
			die Streuung		Levene	Streuungsparameter der Grundgesamt-heiten sind gleich	

A detailed case study for the circled t test (O) is provided on the next few pages.
Practical example:

Zweistichproben t-Test 1/7

Ziel:
In diesem Fallbeispiel soll zunächst gezeigt werden, wie statistische Tests durchgeführt werden und anschließend, wie speziell ein Zweistichproben t-Test durchgeführt wird. Die Ergebnisse eines Zweistichproben t-Tests werden ausführlich vorgestellt.

Nach der Durcharbeitung der Fallstudie können Sie selbständig einen Zweistichproben t-Test durchführen und – bei entsprechenden Vorkenntnissen – auch andere statistische Tests.

Schwerpunkte:

- ☑ *Durchführung von statistischen Tests*
- ☑ *Anwendung am Beispiel des Zweistichproben t-Tests*

Vorkenntnisse:

- ☑ *Grundlagen Statistische Tests*

Wichtig:
Um die beschriebenen Funktionalitäten zur Verfügung zu haben, wählen Sie bitte das Programmmodul `Verfahren` (Menübefehl: `Modul|Regressions-/Varianzanalyse`).

MODUL|
REGRESSIONS-/
VARIANZANALYSE

Ausgangssituation:
Bei einem Schweißprozess soll ein neues Schweißverfahren eingeführt werden. Das neue Schweißverfahren soll mit dem alten Verfahren anhand einer Stichprobe von jeweils 10 geschweißten Teilen verglichen werden. Es soll untersucht werden, ob sich die Zugfestigkeit [kN] der Schweißverbindungen durch das neue Verfahren signifikant verbessert hat.

Die Werte der Stichprobe sind in folgender Tabelle zusammengefasst:

Hinweis:
Die Daten finden Sie auch in der Datei ZUGFESTIGKEIT.DFQ

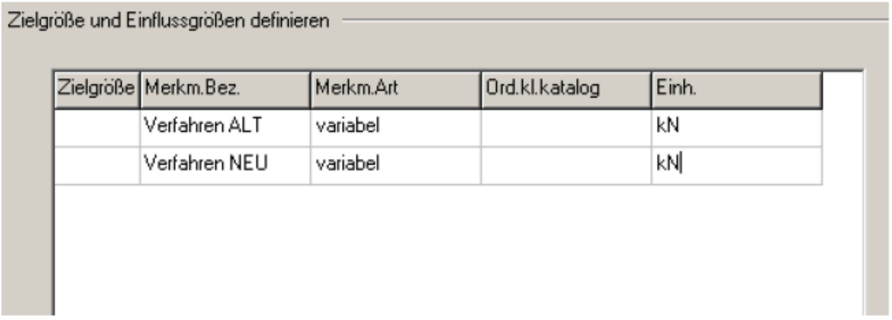
altes Verfahren	neues Verfahren
2.6	2.1
2.0	2.9
1.9	2.4
1.7	2.5
2.1	2.5
2.2	2.8
1.4	1.9
2.4	2.7
2.0	2.7
1.6	2.3

2/7 Zweistichproben t-Test

Aufgabe:
Die erhobenen Daten sollen mittels eines Zweistichproben t-Tests verglichen auf einen signifikanten Unterschied der Zugfestigkeit untersucht werden.

Vorgehensweise:

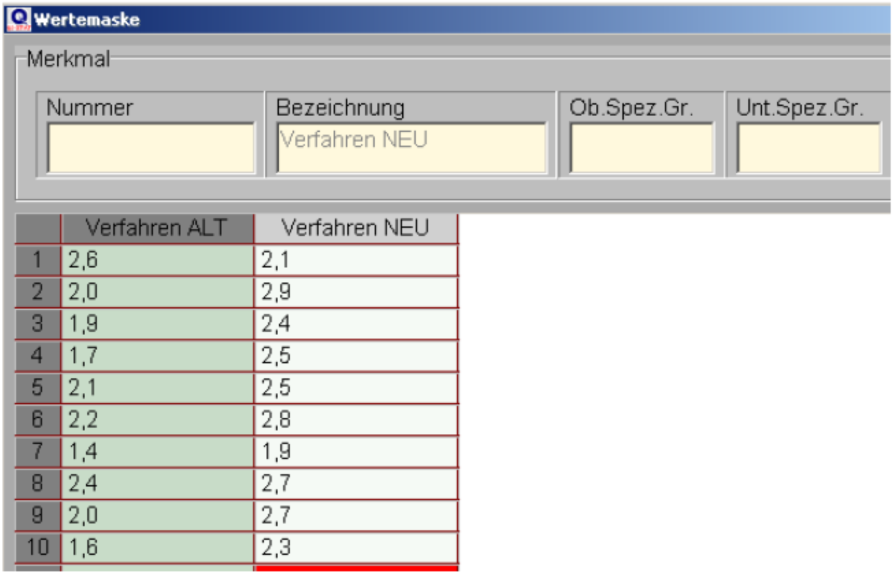
1. Wählen Sie den Menübefehl `Datei|Neu` und legen Sie im Fenster `neues Merkmal anlegen` … zwei neue Merkmale wie folgt an:



Zielgröße und Einflussgrößen definieren

Zielgröße	Merkm.Bez.	Merkm.Art	Ord.kl.katalog	Einh.
	Verfahren ALT	variabel		kN
	Verfahren NEU	variabel		kN

2. Durch eine Bestätigung mit `OK` gelangen Sie in die Wertemaske, wo Sie die Werte der Zugfestigkeit des alten und neuen Verfahrens eingeben können.



Wertemaske

Merkmal

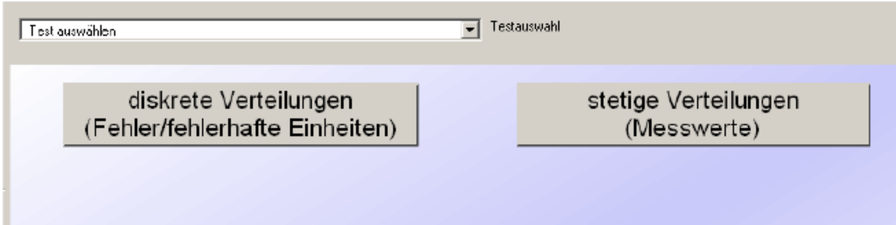
Nummer	Bezeichnung	Ob.Spez.Gr.	Unt.Spez.Gr.
	Verfahren NEU		

	Verfahren ALT	Verfahren NEU
1	2,6	2,1
2	2,0	2,9
3	1,9	2,4
4	1,7	2,5
5	2,1	2,5
6	2,2	2,8
7	1,4	1,9
8	2,4	2,7
9	2,0	2,7
10	1,6	2,3

ANALYSE / VERFAHREN | TESTVERFAHREN

3. Wählen Sie nun im Menü ANALYSE / VERFAHREN die TESTVERFAHREN aus. Dadurch gelangen Sie in das folgende Auswahlmenü:

Zweistichproben t-Test



AUSWAHLMENÜ / TEST AUSWÄHLEN

Grundsätzlich besteht die Möglichkeit über das Auswahlmenü `Testauswahl` den gewünschten Test – sofern er bekannt ist – direkt auszuwählen.

Hier wollen wir aber die zweite Möglichkeit der Testauswahl verwenden, die auf einfachen Entscheidungen auf der Basis grundlegender Statistikkenntnisse beruht.

Zunächst muss entschieden werden, ob es sich um diskrete oder stetige Verteilungen handelt. Da es sich bei der Zugfestigkeit um Messwerte handelt, wird `(1) stetige Verteilungen` gewählt.

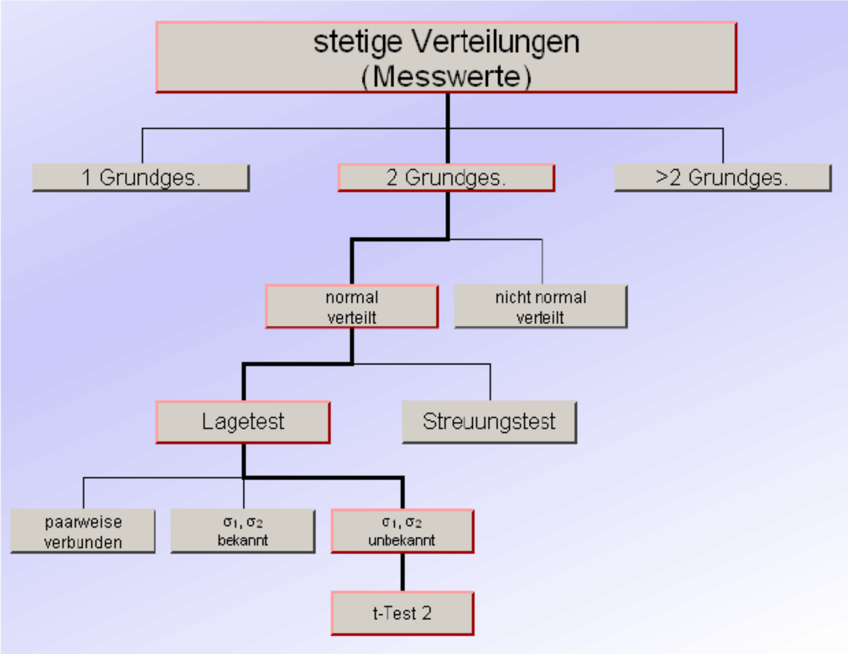
Danach muss entschieden werden, wie viele Grundgesamtheiten untersucht werden sollen. Im vorliegenden Fall: `(2) 2 Grundges..`

Wir legen des Weiteren fest, dass die Merkmale `(3) normal verteilt` sind und dass es sich um einen `(4) Lagetest` handelt.

Im Beispiel ist (5) σ_1 und σ_2 unbekannt, so dass der Zweistichproben t-Test ausgewählt (`(6) t-Test 2`) wird.

Den Auswahlbaum der Entscheidungen sehen Sie in der nächsten Abbildung.

4/7 Zweistichproben t-Test



4. Durch den Klick auf `t-Test 2` oder auf `Weiter` gelangen Sie in das Register `Daten` zur Auswahl der Merkmale. Im Beispiel liegen nur zwei Merkmale vor, die automatisch angewählt sind.

Auswahl | Daten | Planung | Testen

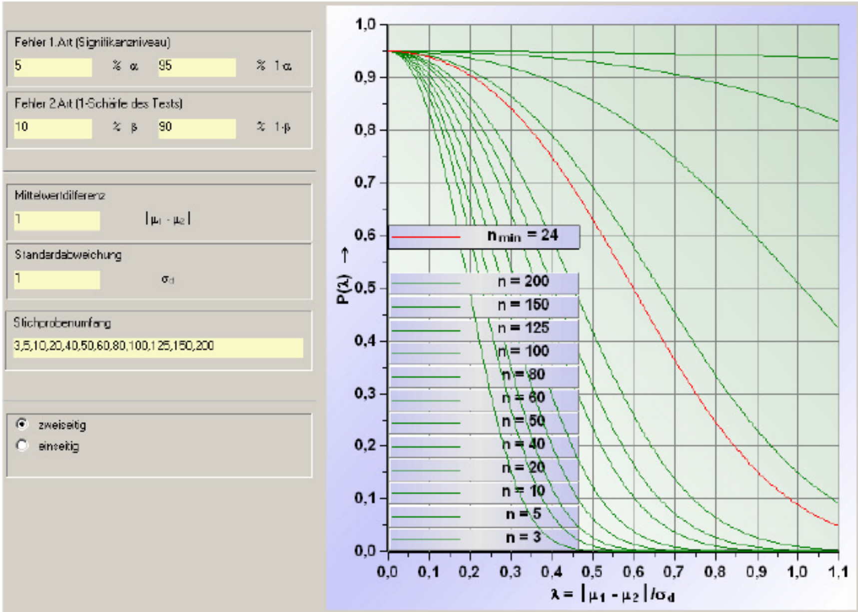
GG	aktiv	Bezeichnung	n
1	X	Verfahren ALT	10
2	X	Verfahren NEU	10

Exkurs:

Das folgende Register `Planung` wird zwar für das Beispiel nicht benötigt; dennoch soll kurz dessen Funktionen erläutert werden.

Grundsätzlich kann in diesem Register der Stichprobenumfang für einen Test ermittelt werden. Dazu müssen einige Vorkenntnisse vorhanden sein und einige Annahmen getroffen werden.

Zweistichproben t-Test 5/7



Annahmen:
Der Fehler 1. Art (α) gibt die Wahrscheinlichkeit an, die Nullhypothese fälschlicherweise abzulehnen. Der Fehler 2. Art (β) gibt die Wahrscheinlichkeit an, die Alternativhypothese fälschlicherweise nicht zu verwenden.

Vorgaben:
Für die Bestimmung des Stichprobenumfangs muss festgelegt werden, welche `Mittelwertdifferenz` durch den Test gesichert (signifikant) erkannt werden soll. Dafür ist natürlich auch die Information über die `Standardabweichung` notwendig.
Im Datenfeld `Stichprobenumfang` werden die, in der rechten Abbildung dargestellten Stichprobenumfänge, eingegeben. Des Weiteren kann festgelegt werden, ob der Test einseitig oder zweiseitig durchgeführt werden soll.

5. Im Register `Testen` wird das Testergebnis mit weiteren Informationen dargestellt.

Die Ausgabe der Testergebnisse soll anhand dreier Bereiche im Ausgabefenster erläutert werden. Zunächst die zentralen Testergebnisse:

6/7 **Zweistichproben t-Test**

Vergleich der Erwartungswerte von zwei Normalverteilungen (Varianzen der Grundgesamtheiten sind unbekannt)							
t-Test 2							
Verfahren ALT				Verfahren NEU			
$\overline{x}$	1,99	n_{eff}	10	$\overline{x}$	2,48	n_{eff}	10
s	0,36347	s^2	0,13211	s	0,31552	s^2	0,099556
H_0	Die Erwartungswerte der Grundgesamtheiten sind gleich						
H_1	Die Erwartungswerte der Grundgesamtheiten sind NICHT gleich						

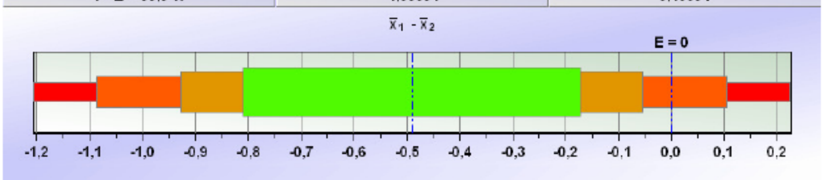
Testniveau	kritische Werte unten	kritische Werte oben	Prüfgröße
$\alpha = 5$ %	---	2,10	$\dfrac{\lvert\overline{x}_1 - \overline{x}_2\rvert}{\sqrt{\dfrac{(n_1-1)s^2_1+(n_2-1)s^2_2}{n_1+n_2-2}\,\dfrac{n_1+n_2}{n_1 n_2}}}$ 3,21932**
$\alpha = 1$ %	---	2,88	
$\alpha = 0{,}1$ %	---	3,92	
Testergebnis: Nullhypothese wird zum Niveau $\alpha \le 1\%$ verworfen			
P-Wert	0,47560 %		

Ganz oben auf der Ergebnissausgabe steht eine kurze Testbeschreibung und im Anschluss die statistischen Kennwerte der beiden Stichproben. Danach folgt die Definition der Nullhypothese (H_0) und der Alternativhypothese (H_1).

Im Anschluss finden Sie rechts die Prüfgröße (Teststatistik) mit der entsprechenden Formel. Links gegenüber sind in einer Tabelle die Testniveaus (α-Niveaus) mit den dazugehörigen kritischen Werten dargestellt. Direkt darunter findet sich das Testergebnis als Aussage, ob die Nullhypothese verworfen oder angenommen wird.

Im vorliegenden Fall wird die Nullhypothese zum Niveau von $\alpha \le 1\%$ verworfen, d.h. der Fehler 1. Art ist kleiner als 1 %. Der genaue Wert ist im Anschluss als P-Wert (0,4756 %) zu erkennen.

Vertrauensniveau	Vertrauensgrenze unten	Vertrauensgrenze oben
$1 - \alpha = 95$ %	-0,80977	-0,17023
$1 - \alpha = 99$ %	-0,92812	-0,051884
$1 - \alpha = 99{,}9$ %	-1,08691	0,10691

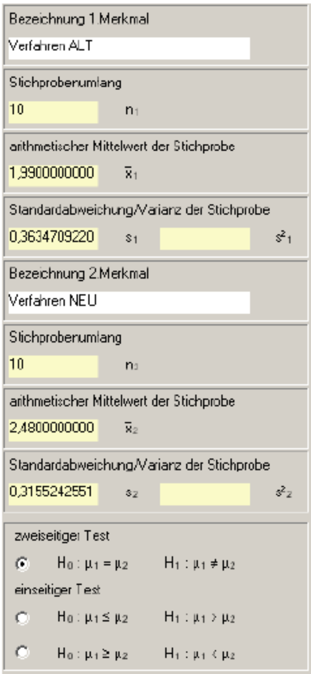


Der untere Bereich der Ausgabe stellt den Vertrauensbereich des getesteten statistischen Kennwerts dar. Für den Zweistichproben t-Test ist dies die Mittelwertdifferenz ($\overline{x}_1 - \overline{x}_2$). Der innere Bereich (grüne Far-

Zweistichproben t-Test 7/7

be) stellt den 95%-igen Vertrauensbereich dar. Anschließend folgt der 99%-ige und der 99,9%-ige Vertrauensbereich. Die Abbildung zeigt, dass die Nullhypothese (E=0) außerhalb des 99%igen Vertrauensbereichs liegt.

Oberhalb der Grafik sind in Tabellenform die verschiedenen Niveaus mit den entsprechenden Intervallgrenzen aufgeführt.



Auf der linken Seite des Ausgaberegisters Testen werden die Bezeichnungen und die statistischen Kennwerte für den Test angegeben.

Es besteht die Möglichkeit diesen Test auch anhand von Kennwerten durchzuführen, die direkt in die entsprechenden Felder eingegeben werden.

Zusätzlich kann auch festgelegt werden, ob der Test einseitig oder zweiseitig durchgeführt wird.

D.2 Regression Analysis

Mehrfache Lineare Regression 1/9

Ziel:
In diesem Fallbeispiel soll die Durchführung einer mehrfachen linearen Regressionsanalyse auf der Basis vorhandener Prozessdaten (Felddaten) beschrieben werden. Nach der Durcharbeitung der Fallstudie können Sie selbständig solche Regressionsanalysen durchführen und können die Ergebnisse anhand verschiedener Kenngrößen und Grafiken beurteilen.

Schwerpunkte:

☑ *Durchführen einer Regressions-analyse*

Vorkenntnisse:

☑ *Grundlagen der Regression*

Wichtig:
Um die beschriebenen Funktionalitäten zur Verfügung zu haben, wählen Sie bitte das Programmmodul `Verfahren` (Menübefehl: `Modul|Regressions-/Varianzanalyse`).

MODUL| REGRESSIONS-VARIANZANALYSE

Ausgangssituation:
Ammoniumsulfat wird in Säcke gefüllt. Dabei treten häufig Verklumpungen auf, die die Füllanlage blockieren. Die Beobachtung (Messung) möglicher Ursachen soll Hinweise geben, von welchen Einflussgrößen die Zielgröße Durchflussrate der Füllanlage abhängt. Folgende potentielle Einflussgrößen wurden untersucht:

x1 = Feuchte des Ammoniumsulfats (in 0,01%),
x2 = Verhältnis Länge/Breite der Kristalle und
x3 = Verunreinigung des Ammoniumsulfats (in 0,01%)

Insgesamt wurden 48 Datensätze erhoben.

Hinweis:
Die Daten finden Sie in der Datei DURCHFLUSSREG.DFQ

Alternativ legen Sie die Datei mit der Datentabelle am Ende dieses Beispiels an

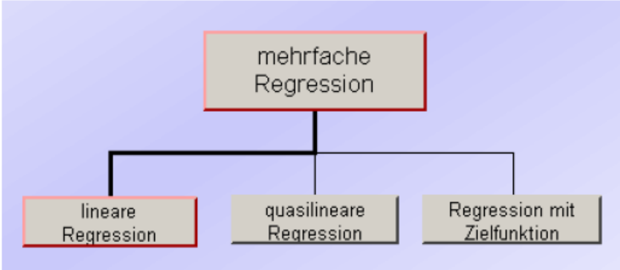
Aufgabe:
Die erhobenen Daten sollen mittels einer mehrfachen linearen Regressionsanalyse untersucht werden, um die Bedeutung der einzelnen Einflussgrößen zu bestimmen.

Vorgehensweise:

1. Wählen Sie den Menübefehl `Datei|Öffnen` und öffnen Sie die Datei DURCHFLUSSREG.DFQ
2. Wählen Sie im Menü ANALYSE / VERFAHREN die REGRESSIONSANALYSE aus und markieren Sie MEHRFACHE REGRESSION / LINEARE REGRESSION.

REGRESSIONSANALYSE

2/9 Mehrfache Lineare Regression



Icon `Weiter`

3. Durch einen Mausklick auf „lineare Regression“ oder auf das Icon `Weiter` gelangen Sie in ein Auswahlmenü. Hier müssen Sie die Zielgröße und die Einflussgrößen durch Mausklick „ankreuzen“.

Auswahl | Daten

MM-Nr.	Merkmal	n	a,b,...!!!	Einflussg	Zielgr.
	Durchfluss	48	37		X
	Feuchte	48	20	X	
	Länge zu Breite Verhältnis	48	16	X	
	Verunreinigung	48	12	X	

Die Interpretation der Ergebnisse wird im Folgenden besprochen. Dabei wird im Fallbeispiel nur auf die wichtigsten Sachverhalte eingegangen.

Koeffizienten

Parameterschätzung

Die ersten Ergebnisse sind die Schätzungen für die Regressionskoeffizienten.

B = 57,493% B* = 54,595%

Merl	Merkm.Bez.	x_i	b_i	b_i	s_{ci}	$\lvert t_i \rvert$	$\lvert t_i \rvert$	VIF
	Durchfluss	$f(x_1..x_3)$						
		Konst.	6,737	5,393...8,081	0,667	10,101*		
	Feuchte	x_1	-0,048	-0,1052...0,0076	0,0280	1,745		2,244
	Länge zu Breite Verl	x_2	-0,569	-1,079... -0,059	0,253	2,248*		1,114
	Verunreinigung	x_3	-0,165	-0,268... -0,063	0,0509	3,253**		2,085

Das Bestimmtheitsmaß ist mit B=57,493% nicht sehr hoch. Es gibt an, wie gut die Streuung der Zielgröße durch die Einflussgrößen erklärt werden kann.

Mehrfache Lineare Regression 3/9

Nach den Bezeichnungen der Ziel- und Einflussgrößen werden die Regressionskoeffizienten und deren Vertrauensbereiche (b_i) ausgegeben. Für die Beurteilung der Koeffizienten wird deren Standardabweichung (s_{ci}) und die t-Statistik ausgegeben. Die Balkengrafik zeigt analog den t-Werten, ob die Wirkung der Einflussgröße signifikant ist. Zusätzlich werden die VIF-Werte als Maße für die gegenseitige Abhängigkeit der einzelnen Einflussgrößen ausgegeben.

Interpretation:
Die Einflussgrößen erklären die Streuung vom Durchfluss nur zu 57,5 %. Somit wurden wichtige Effekte außer Acht gelassen.
Die Verunreinigung ist die wichtigste Einflussgröße, gefolgt von dem Verhältnis Länge zu Breite.

Modellbeurteilung

Die nächsten Ergebnisse dienen der Beurteilung des gesamten Regressionsansatzes. Es wird geprüft, ob grundlegende Forderungen an das Modell erfüllt sind.

Linearitäts F-Test (Test des linearen Zusammenhangs)			
H_0	Der (quasi-) lineare Regressionsansatz ist richtig		
H_1	Der (quasi-) lineare Regressionsansatz ist falsch		
Testniveau	kritische Werte unten	kritische Werte oben	Prüfgröße
$\alpha = 5$ %	---	19,47	7,38990
$\alpha = 1$ %	---	99,48	
$\alpha = 0{,}1$ %	---	999,47	
Testergebnis	Nullhypothese wird nicht widerlegt		
Test der Unabhängigkeit von allen Einflußgrössen $x_1,\ldots,x_p$			
H_0	$ß_1 = ß_2 = \ldots = ß_p = 0$		
H_1	$ß_i \neq 0$ für mindestens ein $i = 1,\ldots,p$		
Testniveau	kritische Werte unten	kritische Werte oben	Prüfgröße
$\alpha = 5$ %	---	2,82	19,8378***
$\alpha = 1$ %	---	4,26	
$\alpha = 0{,}1$ %	---	6,48	
Testergebnis	Nullhypothese wird zum Niveau $\alpha \leq 0{,}1\%$ verworfen		

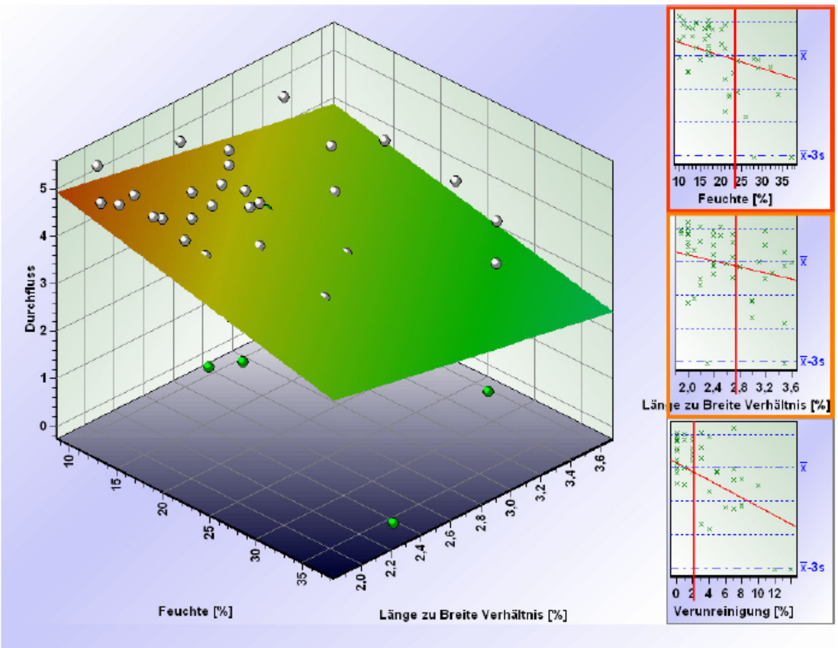
Der erste Test dient der Überprüfung des (quasi-) linearen Zusammenhangs des gewählten Ansatzes.
Der zweite Test prüft, ob die Einflussgrößen gemeinsam signifikant auf die Zielgröße wirken.

4/9 **Mehrfache Lineare Regression**

Interpretation:
Der gewählte lineare Zusammenhang für die Problemstellung kann verwendet werden. Die Hypothese des linearen Zusammenhangs wird nicht verworfen (grüne Farbe).
Der gemeinsame Einfluss aller Einflussgrößen auf die Zielgröße ist signifikant (rote Farbe). Der gewählte Regressionsansatz ist also sinnvoll.

Übersicht Funktion 3D

Eine anschauliche grafische Interpretation des Zusammenhangs ist mit Hilfe dieser grafischen Darstellung möglich. Die Grafik zeigt den Einfluss zweier Einflussgrößen auf die Zielgröße unter der Bedingung der anderen Einflussgrößen.

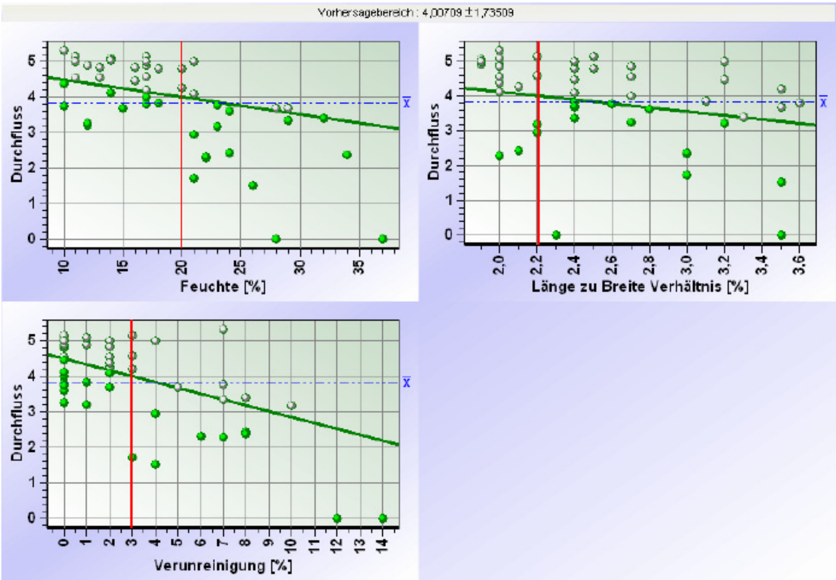


Interpretation:
Die Abbildung zeigt die Wirkung der Feuchte [%] und dem Länge zu Breite Verhältnis [%] unter der gegebenen Verunreinigung von ca. 2 %. Je nach Variation der Verunreinigung [%] ändert sich die Fläche. Bei der gewählten Einstellung ist der höchste Durchfluss oben links (rot) zu erkennen.

Mehrfache Lineare Regression 5/9

Einflussgrößen Übersicht

In der Einflussgrößen Übersicht ist erkennbar, welche Einflussgrößen wie wirken und mit welchem Prognosewert für eine vorgegebene Einstellung der Einflussgrößen zu rechnen ist.

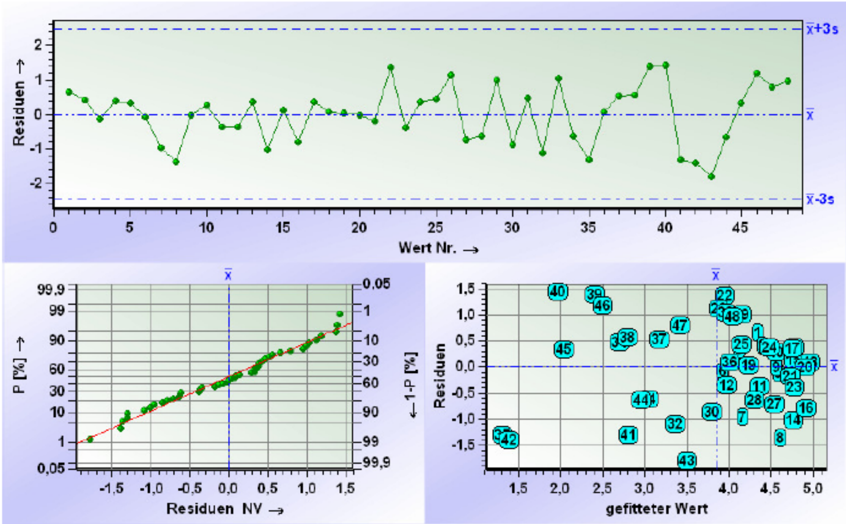


Interpretation:
Bei den gewählten Einstellungen für die Einflussgrößen (Rote Linien) ist mit einem Durchfluss von ca. 4 zu rechnen, mit einem Vorhersageintervall von ± 1,7, das die Genauigkeit der Prognose wiedergibt.

Analyse der Residuen

Anhand der Residuen (Abweichung zwischen berechnetem und gemessenem Wert für die Zielgröße) lässt sich grafisch beurteilen, ob wichtige Annahmen des Regressionsansatzes erfüllt sind.

6/9 **Mehrfache Lineare Regression**



1. Der Werteverlauf der Residuen (Abbildung oben) soll zeigen, wie sich die Residuen über die Wertenummern verhalten. Im Idealfall verlaufen die Residuen zufällig.
2. Das Wahrscheinlichkeitsnetz (Abbildung unten links) dient der Beurteilung der Annahme der Normalverteilung der Residuen.
3. Die Abbildung unten rechts stellt die Residuen und die geschätzten Werte (gefittete Werte) in einem Streuungsdiagramm gegenüber. Im Idealfall liegen diese zufällig im Koordinatensystem.

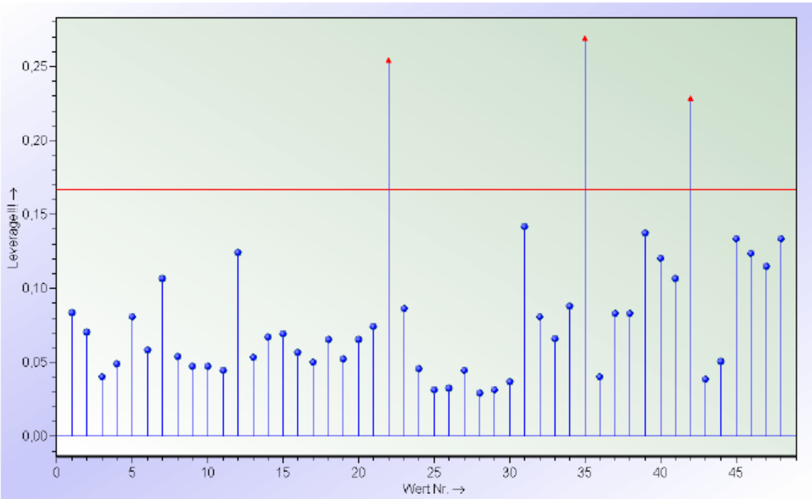
Interpretation:
Die Residuen scheinen zumindest ab dem 35-igsten Wert nicht mehr zufällig. Hier sollte z.B. geprüft werden, ob sich während der Datenerhebung etwas Besonderes ereignet hat.
Die Annahme der Normalverteilung der Residuen lässt sich anhand des Wahrscheinlichkeitsnetzes nicht widerlegen. Das Streuungsdiagramm zwischen den gefitteten Werten und den Residuen weist ebenfalls keine Besonderheiten auf.

Mehrfache Lineare Regression 7/9

Weitere grafische Beurteilungen des Modells

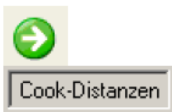
Leverage

Der Leverage gibt an, wie weit die einzelnen Werte der Einflussgrößen von ihrem Mittelpunkt (Mittelwertvektor) entfernt sind. Das Maß dient der Überprüfung, ob einzelne Wertesätze der Einflussgrößen als Ausreißer interpretiert werden können. Bei geringen Stichprobenumfängen können extreme Werte die Berechnung der Regressionskoeffizienten stark beeinflussen.



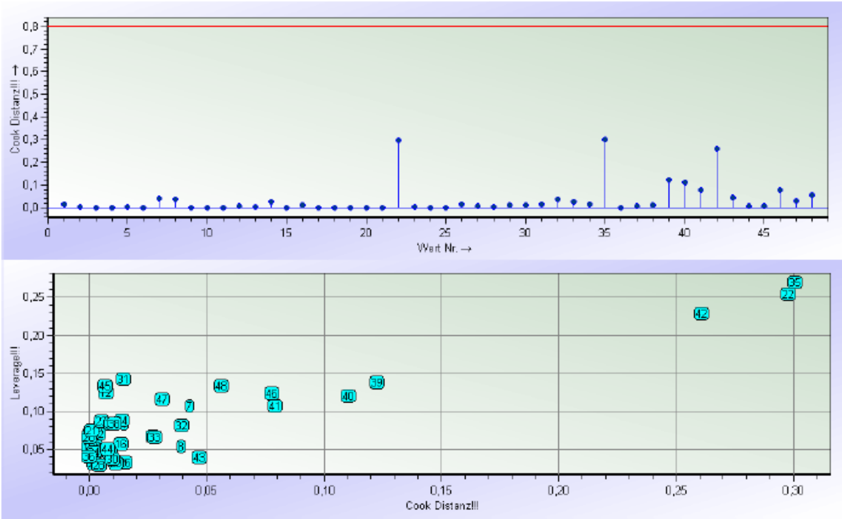
Interpretation:
Die Werte Nummer 22, 35 und 42 können als Ausreißer betrachtet werden und die Berechnungen beeinflussen. Zur Überprüfung könnte die Regression ohne diese Werte berechnet und mit dem bereits vorhandenen Ansatz verglichen werden. Dies würde im vorliegenden Fall zu einem etwas geringeren Bestimmtheitsmaß führen, die Bedeutung der Einflussgrößen würde sich aber nicht ändern.

Cook-Distanzen



Die Cook-Distanzen beurteilen die Bedeutung einzelner Datensätze für die Schätzung der Modellparameter. Geprüft wird, wie sich die Schätzung der Zielgröße ändert, wenn ein Wertesatz aus der Stichprobe entfernt wird.
Werden die Cook-Distanzen den Leverage-Werten in einem Streuungsdiagramm gegenübergestellt, wird

ersichtlich, ob bestimmte Ausreißer der Einflussgrößen für die Schätzung der Parameter verantwortlich sind.



Interpretation:
Hier sind keine Auffälligkeiten zu erkennen. Die einzelnen Cook-Distanzen sind gering.
Der extremen Ausreißer (hoher Lerverage-Wert: Datensätze 22, 35 und 42) haben eine relativ hohe Cook-Distanz und damit einen wichtigen Einfluss auf die Schätzung der Modellparameter.

Datensätze:

Nr.	Durchfluss	Feuchte	Länge zu Breite	Verunreinigung
1	5,00	21	2,40	0
2	4,81	20	2,40	0
3	4,46	16	2,40	0
4	4,81	18	2,50	0
5	4,46	16	3,20	0
6	3,85	18	3,10	1
7	3,21	12	3,20	1
8	3,25	12	2,70	0
9	4,55	13	2,70	0
10	4,85	13	2,70	0
11	4,00	17	2,70	0
12	3,62	24	2,80	0
13	5,15	11	2,50	0
14	3,76	10	2,60	0
15	4,90	17	2,00	0

Mehrfache Lineare Regression 9/9

Nr.	Durchfluss	Feuchte	Länge zu Breite	Verunreinigung
16	4,13	14	2,00	0
17	5,10	14	2,00	1
18	5,05	14	1,90	0
19	4,27	20	2,10	2
20	4,90	12	1,90	1
21	4,55	11	2,00	2
22	5,32	10	2,00	7
23	4,39	10	2,00	2
24	4,85	16	2,00	2
25	4,59	17	2,20	3
26	5,00	17	2,40	4
27	3,82	17	2,40	0
28	3,68	15	2,40	2
29	5,15	17	2,20	3
30	2,94	21	2,20	4
31	3,18	23	2,20	10
32	2,28	22	2,00	7
33	5,00	21	1,90	4
34	2,43	24	2,10	8
35	0,00	37	2,30	14
36	4,10	21	2,40	2
37	3,70	28	2,40	5
38	3,36	29	2,40	7
39	3,79	23	3,60	7
40	3,40	32	3,30	8
41	1,51	26	3,50	4
42	0,00	28	3,50	12
43	1,72	21	3,00	3
44	2,33	22	3,00	6
45	2,38	34	3,00	8
46	3,68	29	3,50	5
47	4,20	17	3,50	3
48	5,00	11	3,20	2

D.3 Design of Experiments (DOE) and Variance Analysis (ANOVA)

Q-DAS

Erstellen eines Versuchsplans 1/6

Ziel:
In diesem Fallbeispiel wird gezeigt, wie ein Versuchsplan erstellt wird. Die Auswahl und Erstellung eines Versuchsplans ist im Rahmen der Statistischen Versuchsplanung (DoE: Design of Experiments) eine wichtige Aufgabe. Sie können nach dem Durcharbeiten selbstständig verschiedene Versuchspläne erstellen.

Zuerst wird ein zweistufiger vollfaktorieller Versuchsplan erstellt und im Anschluss ein teilfaktorieller Versuchsplan.

Schwerpunkte:

☑ *Erstellung von zweistufigen faktoriellen und teilfaktoriellen Versuchsplänen*

Vorkenntnisse:

☑ *Grundlagen der Versuchsplanung*

Wichtig:
Um die beschriebenen Funktionalitäten zur Verfügung zu haben, wählen Sie bitte das Programmmodul `Verfahren` (Menübefehl: `Modul|Regressions-/Varianzanalyse`).

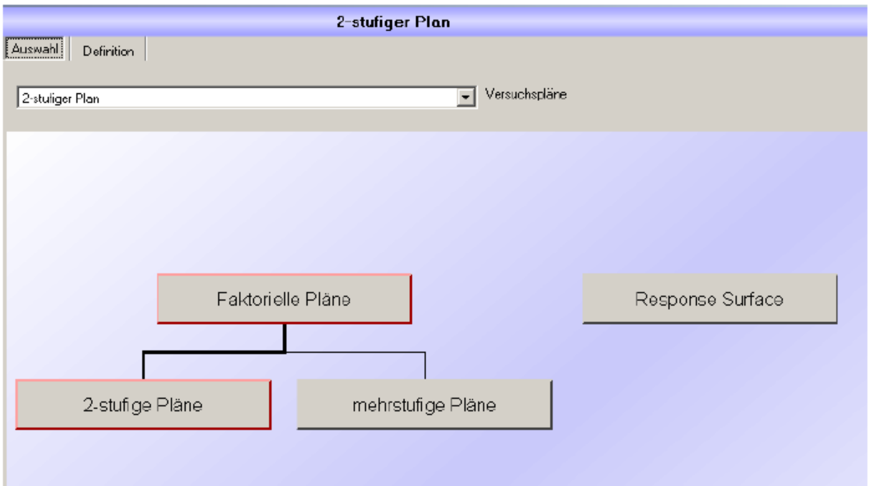
MODUL|REGRESSIONS-/VARIANZANALYSE

Ausgangssituation:
Wir betrachten die Befestigung von Stahlbolzen auf Stahlblechen mithilfe des Lichtbogenschweißverfahrens. Durch Versuche ist zu klären, welche der betrachteten vier **Einflussgrößen**, hier *Vorstrom*, *Vorstromzeit*, *Schweißstrom* und *Schweißzeit*, eine besonders starke Wirkung auf die Schweißfestigkeit haben.

Aufgabenstellung 1:
Aufgrund der verhältnismäßig kleinen Anzahl an Faktoren wird ein *vollfaktorieller zweistufiger 2^4-Plan ohne Wiederholungen* gewählt. In der zweiten Aufgabenstellung wird auf der gleichen Fragestellung ein teilfaktorieller zweistufiger Plan erstellt.

Vorgehensweise:
1. Wählen Sie den Menübefehl `Datei|Neu`. Es öffnet sich das Fenster `neues Merkmal anlegen...`
2. Klicken Sie auf die Schaltfläche `Plan erstellen.` Danach öffnet sich das nachfolgend abgebildete Fenster.

`Datei|Neu`
bzw.
`Analse/Verfahren|Versuchsplan anlegen`



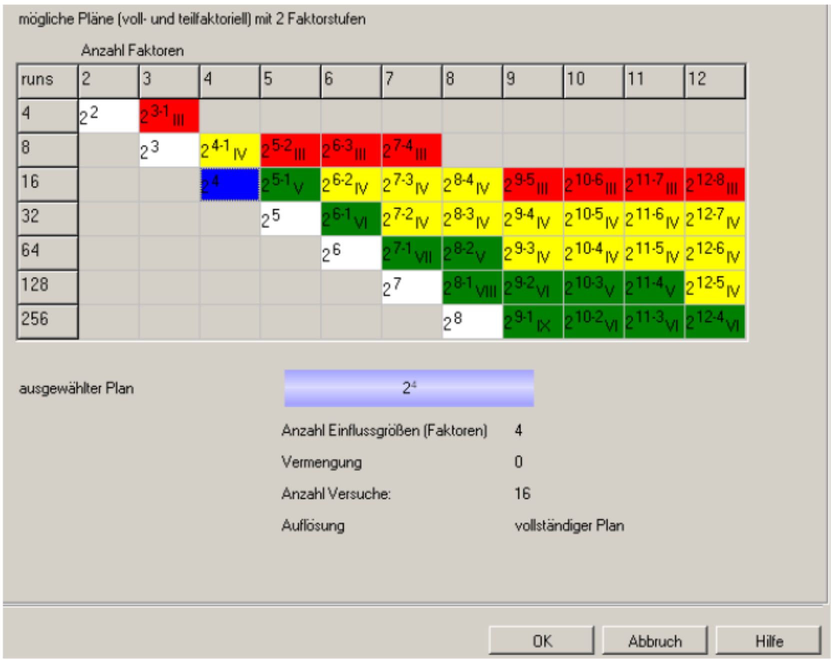
3. Dort klicken Sie zunächst auf die Schaltfläche `Faktorielle Pläne` und anschließend auf die Schaltfläche `2-stufige Pläne`.

Icon `Weiter`

4. Durch einen Mausklick auf das Icon `Weiter` gelangen Sie in das Fenster `Auswahl für faktorielle Pläne mit 2 Faktorstufen`. Hier klicken Sie auf das Feld mit dem Inhalt 2^4.

Hinweis:

Die vollfaktoriellen Versuchpläne sind weiß hinterlegt, die teilfaktoriellen farbig.



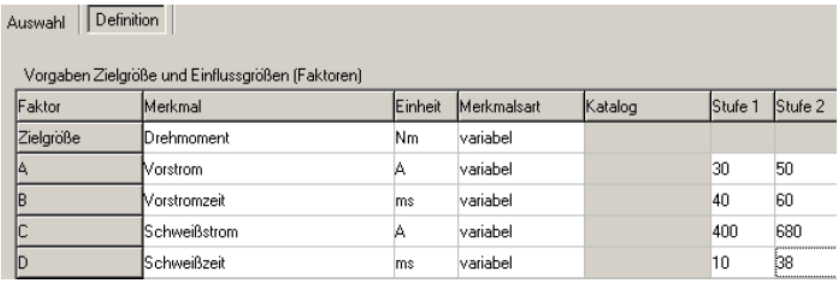
runs	2	3	4	5	6	7	8	9	10	11	12
4	2^2	2^{3-1}_{III}									
8		2^3	2^{4-1}_{IV}	2^{5-2}_{III}	2^{6-3}_{III}	2^{7-4}_{III}					
16			2^4	2^{5-1}_{V}	2^{6-2}_{IV}	2^{7-3}_{IV}	2^{8-4}_{IV}	2^{9-5}_{III}	2^{10-6}_{III}	2^{11-7}_{III}	2^{12-8}_{III}
32				2^5	2^{6-1}_{VI}	2^{7-2}_{IV}	2^{8-3}_{IV}	2^{9-4}_{IV}	2^{10-5}_{IV}	2^{11-6}_{IV}	2^{12-7}_{IV}
64					2^6	2^{7-1}_{VII}	2^{8-2}_{V}	2^{9-3}_{IV}	2^{10-4}_{IV}	2^{11-5}_{IV}	2^{12-6}_{IV}
128						2^7	2^{8-1}_{VIII}	2^{9-2}_{VI}	2^{10-3}_{V}	2^{11-4}_{V}	2^{12-5}_{IV}
256							2^8	2^{9-1}_{IX}	2^{10-2}_{VI}	2^{11-3}_{VI}	2^{12-4}_{VI}

Erstellen eines Versuchsplans 3/6

5. Das Fenster verlassen Sie mit einem Mausklick auf die Schaltfläche OK. Anschließend befinden Sie sich in dem Dialogfenster `Versuchsplanung`. Hier nehmen Sie die Eingaben für die Einflussgrößen und Zielgrößen vor (siehe nachfolgende Abbildung).

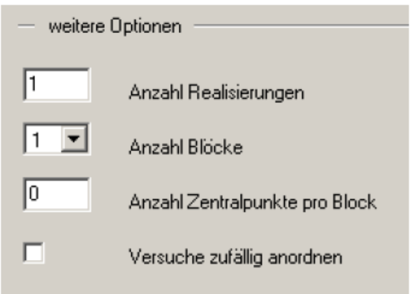
Einflussgröße	Einheit	Stufe 1	Stufe 2
Vorstrom	A	30	50
Vorstromzeit	ms	40	60
Schweißstrom	A	400	680
Schweißzeit	ms	10	38

Das Wort `Zielgröße` ersetzen Sie durch das Wort `Drehmoment` und tragen als Einheit `Nm` ein.



Faktor	Merkmal	Einheit	Merkmalsart	Katalog	Stufe 1	Stufe 2
Zielgröße	Drehmoment	Nm	variabel			
A	Vorstrom	A	variabel		30	50
B	Vorstromzeit	ms	variabel		40	60
C	Schweißstrom	A	variabel		400	680
D	Schweißzeit	ms	variabel		10	38

Unter `weitere Optionen` lassen Sie die Voreinstellungen stehen.



Hinweis:

Die Anzahl der Realisierungen gibt an, wie oft jede Versuchseinstellung durchgeführt werden soll.

6. Durch Mausklick auf das Icon `Weiter` gelangen Sie zum Vorschaufenster des Versuchsplanes.


Icon `Weiter`

4/6 Erstellen eines Versuchsplans

resultierender Versuchsplan

std. Nr.	run Nr.	A - Vorstrom	B - Vorstromzeit	C - Schweißstrom	D - Schweißzeit
1	1	30	40	400	10
2	2	50	40	400	10
3	3	30	60	400	10
4	4	50	60	400	10
5	5	30	40	680	10
6	6	50	40	680	10
7	7	30	60	680	10
8	8	50	60	680	10
9	9	30	40	400	38
10	10	50	40	400	38
11	11	30	60	400	38
12	12	50	60	400	38
13	13	30	40	680	38
14	14	50	40	680	38
15	15	30	60	680	38
16	16	50	60	680	38

Icon `Weiter`

7. Durch Klick auf das Icon `Weiter` erhalten Sie die Merkmalsmaske. Hier werden die Versuchsergebnisse eingetragen, die sich aufgrund der Versuchsanordnung ergeben. Nach der Eingabe ist der Versuchsplan für die Auswertung bereit.

Wertemaske

Merkmal

Nummer	Bezeichnung	Ob.Spez.Gr.	Unt.Spez.Gr.
	Vorstrom		

	Vorstrom	Vorstromzeit	Schweißstrom	Schweißzeit	Drehmoment
1	30,0	40,0	400,0	10,0	
2	50,0	40,0	400,0	10,0	
3	30,0	60,0	400,0	10,0	
4	50,0	60,0	400,0	10,0	
5	30,0	40,0	680,0	10,0	
6	50,0	40,0	680,0	10,0	
7	30,0	60,0	680,0	10,0	
8	50,0	60,0	680,0	10,0	
9	30,0	40,0	400,0	38,0	
10	50,0	40,0	400,0	38,0	
11	30,0	60,0	400,0	38,0	
12	50,0	60,0	400,0	38,0	
13	30,0	40,0	680,0	38,0	
14	50,0	40,0	680,0	38,0	
15	30,0	60,0	680,0	38,0	
16	50,0	60,0	680,0	38,0	

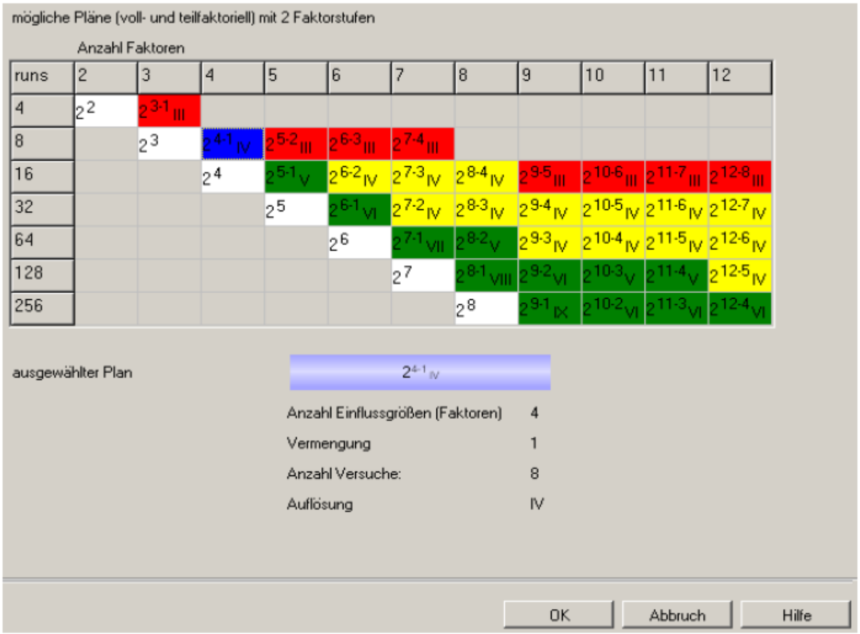
Erstellen eines Versuchsplans 5/6

Aufgabenstellung 2:
Es soll für die obige Fragestellung ein teilfaktorieller *zweistufiger 2^{4-1}-Plan mit einer Wiederholung* erstellt werden.

Vorgehensweise:
Führen Sie die Schritte 1-3 analog der ersten Aufgabenstellung durch.

4. Durch einen Mausklick auf das Icon `Weiter` gelangen Sie in das Fenster `Auswahl für faktorielle Plane mit 2 Faktorstufen`. Hier klicken Sie auf das Feld mit dem Inhalt 2^{4-1}.

Icon `Weiter`



Hinweis:

Die Auflösung der reduzierten Pläne ist farbig markiert. Je höher die Auflösung, desto bessere Eigenschaften hat der Versuchsplan. Ab der Auflösung V sind die Pläne grün markiert.

5. Das Fenster verlassen Sie mit einem Mausklick auf die Schaltfläche OK. Anschließend befinden Sie sich in dem Dialogfenster `Versuchsplanung`. Hier nehmen Sie die Eingaben für die Einflussgrößen und Zielgrößen vor (Siehe nachfolgende Abbildung).

Einflussgröße	Einheit	Stufe 1	Stufe 2
Vorstrom	A	30	50
Vorstromzeit	ms	40	60
Schweißstrom	A	400	680
Schweißzeit	ms	10	38

6/6 Erstellen eines Versuchsplans

Das Wort `Zielgröße` ersetzen Sie durch das Wort `Drehmoment` und tragen als Einheit `Nm` ein.

Hinweis:

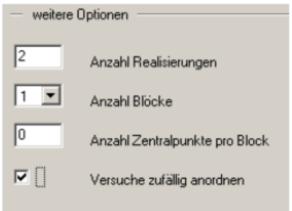
Über den Generator wird die Vermengungsstruktur des Versuchsplans berechnet.

Vorgaben Zielgröße und Einflussgrößen (Faktoren)

Faktor	Merkmal	Einheit	Merkmalsart	Katalog	Stufe 1	Stufe 2	Generator
Zielgröße	Drehmoment	Nm	variabel				
A	Vorstrom	A	variabel		30	50	
B	Vorstromzeit	mS	variabel		40	60	
C	Schweißstrom	A	variabel		400	680	
D	Schweißzeit	mS	variabel		10	38	ABC

Der Generator wird für diesen Versuchsplan auf den Faktor D gesetzt.

Unter `weitere Optionen` werden hier nun 2 Realisierungen eingeben. Zusätzlich sollen die Versuche zufällig angeordnet werden.



Icon `Weiter`

6. Durch Mausklick auf das Icon `Weiter` gelangen Sie zum Vorschaufenster des Versuchsplanes. Die Abfolge der Versuchseinstellungen ist nun zufällig.

resultierender Versuchsplan

std. Nr.	run Nr.	A - Vorstrom	B - Vorstromzeit	C - Schweißstrom	D - Schweißzeit
3	1	30	60	400	38
4	2	50	60	400	10
6	3	50	40	680	10
2	4	50	40	400	38
4	5	50	60	400	10
6	6	50	40	680	10
3	7	30	60	400	38
5	8	30	40	680	38
1	9	30	40	400	10
2	10	50	40	400	38
5	11	30	40	680	38
1	12	30	40	400	10
7	13	30	60	680	10
8	14	50	60	680	38
7	15	30	60	680	10
8	16	50	60	680	38

Icon `Weiter`

7. Durch einen Klick auf das Icon `Weiter` erhalten Sie die Merkmalsmaske. Hier werden die Versuchsergebnisse eingetragen.

Auswertung eines Versuchsplans 1/9

Ziel:
In diesem Fallbeispiel lernen Sie die grundlegenden Auswertungen eines Versuchsplans durchzuführen und zu interpretieren.

Wichtig:
Um die beschriebenen Funktionalitäten zur Verfügung zu haben, wählen Sie bitte das Programmmodul `Verfahren` (Menübefehl: `Modul|Regressions-/Varianzanalyse`).

Ausgangssituation:
Wir betrachten die Befestigung von Stahlbolzen auf Stahlblechen mithilfe des Lichtbogenschweißverfahrens. Durch Versuche ist zu klären, welche der betrachteten vier **Einflussgrößen**, hier *Vorstrom*, *Vorstromzeit*, *Schweißstrom* und *Schweißzeit*, eine besonders starke Wirkung auf die Schweißfestigkeit haben. Es wurde ein vollfaktorieller Versuchsplan aufgestellt und ohne Wiederholungen durchgeführt.

Aufgabe:
Ausgehend von einem, mit dem `Modul|Regressions-/ Varianzanalyse` erstellten Versuchsplan, soll eine grundlegende Auswertung der Versuchsdaten durchgeführt werden. Die Versuchsergebnisse finden Sie in der Datei `Lichtbogen.dfq` oder können Sie aus den nachfolgenden Informationen entnehmen.

Für die Einflussgrößen wurden nachfolgende Faktorstufen gewählt:

Einflussgröße	Einheit	Stufe 1	Stufe 2
Vorstrom	A	30	50
Vorstromzeit	ms	40	60
Schweißstrom	A	400	680
Schweißzeit	ms	10	38

Die Zielgröße ist das Drehmoment mit der Einheit Nm. Folgende Tabelle zeigt die Ergebnisse der Versuchs-

Schwerpunkte:

- ☑ *Auswertung und Interpretation von Versuchen*
- ☑ *Durchführung einer Varianzanalyse*

Vorkenntnisse:

- ☑ *Grundlagen der Versuchsplanung*

MODUL| REGRESSIONS-/ VARIANZANALYSE

2/9 Auswertung eines Versuchsplans

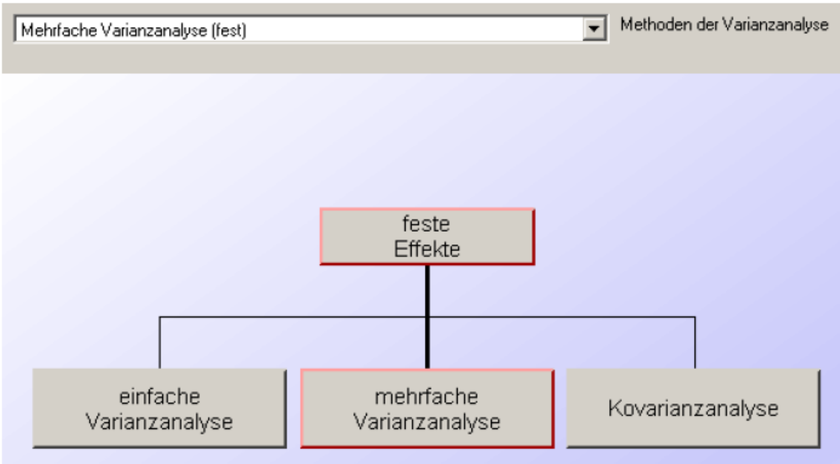
durchführungen für die jeweilige Faktoreinstellung in der letzten Spalte der Tabelle:

	Vorstrom	Vorstromzeit	Schweißstrom	Schweißzeit	Drehmoment
1	30,0	40,0	400,0	10,0	0,0
2	50,0	40,0	400,0	10,0	0,0
3	30,0	60,0	400,0	10,0	0,0
4	50,0	60,0	400,0	10,0	0,0
5	30,0	40,0	680,0	10,0	0,3
6	50,0	40,0	680,0	10,0	0,0
7	30,0	60,0	680,0	10,0	4,0
8	50,0	60,0	680,0	10,0	0,0
9	30,0	40,0	400,0	38,0	4,6
10	50,0	40,0	400,0	38,0	2,8
11	30,0	60,0	400,0	38,0	0,0
12	50,0	60,0	400,0	38,0	1,1
13	30,0	40,0	680,0	38,0	18,5
14	50,0	40,0	680,0	38,0	17,1
15	30,0	60,0	680,0	38,0	17,9
16	50,0	60,0	680,0	38,0	18,6

Vorgehensweise:

ANALYSE/VERFAHREN VERSUCHSPLAN AUSWERTEN oder VARIANZANALYSE

1. Der Auswertung des Versuchsplans erfolgt durch den Befehl `Analyse/Verfahren| Versuchsplan auswerten`. Die Software wählt automatisch die mehrfache Varianzanalyse als Auswerteverfahren, sofern der Versuchsplan mit *destra*® erstellt wurde.



Icon `Weiter`

2. Durch Klick auf das Icon `Weiter` oder auf den Begriff `mehrfache Varianzanalyse` gelangen Sie in die Merkmalsauswahl.

Auswertung eines Versuchsplans 3/9

Auswahl | Daten

MM-Nr.	Merkmal	n	Anz. Stufen	Faktor	Zielgr.
	Vorstrom	16	2	X	
	Vorstromzeit	16	2	X	
	Schweißstrom	16	2	X	
	Schweißzeit	16	2	X	
	Drehmoment	16	10		X

3. Mit einem erneuten Klick auf das Icon `Weiter` gelangen Sie in die Modellauswahl. Hier wird das geplante Versuchsmodell (vollfaktorieller Versuch) ausgewählt.

Auswahl | Daten | Modell

Zuordnung Faktor | Merkmal

A | Vorstrom
B | Vorstromzeit
C | Schweißstrom
D | Schweißzeit

Modellauswahl

Modell aus Versuchsplanung
- Vollfaktoriell

Modellfunktion

$y = \mu + a + b + c + d + ab + ac + ad + bc + bd + cd + abc + abd + acd + bcd + abcd$

Die Modellfunktion mit den Haupt- und Wechselwirkungen wird angezeigt.

4. Der nächste Klick auf das Icon `Weiter` führt die Varianzanalyse durch.

B = 100,000% B* = 0,000%

Typ III Sum of Squares

Merkr	Merkm.Bez.	x_i	SS	MS	DF	F_0	F_0	P
	Vorstrom	A	2,031	2,031	1,000	---		---
	Vorstromzeit	B	0,181	0,181	1,000	---		---
	Schweißstrom	C	288,2	288,2	1,000	---		---
	Schweißzeit	D	363,9	363,9	1,000	---		---
		AB	0,106	0,106	1,000	---		---
		AC	1,156	1,156	1,000			

In diesem Fall erkennt man die Quadratsummenzerlegung der Varianzanalyse (SS: Sums of Squares bzw. MS: Mean Sums of Squares, DF: Degrees of Freedom).
Da keine Wiederholung der Versuche durchgeführt wurde, kann die Signifikanz der einzelnen Wirkungen (Haupt- und Wechselwirkungen) nicht berechnet werden. Deshalb soll

Hinweis:
destra erkennt automatisch, welche Merkmale die Faktoren und die Zielgröße sind, vorausgesetzt, der Plan wurde mit destra erstellt.

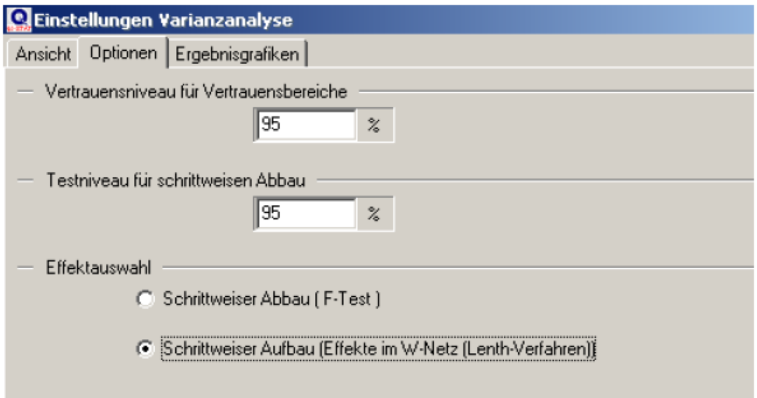
Icon `Weiter`

4/9 Auswertung eines Versuchsplans

zunächst eine Auswahl der Wirkungen über das Wahrscheinlichkeitsnetz durchgeführt werden.

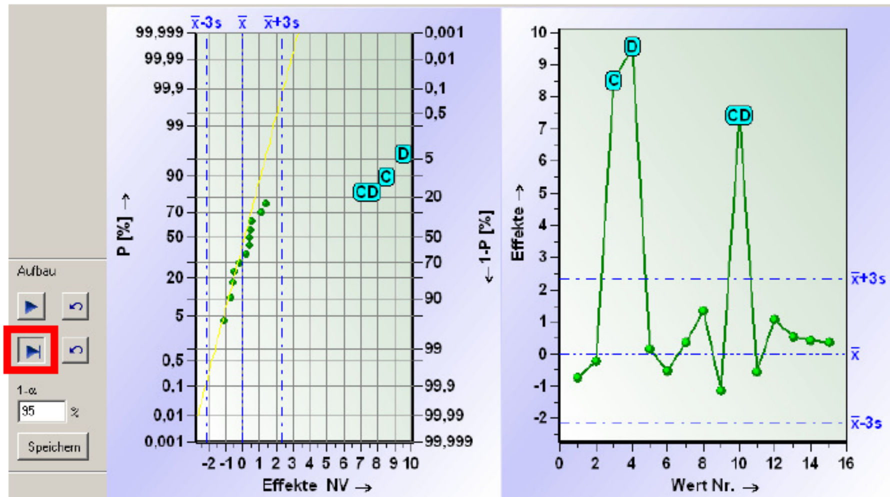
`Einstellungen`

5. Über `Einstellungen Varianzanalyse | Optionen` kann die Effektauswahl auf das sogenannte Lenth-Verfahren umgestellt werden.



Effekte im W-Netz

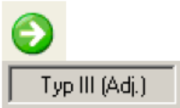
6. Nun können über den Reiter `Effekte im W-Netz` durch einen `Klick` auf den Auswahlbutton die wichtigen Effekte ausgewählt werden.



Interpretation:
Die Hauptwirkungen C (Schweißstrom) und D (Schweißzeit) sowie deren Wechselwirkung sind für die Zielgröße Drehmoment von Bedeutung. Durch deren Wirkung entsteht eine deutliche Abweichung von den anderen Versuchsergebnissen.

Auswertung eines Versuchsplans 5/9

7. Die genaue Bedeutung der Effekte kann nun im Reiter Typ III (Adj.) entnommen werden.



B = 97,208% B* = 96,510%

Typ III Sum of Squares

Merk	Merkm.Bez.	x_i	SS	MS	DF	F_0	F_0	P
	Schweißstrom	C	288,2	288,2	1,000	138,1		< 0.0001
	Schweißzeit	D	363,9	363,9	1,000	174,4		< 0.0001
		CD	219,8	219,8	1,000	105,3		< 0.0001
		Modell	871,8	290,6	3,000	139,2		< 0.0001
		Rest	25,04	2,087	12,00	---		---
		Gesamt	896,8	59,79	15,00	---		---

Interpretation:
Der Schweißstrom und die Schweißzeit sowie deren Zweifach-Wechselwirkung haben einen signifikanten Einfluss auf das Drehmoment. Der gesamte Ansatz (Modell) ist ebenfalls signifikant. Die Varianz (Streuung) des Drehmoments lässt sich zu B = 97,2% durch diese Effekte erklären.

8. Im folgenden Reiter `Modellbeurteilung` wird das gewählte Modell anhand mehrerer Kennwerte und statistischen Tests überprüft.

Korrelationskoeffizient	=	r	0,9859
Bestimmtheitsmaß	=	B	97,208%
korrigiertes Bestimmtheitsmaß	=	B*	96,510%
Restvarianz	=	s^2	25,0425
Reststandardabweichung	=	s	5,00425

Interpretation:
Mehrere Kenngrößen zur Beschreibung der Ergebnisse der Varianzanalyse werden hier zusammengefasst. Das Bestimmtheitsmaß gibt an, wie gut die Varianz des Drehmoments durch das Modell erklärt werden kann. Die nicht erklärte Streuung wird durch die Restvarianz bzw. die Reststandardabweichung ausgedrückt.

6/9 Auswertung eines Versuchsplans

Modifizierter Levene Test			
H_0	Die Varianzen aller Zellen sind gleich		
H_1	Die Varianzen aller Zellen sind NICHT gleich		
Testniveau	kritische Werte unten	kritische Werte oben	Prüfgröße
$\alpha = 5$ %	---	3,49	1,70469
$\alpha = 1$ %	---	5,93	
$\alpha = 0,1$ %	---	10,54	
Testergebnis	Nullhypothese wird nicht widerlegt		

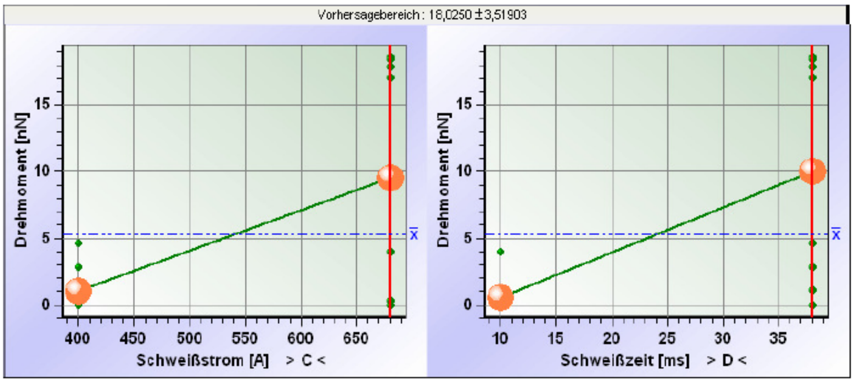
Interpretation:
Die Gleichheit der Varianzen in den verschiedenen Zellen (Faktorstufenkombinationen) ist eine. Annahme der Varianzanalyse und wird mit dem modifizierten Levene Test geprüft. In diesem Fall wird die Nullhypothese der Varianzgleichheit angenommen.

Epps-Pulley-Test			
H_0	Die Residuen stammen aus einer Normalverteilung		
H_1	Die Residuen stammen NICHT aus einer Normalverteilung		
Testniveau	kritische Werte unten	kritische Werte oben	Prüfgröße
$\alpha = 5$ %	---	0,366	0,28199
$\alpha = 1$ %	---	0,561	
$\alpha = 0,1$ %	---	---	
Testergebnis	Nullhypothese wird nicht widerlegt		

Interpretation:
Der Epps-Pully-Test prüft die Residuen auf Normalverteilung. Eine Annahme der Nullhypothese ist eine Voraussetzung für die Durchführung der Varianzanalyse.

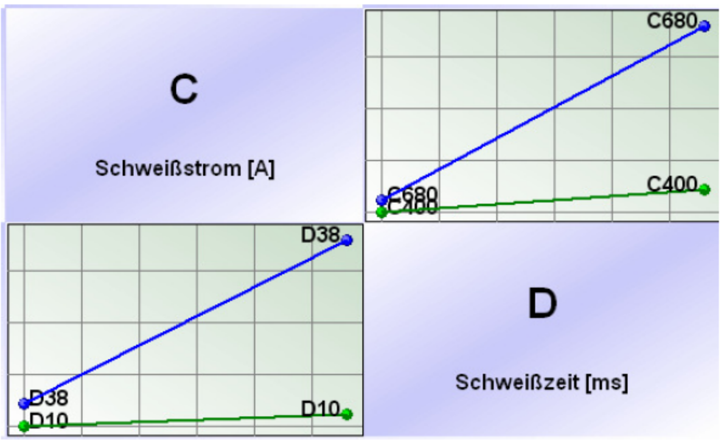
9. Über den Reiter `Hauptwirkungen` erhält man eine grafische Darstellung der betrachteten Hauptwirkungen.

Auswertung eines Versuchsplans 7/9



Interpretation:
Die kleineren grünen Punkte stellen die einzelnen Versuchsergebnisse dar, die größeren orangenen die Stufenmittelwerte. Aus den Grafiken lässt sich also ablesen, welcher Drehmomentunterschied bezogen auf einen Faktor zu erwarten ist. In der obersten Zeile ist der Vorhersagebereich, der sich für eine bestimmte Einstellung (rote Linien) ergibt.

10. Die Wechselwirkungen erhalten Sie über den Reiter `Wechselwirkungen`.



Interpretation:
Betrachten wir zunächst die Abbildung oben rechts. Hier wird der Schweißstrom (C) in Abhängigkeit der Schweißzeit (D) dargestellt. Man erkennt, dass einer geringen Schweißzeit (linke Seite der Grafik) nur ein geringer Unterschied zwischen einem Schweißstrom von 400 [A] und 680 [A] liegt. Der Unterschied bei einer langen Schweißzeit ist dagegen größer.

8/9 Auswertung eines Versuchsplans

Das höchste Drehmoment ergibt sich bei einer langen Schweißzeit (38 [ms]) und beim hohen Schweißstrom (680 [A]). Die Grafik unten links ist analog zu interpretieren. Nur dass hierbei die Schweißzeit in Abhängigkeit des Schweißstroms dargestellt ist.

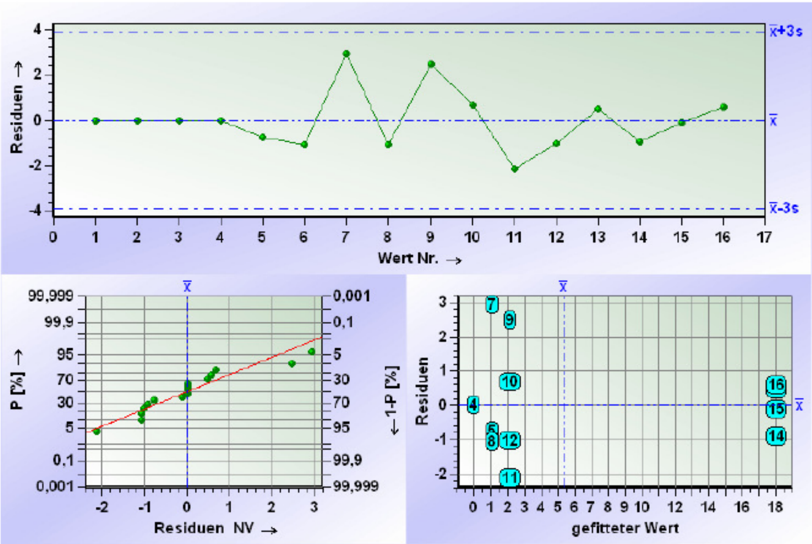
11. Die Effekte der einzelnen Faktoren sind dem Register `Effekte` zu entnehmen

Merkn	Merkm.Bez.	x_i	Stufe	b_i	s_{b_i}	t_i	$\lvert t_i \rvert$	P	E_i	$\lvert E_i \rvert$
		Gesamtmi		5,306	0,361	14,693***		< 0.0001	---	
	Schweißstrom	C	400,0	-4,244	0,361	-11,751***		< 0.0001	8,488	
	Schweißstrom	C	680,0	4,244	0,361	11,751***		< 0.0001	8,488	
	Schweißzeit	D	10,00	-4,769	0,361	-13,204***		< 0.0001	9,537	
	Schweißzeit	D	38,00	4,769	0,361	13,204***		< 0.0001	9,537	
		CD	400,0, 10,0	3,706	0,361	10,262***		< 0.0001	7,413	
		CD	400,0, 38,0	-3,706	0,361	-10,262***		< 0.0001	7,413	
		CD	680,0, 10,0	-3,706	0,361	-10,262***		< 0.0001	7,413	
		CD	680,0, 38,0	3,706	0,361	10,262***		< 0.0001	7,413	

Interpretation:
Die Effekte beziehen sich grundsätzlich auf jede Faktorstufenkombination, die untersucht wird. Es handelt sich dabei um die Abweichung einer Faktorstufenkombination vom Mittelwert unter Berücksichtigung der Streuung (Signifikanz).
Speziell bei zweistufigen Versuchsplänen sind die positiven und negativen Abweichungen symmetrisch. Deshalb werden in den letzten beiden Spalten der Tabelle (Ei und |Ei|) die gleichen Werte angezeigt. Die anderen Spalten der Darstellung beschreiben die einzelnen Faktorstufen, deren Abweichung vom Gesamtmittelwert und die entsprechenden Signifikanzen.

Auswertung eines Versuchsplans 9/9

12. Analyse der Residuen



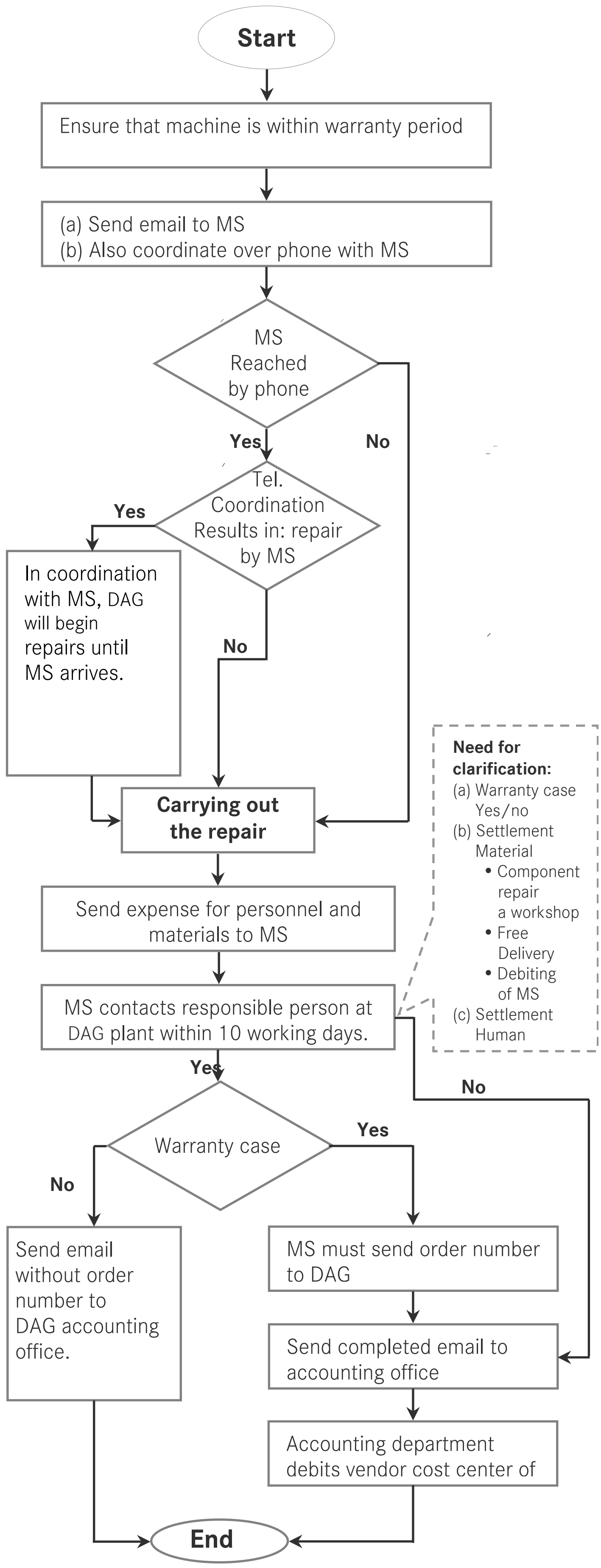
Interpretation:
Die Residuen sind die, durch das Modell nicht erklärten Abweichungen. Ihre grafische Analyse gibt Aufschluss darüber, ob die Modellannahmen (in diesem Fall der Varianzanalyse) erfüllt sind. In der oberen Grafik werden die Residuen über der Wertenummer dargestellt. Diese sollen zufällig verlaufen, also keine Struktur aufweisen. Links unten werden die Residuen im Wahrscheinlichkeitsnetz auf Normalverteilung geprüft. Die Annahme der Normalverteilung ist Voraussetzung für einige Tests im Rahmen der Varianzanalyse. Unten rechts werden die geschätzten Werte (gefittete Werte) den Residuen gegenübergestellt. Die Werte sollten in dieser Grafik zumindest näherungsweise in einen gleich breiten Band von links nach rechts auftreten.

E Terms and Abbreviations

ANOVA	Analysis of Variances	
c_m	Process performance	During acceptance of production equipment (machine capability)
c_{mk}	Process capability	
c_p	Ongoing process performance	With stable processes
c_{pk}	Ongoing process capability	
f	Degree of freedom	
k	No. of random samples	
μ	Mean value of total population	
$\hat{\mu}$	Estimated value of process level	
N	Random sample size	
o_p	Former description for X_{ob}	
UIT	**U**pper **I**ntervention **T**hreshold	
USL	**U**pper **S**pecification **L**imit	
P_p	Process performance	For processes whose stability has not yet been confirmed
P_{pk}	Process capability	
Q_{ob}	Former description as per DIN 55319 for X_{ob}	
Q_{un}	Former description as per DIN 55319 for X_{un}	
Q_{MS}	Capability characteristic value of the measuring system	
Q_{MP}	Capability characteristic value of the measurement process	
R	Range	
s	Standard deviation in the random sample	
σ	Standard deviation in the total population	
$\hat{\sigma}_A$	Standard deviation between the random samples as per ANOVA	
u_p	Former description for X_{un}	
LIT	**L**ower **I**ntervention **T**hreshold	
LSL	**L**ower **S**pecification **L**imit	
X_{ob}	Quantile of the distribution function for P = 99.865% (upper percentage point (99.865%)) as per DIN ISO 21747	
X_{un}	Quantile of the distribution function for P = 0.135% (lower percentage point (0.135%)) as per DIN ISO 21747	

F Change History

Date	Version	Chapter	Change
2007-01-01	2007 /1		Update of version number
2007-01-01	2007 /1	0.2.5	Example of adjusting the required indices added
2007-01-01	2007 /1	0.3 C.3	"Remarks" section revised Examples revised
2007-01-01	2007 /1	A.4.2, B.5.1 C.1.3.4.1, C.4.2	Correction of spelling mistakes and deletion of some statements
2008-07-01	2008 /1		Complete revision
2010-07-15	2010 /1		Update of version number (qs-STAT and LF1236)
2010-07-15	2010 /1	A.5	Pseudo machine capability examination "Max. tolerance utilization" included
2010-07-15	2010 /1	B.1.1	Detailing of requirements following tool change
2010-07-15	2010 /1	B.2.3	Information regarding possible procedure for "geometrically identical" combinations
2013-04-01	2013/1		Update of version number
2013-04-01	2013/1	A2	Availability
2013-04-01	2013/1	B3	Notes about changed software packages
2013-04-01	2013/1	B4	Calculation of measurement uncertainty using VDA5, 2nd edition
2013-04-01	2013/1	E	Terms and abbreviations using VDA5, 2nd edition



Ser. no.	Warranty settlement	Result Services/Description	Responsible
1			
2		Send filled-in form with error description, date, time and signature to machine supplier by email. Additionally, coordination by telephone must take place.	Daimler AG
3		If the machine supplier wants to carry out the repair itself, this must be coordinated with the Maintenance department. In coordination with the machine supplier, the repair will be started by the Maintenance department until the machine supplier arrives.	Machine Supplier/Daimler AG
4			
5		Send repair expense and material requirements to machine supplier.	Daimler AG
6		Machine supplier shall get in touch within 10 working days to completely clarify the occurrence with the responsible DAG employee.	Daimler AG
		If the machine supplier fails to get in touch within 10 working days, the occurrence shall be evaluated as a warranty case and the completed email shall be sent directly to the accounting office.	Machine Supplier
7			
8		After the procedure has been clarified with the machine supplier, the completed email (incl. the order number), the feedback regarding the expenditure and any receipts for the material are sent to the accounting office and the vendor account of the machine supplier is then charged.	Daimler AG
9			

Warranty – Cost Accounting:
Further Calculation of Services Provided by Daimler

Dear Sir/Madam,

We procure high-quality production equipment from your company for Daimler Production according to the requirement specifications. In association with this, we assume there to be a minimal number of warranty cases.

Should a warranty case arise, we accept a response time of one hour after written notification by our Maintenance department.
After receiving this information, you are obligated to notify us immediately on your decision to dispatch technicians or order allocation to Daimler.
Should you decide to dispatch technicians, time scheduling shall be coordinated with our Maintenance department.
If you allocate an order to Daimler, please send us the order number.
Failure to reply shall result in order processing by Daimler with corresponding invoicing.
This includes the materials and the resulting labor time.
The current hourly rates of the respective organizational unit shall be charged.
There is no limit for the calculation.

Production equipment for Daimler plants will be procured as described above in accordance with the requirement specifications or manual. The future process flow for the warranty cost accounting has been specified based on this.

If a warranty case arises or is possible, you will be informed immediately by our maintenance personnel by means of a form.
In this document you will be provided with information on the affected production equipment, when the malfunction began and a short error description.

Repairs that, for the aforementioned reasons, must be carried out by Daimler do not affect the contractual guarantee/warranty claims in any way.

<u>Availability of service personnel at Daimler plants concerned:</u>
The service personnel of each machine and equipment manufacturer shall generally be available <u>starting immediately</u> on Monday to Sunday, 24 hours a day. In addition, availability is to be ensured on public holidays by means of a hotline and/or service number. Your service personnel and the required spare parts shall be delivered to Daimler within 6 hours.

When commissioning upcoming projects, we not only expect the service availability specified above for new machines and equipment, but also for those already delivered at Daimler plants.

Both the service agreement and warranty cost accounting shall be clarified consensually between the supplier, Planning and the responsible department prior to order allocation.

Detailed agreements on this shall be concluded on site with the maintenance departments of the individual plants.

In the event of queries regarding the aforementioned process flow, please contact the representative of the Daimler plant:

	Supplier's Signature:		**Signature of Responsible Department:**
Name in block letters:	____________________	Name in block letters:	________________________
Signature:	____________________	Signature:	________________________
Place/Date:	____________________	Place/Date:	________________________

	Signature of Purchasing:
Name in block letters:	____________________
Signature:	____________________
Place/Date:	____________________

DAIMLER

Daimler Trucks Powertrain

Mercedes-Benz FREIGHTLINER FUSO WESTERN STAR Thomas BUILT BUSES BHARATBENZ

Manual

Process capability

Appendix
List of Requirements for Process Capability

Quality Management

TABLE OF CONTENTS

1 Requirements for the capability of the test equipment

Description	Capability key performance indicator	Number of measurements	Additional restrictions
Method 1 (M1)	c_g / c_{gk} ≥ 1.33	≥ 20 (to be conducted with a suitable normal)	Resolution RE ≤ 5% *
Method 2 (M2) New machines Old machines	R&R *(repeatability and reproducibility)* **≤ 20%** of the tolerance **≤ 30%** of the tolerance	≥ 40 Min. 5 series production parts Min. 2 measurements/part Min. 2 inspectors required	Status: M1 = o.k.
Method 3 (M3) New machines Old machines	R&R *(only repeatability)* **≤ 20%** of the tolerance **≤ 30%** of the tolerance	≥ 50 Min. 5 series production parts Min. 2 measurements/part	Status: M1 = o.k.

* If the characteristics have low tolerances, exceptions can be made in special cases.
  See: VDA 5, Chapter 6 (Use of Test Equipment)

Figure: Essential limit values for characteristics with capable test equipment

Note:
The calibration uncertainty must be observed when selecting the normal. This should be at most 10% of the work piece tolerance. The situation should also be aimed for where the normal is as similar to the work piece as possible. This applies for the dimensions and the functionality/kinematics of the normal.

2 Specifications for capability key performance indicators

2.1 These key performance indicators must be attained

Description/ Application examples	Limit values for capability characteristics	Absolute capability key performance indicator	Number of work pieces (batch size)
Short-term capability assessment Machine capability Shipping acceptance/ Final acceptance/General overhaul	Cm ≥ 1.67	Cmk ≥1.67	≥ 50 parts in a batch or adaptation of the capability key performance indicators if smaller batch sizes are used
Short-term capability assessment for DS/DZ characteristics apart from special measurement categories, see Chapter 2.2.3	Cm ≥ 1.67	Cmk ≥1.67	☐For shipping and final acceptance, 25 parts must always be complied with in the case of DS/DZ characteristics. However, it is recommended that these acceptances be carried out with 50 parts
Short-term capability assessment Production process (PPC) New parts/ Changes in the production process/ Machine relocation / Production process in the case of subcontracting	Cm ≥ 1.67	Cmk ≥1.67	25 parts *
Long-term capability assessment Stable processes Unstable processes	Cp ≥ 1.33 Pp ≥ 1.33	Cpk ≥ 1.33 Ppk ≥ 1.33	≥ 125 parts in batches of 5 (3 or 1 are also possible). Regular production for normally 20 production days
Long-term capability assessment for DS/DZ characteristics Stable processes Unstable processes			

Production systems (Transfer series or hybrid systems) Short-term capability during the release for the entire system/system check	Cm ≥ 1.33	Cmk ≥1.33	≥ 50 units in one batch Remark: All machines/spindles/ jigs & fixtures shall be process capable. For the production system: One production system path (one spindle/one jig or fixture) shall be selected for the capability analysis of the entire system.

* The sample size selected here is an economic quantity which, when applied regularly, delivers a more accurate statement than short-term capability assessments conducted long in the past. The statistical basis is guaranteed but the known residual statistical risk remains

The requirements for the short-term assessment are higher in terms of the statistical aspect, as the process capability assessments are carried out with fewer measured values. The quality in series production must nevertheless be ensured.
For shipping and final acceptance, 25 parts must always be complied with in the case of DS/DZ characteristics. However, it is recommended that these acceptances be carried out with 50 parts.
Higher minimum values for capability key performance indicators can be defined. The definition and documentation of the higher limit values can be plant specific.

2.2 Dynamization of the capability key performance indicators

2.2.1 Dynamization of the short-term key capability indices Cm/Cmk

	Defined minimum values for machine inspections
Number of work pieces	c_m / c_{mk}
≥ 50	≥1.67
40	≥1.78
30	≥1.96
25	≥2.11
20	≥2.36
10	≥3.97

Confidence interval 99.99%

Figure: Dynamization of the minimum values defined for the short-term capability key performance indicators

2.2.2 Dynamization of the long-term capability indices

A use of fewer than 125 measured values is only permissible for long-term capability assessments under particular circumstances, such as economic reasons, lack of work pieces, e.g. during the production of low-volume series, etc.

Number of work pieces	Minimum values for Cp, Cpk adaptation
125	1.33
120	1.34
110	1.36
100	1.38
90	1.40
80	1.43
70	1.47
60	1.52
50	1.59

Confidence interval 99.99%

Figure: Dynamization of the minimum values for characteristics for long-term capability assessments if fewer than 125 parts are used

2.2.3 Adaptation of the values for special measuring categories

The following divergent key performance indicators apply for geometric characteristics such as roundness, roughness, etc.:

Designation		Capability limit value	Number of work pieces
Roughness (Rz, Rp,Ra, Rv, Rk, 3z...)	Short-term capability: Production process (PPC) Machine capability	87.5% of the tolerance	 25 50
	Long-term capability	Cpk ≥ 1.00	125
Unilateral form and position tolerances	Short-term capability: Production process (PPC) Machine capability	Cmk ≥ 1.33	25 parts* ≥ 50 parts in a batch or adaptation of the capability key performance indicators if smaller batch sizes are used
	Long-term capability	Cpk ≥ 1.00	125
Production with 100% measurement (In-process/Post-process measurement)	Short-term capability: (during acceptance) Long-term capability	87.5% of the tolerance Not required	50 -

Figure: Values of characteristics for geometric criteria

* The sample size selected here is an economic quantity which, when applied regularly, delivers a more accurate statement than short-term capability assessments conducted long in the past. The statistical basis is guaranteed but the known residual statistical risk remains

Daimler Trucks Powertrain

The Transmission of Quality Data

from Systems which Record Quality Data

to the QDA System as a Global Quality Management System

Description of the Interface

On the basis of the
ASCII transfer format
developed by Q-DAS

Version : 01
Date : 09.12.2013

Contacts at the Daimler locations:

Global coordination:
Kirn, Oliver – TG/LQS
+49 (0) 621/393-3231
oliver.kirn@daimler.com

Schweikert, Simon – TG/LQS
+49 (0) 621/393-2777
simon.schweikert@daimler.com

Gaggenau:
Rieger, Erhard – TG/OT-QX
+49 (0) 7225/61-2782
erhard.rieger@daimler.com

Schneider, Clemens – TG/OT-QX
+49 (0) 7225/61-5895
clemens.schneider@daimler.com

Mannheim:
Harbarth, Rainer – TG/OE-QS
+ 49 (0) 621/393-4556
rainer.harbarth@daimler.com

Kassel:
Trubel, Ralf – TG/LQG-A
+ 49 (0) 561/802-2618
ralf.trubel@daimler.com

Detroit:
tba

Sao Bernado:
tba

Atlantis Foundries:
tba

Contents

1 General Information and Basic Requirements

1.1 General Information on the QS-STAT Format

This description covers the extent of the data which is necessary to be able to save data provided by measuring equipment (statistical process control station, automatic measuring system, coordinate measuring machine, ...) to a higher level quality management system. The transmitted data must be so complete that the QDA system can use it to create a test plan, even automatically.

The interface is based on the ASCII transfer interface (DFQ format) defined by Q-DAS, from version 3, which is also known as AQDEF format.

The AQDEF format was agreed in a working group made up of car makers and suppliers to the automotive industry (BMW AG, Robert Bosch GmbH, DaimlerChrysler, Ford-Werke AG, Getrag GmbH & Cie KG, Getrag Ford GmbH, GMPT Europe, Volkswagen AG) and is the basis of this set of requirement specifications. Documentation on the ASCII transfer interface and on the AQDEF package can be downloaded from the Q-DAS web site, under www.q-das.de.

This set of requirement specifications restricts the generally applicable basic requirements of the AQDEF package to the specific requirements of the QDA project within Daimler Trucks Powertrain.

The contents of the fields used in the interface must be agreed with those responsible from Daimler Trucks, before the measuring equipment is delivered and before a measuring program is created.

The formal approval of the measuring equipment includes the approval of the interface for the quality data.

To clearly assign the data from a database, the following are required:
- Item number (part number)
- The name of the item number (name in the test plan)
- The name of the process (assembly operation or sequence of operations)
- The clear and unique name of the characteristic concerned

This document contains a complete description of these fields, amongst others.

Comments

- The formats of the fields may be restricted due to internal Daimler concerns and may thus differ from Q-DAS's definitions.

- For each transmission of measurement results, the results from several measured parts can be sent. This must be locally configurable (see the data transmission chapter).

- Supplementary information about the process for the part made such as inspector, test equipment, job number, the machine used for manufacture etc. must be transmitted as parameters for the process. Entries are only permitted in the file header (K1000 fields) if the information quite clearly belongs to the parts measured. In extreme cases, information for just a single part can be transmitted. For automatic measuring equipment or for measuring equipment with a high throughput of data, this is not permissible.

- In the Q-DAS format, possible *subcatalogs* are not permissible for supplementary information about a process.
- If, in addition to the measurement results, the measuring equipment can also provide graphical output in PDF format, then it must be a possible option to transmit this information too (see the data transmission chapter)
- Unique key fields may not occur more than once in the transmitted file, which means that the fields K1001 and K1086 may not occur more than once.

2 Description of the data fields

2.1 The Field Names:

- Ax = alphanumeric, x characters long
- I3 = integer (1 byte)
- I5 = integer (2 bytes)
- I10 = integer (4 bytes)
- Fx = floating point number
- R5.6 = numerical value, 5 digits before the decimal point, 6 digits after
- S = special coding
- m = mandatory field (must contain something)
- p = mandatory/unique key field (primary key)
- k = optional field (can contain something)

2.2 Header and Characteristics

2.2.1 Headers

Field	QS-STAT field	Mandatory/ must/can	Format DC (mandatory)	Format Q-DAS
Number of characteristics	K0100	C	I5	I5
Item number (without spaces, spaces will be eliminated)	K1001	p	A30	A30
Text for the item no. (test plan name)	K1002	k	A40	A80
Abbreviation for the item number	K1003	k	A40	A20
Revision level of part	K1004	k	A20	A20
Part ID (see measurement results □K0014)				
Drawing number	K1041	k	A20	A20
Revision level of drawing (changes to drawing) drawing geometry date e.g. 008-05-08-2012	K1042	k	A20	A20
Job (job number) (see measurement results □K0053)	K1053	k	A40	A40
Machine number (see measurement results □K0010)	K1081	C	A40	A24
Name of machine (see measurement results □K0010)	K1082	k	A40	A40
Assembly operation □see **Chapter 2.5.1**	K1086	p	A40	A40
Department	K1101	k	A40	A40
a) Number of test facility/number of equipment (in part, previously used for equipment index) (see measurement results □K0012)	K1201	C	A40	A24
Name of test facility/alternatively, the device index (for the device index, see K1822 too)	K1202	k	A40	A40
Reason for test/test equipment group (KMG, SPC, MA, ...)	K1203	k	A40	A80

Field	QS-STAT field	Mandatory/ must/can	Format DC (mandatory)	Format Q-DAS
Test point/test station (in part, previously used for equipment index)	K1206	k	A40	A40
Type of test/purpose of investigation (series, audit measurement, ...) (see measurement results □K0015)	K1209	C	A20	A20
Cost center (1 job per cost center) **e.g. 024-01502**	K1103	k	A40	A40
Inspector (see measurement results □K0008)	K1222	k	A40	A40
Free field e.g. for spindle, ... (see measurement results □K0011)	K1802	k	A40	A255
Free field e.g. for pallet, ... (see measurement results □K0011)	K1812	k	A40	A255
Comments (see measurement results □K0009)	K1900	k	A40	A255

- Nomenclature for **assembly operation (K1086)**
  see Chapter 2.5.1 "Possible instances of fields – name of process"
- Possible instances and comments **Purpose of investigation (K1209 or K0015)**
  see Chapter 2.5.2 "Possible instances of fields – Purpose of investigation"
- The test job number (K1053) must be freely editable if transmission is required. If DC does not specify this, then this field can be left out.

2.2.2 Characteristics

Field	QS-STAT field	Mandatory/ Must/can	Format DC (mandatory)	Format Q-DAS
Characteristic number (sequential number)	K2001	C	A20	A20
Name of the characteristic (standardized name)	K2002	p	A40	A80
Short text for the characteristic (the characteristic text)	K2003	C	A40	A20
Type of result (currently, only variable is supported) (0 = variable/ 1=attributive/2 = classified variable)	K2004	k	I5	I5
Class of the characteristic (0 = non critical/ 1 = somewhat important/ 2 = important/3 = significant/4 = critical)	K2005	k	I5	I5
Characteristic which must be documented	K2006	k	I5	I5
Performance indicator	K2009	k	I5	I5
Digits after the decimal point	K2022	k	I5	I5
Characteristic code (version of name: characteristic space) (**old couplings:** number of measuring point)	K2090	k	A40	A40
Nominal dimension	K2101	C	F22	F22
Lower specified limit	K2110	p	F22	F22
Upper specified limit	K2111	p	F22	F22
The type of lower limit (lower natural limit) (characteristics with one-sided tolerance) (0=no limit, 1=limit, 2=natural limit)(see examples too)	K2120	p	I3	I3
The type of upper limit (upper natural limit) (characteristics with one-sided tolerance) (see K2120)	K2121	p	I3	I3
Lower scrap limit (process tolerance)	K2114	k	F22	F22
Upper scrap limit (process tolerance)	K2115	k	F22	F22
Lower plausibility limit	K2130	k	F22	F22
Upper plausibility limit	K2131	k	F22	F22
Unit	K2142	k	A20	A20
Drawing/reference point - x	K2244	k	I5	I5
Drawing/reference point – y	K2245	k	I5	I5
Drawing/reference point - z	K2246	k	I5	I5
Datum system (ID for changing tolerances)	K2520	k	A20	A20
Lower intervention threshold	K8012	k	F22	F22
Upper intervention threshold	K8013	k	F22	F22
Lower warning limit	K8014	k	F22	F22
Upper warning limit	K8015	k	F22	F22
Size of random sample (size of 3 or 5)	K8500	k	I5	I5
Type of random sample (fixed/shifting)	K8501	k	I3	I3
Frequency of random sample (textual specification of the frequency) [once per shift | 3 from 100]	K8502	k	A40	A40
Frequency of random sample (100)	K8504	k	I5	I5

- The characteristic number QNR (K2001) is a consecutive, increasing number (necessary for direct QS-STAT analyses).
- The characteristic name (K2002) (standardized name) must have a *unique* name.
- The characteristic text (K2003) contains the descriptive part of the characteristic's name.
- If the tolerance of a characteristic 1 depends on a characteristic 2, then for characteristic 1, the field K2520 must be used to identify the tolerance which changes from measurement to measurement.

2.3 Supplementary Information on a Process (Process Parameter)

To control a process via the analysis of measurements, additional information can be transmitted via supplementary information on a process such as the machine used for manufacture, the ingot mold used, etc. which is transmitted with the measurement results.
These fields must always be understood as additional information and they do not necessarily have to be used.

There are various options to transmit this information via the ASCII transfer interface: free fields, catalogs with internal Q-DAS content, catalogs e.g. for machines, suppliers etc. and freely definable catalogs of process parameters for cases which cannot be covered by the options listed so far.

The ASCII transfer interface also permits subcatalogs to be formed within catalogs. This option may not be used.

- **The information about the process parameters should be contained in the DFQ file.**
- **The index of catalog entries is not relevant for the entry in the database.**
  Only the fields' plain texts are relevant, e.g. "Machine 1". This is why the entire catalog does not have to be transmitted, just the parameters used for the transmission of a measurement.
- **The local measurement equipment will not automatically be supplied with a central, up to date catalog.**
- **Entries via freely editable fields should be avoided. For specific, fixed inputs, the on-site employee should be offered a menu to make a selection.**

2.3.1 Free Process Parameter Fields Without a Catalog

Field	QS-STAT field	Must/can	Format DC (mandatory)	Format Q-DAS
Number and element of random sample via batch	K0006	k	A14	A14
Comment/Text	K0009	k	A255	A255
Part ID/DMC (data matrix code)	K0014	k	A40	A40
Overall status for part (number of faults) (0 = OK/1 = NOK)	K0021	k	I5	I5

2.3.2 Predefined Process Parameters (Fixed Catalogs)

Field	QS-STAT field	Can/must level 1	Format DC (mandatory)	Format Q-DAS
Machine number (catalog)	K4062	k	A20	A20
Name of machine(catalog)	K4063	k	A40	A100
Machine index	K0010	k	I10	I10

Number of test equipment (catalog)	K4072	k	A20	A20
Name of test equipment (catalog)	K4073	k	A40	A100
Test equipment number	K0012	k	I10	I10

Tester number (catalog)	K4092	k	A20	A20
Name of tester (catalog)	K4093	k	A40	A100
Tester index	K0008	k	I10	I10

Event number (catalog)	K4222	k	A20	A20
Event text (catalog)	K4223	k	A40	A100
Event index	K0005	k	S	S

2.3.3 Freely Definable Process Parameters (Free Catalogs)

Field	QS-STAT field	Can/must level 1	Format DC (mandatory)	Format Q-DAS
Number of the process parameter	K4242	k	A20	A20
Name of the process parameter	K4243	k	A40	A100
Short text for the process parameter	K4244	k	A40	A20
Value of the process parameter – number	K4245	k	A40	A20
Value of the process parameter – text	K4246	k	A40	A100
Assignment Process parameters <-> Process parameter values	K4249	k	I5	I5
Process parameter values (for measurement values, see 1.3)	K0011	k	S	S

2.4 Measured Values

Contents	Comments
9.95¶0¶12.1.97/4:02:01¤9.95¤10.01	Date/time just once per measurement result line Measurement value MM1 date time, measurement value MM2, measurement value MM3
9.95¶0¶12.1.97/4:02:01¤9.95¶0¤10.01 ¶0	As example 1, on the measurement value for MM2 and MM3 but with an attribute entry. This will be ignored by DC.

Character to separate values: ASCII #20, CNTRL-T, (¶)
Character to separate characteristics: ALT 015, cntrl-0, (¤)
End of line: CR, cntrl-m, alt 013

Attribute:
Comes after the value of the measurement.
e.g. 9.95¶0¶12.1.97

Permitted Instances of "Attribute":

0	The value is valid.
255	For tabular input, an empty data field is given this attribute.
256	Identifies a value which only serves to fill the data structure up.
290	Implausible value (if a measurement is detected).
……	**There are other instances which are currently not taken into account.**

Some of the process parameters come after the line containing the measurement results.

Contents	Comments
9.95¶0¶12.1.97/4:02:01¤9.95¤10.01	Measurement value MM1 date time, measurement value MM2, measurement value MM3
K0009 tool change	Comments
K0014 127201035200704500973000	Part ID number

2.4.1 Overview of the Process Parameters

Field	QS-STAT field	Can/must field	Format DC (mandatory)	Format Q-DAS
Event	K0005	k	see above	see above
The random sample counter defines the order of manufacture of the parts (approval of machine) **Resolved via batch.** All parts in this random sample are identified via the job number	K0006	k	see above	see above
Inspector	K0008	k	see above	see above
Comments	K0009	k	see above	see above
Machine number	K0010	k	see above	see above
Test equipment number	K0012	k	see above	see above
Process parameter values	K0011	k	see above	see above
Part ID number	K0014	k	see above	see above
Purpose of investigation	K0015	k	see above	see above
Order number	K0053	k	see above	see above

2.5 Possible instances of fields

2.5.1 Name of process (K1086)

Several processes can be entered into a test plan in QDA. A process reflects one of the measuring procedures, which occur during the manufacture of a part. The processes must be uniquely named, which is why the processes are named after the assembly operation (or operation).
From the combination of the assembly operation with the model series and the component (in abbreviations), the following nomenclature results for the naming:

Model series_Component_Assembly-operation_Flag

e.g. HD471_LB_OP020_KMG
HD472_ZK_OP090_MA
A222_IR_Grinding_SPC

Flag:

MA	Automatic measurement system
SPC	statistical process control station
MES	Measurement control
FMG	Shape measuring equipment
OMM	Surface measuring equipment
CMM	Coordinate measuring machine
OPM	Optical measuring machine
'Scr	Torque screwdriver
EINPR	Press-in process

2.5.2 Purpose of the investigation (K1209)

01	Series
02	Rework
03	Measurement of setup/test of first item
04	Proof of capability
05	Trial/sample part
06	Audit
07	Special measurement/other
08	Blocking part (only relevant for foundry)
09	Reference measurement
10	Calibration measurement

- The purpose of the investigation should be copied into field K1209 as a two-digit numerical combination (index number).

3 Example Files

These are examples and are not complete. Example 1 without, example 2 with the supplementary process information. For the explanation of the colors, see the Chapter "Processing the data in the database".

3.1 Example 1

K0100 2	Number of characteristics
K1001 A4710100610	Item number
K1002 A4710100610	Text for the item no. (test plan name)
K1003 right-hand cylinder head port injection 35 Monoline	Abbreviation for the item number
K1004 PAM049450405	Change level of part (date is also possible)
K1008 0120100	Type of part (KFN) (standardized name)
K1014 12720103520070450097300O	Part ID
K1042 PAM049450402	Change level of drawing (date is also possible)
K1086 HD471_ZK_OP065_MA	Operation
K1103 024-1242	Cost center
K1201 0103245	Number of test facility/number of equipment
K1202 CenterMax left	Name of test facility
K1206 M136/11QPMA2	Test point/test station
K1209 01	Type of test/purpose of investigation
K1900 reworked part	Comments
K2001/1 1	Characteristic no. (consecutive no.) characteristic 1
K2002/1 diameter of bearing 1	Long text for the characteristic (standardized name)
K2004/1 0	Type of result (0=variable)
K2005/1 2	Class of characteristic "significant"
K2009/1 202	Value measured "diameter"
K2101/1 10.00	Nominal dimension
K2110/1 9.95	Lower specified limit
K2111/1 10.05	Upper specified limit
K2120/1 1	Lower natural limit (0=no limit/1 = value of limit/2 = natural limit)
K2121/1 1	Upper natural limit (in the example there are no natural limits. Then, K2120 and K2121 are "can" fields. For a natural limit, this is a "must" field.)
K2142/1 mm	Unit name
K8500/1 5	Size of random sample = 5
K8502/1 5 of 1000	5 of 1000
K8504/1 1000	Every 1000 parts made, one random sample
K2001/2 2	Characteristic no. (consecutive no.) characteristic 2
K2002/2 4712000202	Long text for the characteristic (standardized name)
...	...
9.95¶0¶12.1.97/4:02:01¤9.95	MEs **part 1** for MM1, MM2 => Date/time just once per line
9.98¶0¶12.1.97/4:03:01¤9.95	MEs **part 2** for MM1, MM2
10.01¶0¶12.1.97/4:04:01¤10.01	MEs **part 3** for MM1, MM2

3.2 Processing of the Data When Reading it Into the Database

	K1001	
QDA part number	A4710110810	

	K1001	
QDA test plan name	A4710110810	

	K1086	
QDA process (operation)	HD471_LB_OP020_MA	

4 Transmission of the measurement results

4.1 General

- The measurement results will be made available as a file on a network path. A network connection is required. Each piece of measuring equipment reports on the network path in a directory which is defined in advance. It is not intended for the server to fetch the data provided from the measuring equipment.

- The essential settings for the transmission must be configurable on the measuring equipment.

- The files can be transmitted over the network either via
  - FTP or
  - file sharing

  File sharing is the preferred method.

- On the measuring equipment, you can for instance configure, after how many parts/time units, the host computer will transmit the measurements file onto the network path (for example after every measurement, every 10 measurements, once per day).

- In **random sample mode**, only **complete** random samples may be transmitted. These must be made available in **one** transmission file.

- The measurements file must have a unique name and may only be sent **once** to the network path. The file extension is "*DFQ*" or "*DFD*" and "*DFX*".

- Via the host computer, the files will be further processed on the measuring machine (for example, shifted and supplemented) and will no longer be available to the supplier of the data. After making the file available on the control system/the network path, the file may no longer be changed.

- All of the files saved on the defined network path will be processed there, whatever their extension. Care must be taken to put the files in the correct places.

- If the host computer or the network is not available, or if the file cannot be transmitted,
  - then the data must be temporarily stored locally. As soon as the network is available again, the temporarily saved files should automatically be transmitted.
  - depending on the area, after consultation with the responsible maintenance area, a fault report should be displayed on the local screen. The fault message should prompt the user to notify the maintenance department about the fault. The message must be displayed during the stop at the end of the cycle and the user must acknowledge it; the processing may only be resumed after approval by someone with EKS rights.
  - The error code for the fault message must be forwarded via the PRISMA interface (if available).

- If graphic output in PDF format is possible in parallel to the measurements file, then this file must also be made available as an option.
  - The file may only be made available for **one** measured part.
  - For each measurement results file there can only be a single PDF file.
  - The file names must be identical except for their extensions.
  - PDF files have the extension "*PDF*" and must be put in a subdirectory "*PDF*".
  - There must be **no delay after** the measurements results file in putting the PDF file in the target directory.

- Catalogs may only be used after prior agreement with DT.
  If catalogs are used and if they are put in the separate file "*KATALOGE.DFD*", then this file must be put in the subdirectory "*ETC*" in the QDA network environment. This may only be done once after agreement with DT. When additions are made to the catalogs, then "*KATALOGE.DFD*“ must be updated.

5 Release notes

09.12.2013 – S. Schweikert
Copied from parts of the MB Cars Definition and Adaption of Trucks Boundary Conditions