EUROPEAN TEXTBOOK SERIES
for professions in the metal industry

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Metal Engineering Textbook

1st English edition

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Preface

METAL ENGINEERING TEXTBOOK is the first English edition of "Fachkunde Metall" (57th edition). Fachkunde Metall is the leading textbook for metalworking in Germany, a country that boasts a highly developed metalworking industry and a world renowned dual training system. For years, the textbook has been implemented in a wide range of applications in vocational schools within programs geared towards jobs in the metalworking trade.

METAL ENGINEERING TEXTBOOK encompasses the fundamentals of the entire professional field of metal technology and expert knowledge pertaining to jobs within the fields of mechanical, metal cutting and automation technology. METAL ENGINEERING TEXTBOOK has an extensive spectrum of application in on-the job training and continuing education for apprentices, foremen and technicians in businesses within the metalworking industry.

For students of the various specialist fields of engineering studies, it offers a comprehensive introduction. Together with the reference book MECHANICAL AND METAL TRADES HANDBOOK published by Europa-Lehrmittel it serves as an invaluable source of information and reference also for students doing their professional traineeship and those in their first semesters of study.

Target groups

- Industrial mechanics
- Precision mechanics
- Production mechanics
- Cutting machine operators
- Technical product designers
- Foremen and technicians
- Trainees in the metal-processing industry and in trade
- Technical school students
- Trainees and students in the subject of mechanical engineering

METAL ENGINEERING TEXTBOOK assists users in their qualified vocational endeavours. The information available in the form of text and illustrations helps students hone and broaden their skills in the areas of independent planning, performance and supervision. The authors have placed special importance on application and problem orientation in order to make the scientific-technical operating principles and their context within the production process more accessible to students. The scientific-technical and trade-relevant mathematical foundations are incorporated in certain topic segments so as to provide a clearer understanding of the context.

METAL ENGINEERING TEXTBOOK follows the norms DIN, DIN EN and DIN EN ISO applicable in Germany. Please keep in mind that these norms vary in countries in which other national norms apply.

The authors and the publisher are grateful to all users of METAL ENGINEERING TEXTBOOK for critical information and suggestions for improvement (lektorat@europa-lehrmittel.de).

Summer 2016 The authors

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Subject guide

The content of "Metal Engineering Textbook" is logically structured to give teachers and students maximum educational and methodological freedom. The structure of the topics selected in the book aims to allow students to independently familiarise themselves with the different technical content required in the subject areas.

The following selection shows the allocation of the chapters and the content in the textbook to the individual subject areas. It is provided as a suggestion and guideline in order to hold lessons that target the subject areas.

Subject area	Factual information in the book (examples)
Manufacturing components using hand-held tools Preparing and manufacturing components typical of the profession using hand-held tools. Creating and modifying drawings for simple components.	**Project: Key fob** . . . . 638 3.6.2 Manufacturing with handheld tools 1.2 Principles of metrology 1.2.1 Basic terms 1.2.2 Errors of measurement 1.2.3 Measuring equipment capability and inspection of measuring instruments 1.3 Length-measuring devices 1.5 Tolerances and fits
Planning work steps with tools and materials and performing calculations. Selecting and using appropriate measuring instruments and recording the results. Roughly estimating production costs.	2.7.1 Inspection planning 3.2 Structure of manufacturing processes 3.4.1 Material behaviour during forming 3.4.2 Forming processes 3.4.3 Bend forming 3.5 Cutting 3.5.1 Shear cutting 4.1 General survey of materials and process materials 4.2 Material selection and properties 4.4 Steels and iron casting alloys 4.5 Non-ferrous metals 4.9 Plastics 4.10 Composite materials
Documenting and presenting work results.	10.5 Documenting technical projects
Complying with health and safety and environmental protection regulations.	3.1 Safety at work 3.11 Manufacturing operations and environmental protection 4.12 Environmental issues of materials and process materials
Manufacturing components using machines	**Project: Clamp for round workpieces** 640
Evaluating drawings and part lists. Selecting materials based on specific properties. Planning production sequences using calculations.	5.6 Drive units 5.5 Functional units for power transmission 1.4 Surface testing 1.5 Tolerances and fits 3.7 Manufacturing with machine tools 3.8 Joining 4.4 Steels and iron casting alloys 5.6 Drive units 5.5 Functional units for power transmission
Construction and mode of action of machines. Using tools.	5.1 Classifying machines 5.2 Functional units of machines and devices 3.7.1 Cutting materials
Selecting and using measuring instruments.	1.2 Principles of metrology 1.2.1 Basic terms

Subject area	Factual information in the book (examples)
	1.2.2 Errors of measurement 1.2.3 Measuring equipment capability and inspection of measuring instruments 1.3 Length-measuring devices 2 Quality management 2.3 Quality requirements 2.4 Quality features and defects 2.7.1 Inspection planning
Documenting and presenting work results.	10.5 Documenting technical projects
Complying with health and safety and environmental protection regulations.	3.1 Safety at work 3.11 Manufacturing operations and environmental protection 4.12 Environmental issues of materials and process materials
Manufacturing simple components	**Project: Drill stands for hand drills** 642
Reading and understanding assembly drawings and circuit diagrams. Planning simple controls. Assembling components. Marking parts in compliance with standards.	5.1 Classifying machines 5.4 Functional units for bracing and support 5.6 Drive units 5.5 Functional units for power transmission 8.3.3 Circuit diagrams for pneumatic controls 8.3.4 Systematic designing of circuit diagrams 8.3.5 Examples of pneumatic controls
Distinguishing joining techniques. Selecting tools and standard parts.	3.8 Joining 4.4 Steels and iron casting alloys
Documenting and presenting work results.	2 Quality management 2.1 Scope of QM 2.2 The DIN EN ISO 9000 series of standards 2.3 Quality requirements 2.4 Quality features and defects 10.1.1 Work organisation for the line and project 10.5.1 Word processing 10.5.2 Spreadsheet 10.5.3 Presentation software 10.5.4 Technical communication
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Maintaining technical systems	**Project: Maintaining an upright drilling machine** . . . 644
Evaluating the service and maintenance measures.	1 Inspection technology 1.1 Quantities and units 7.3 Maintenance 7.4 Corrosion and corrosion protection 7.5 Failure analysis and failure prevention 7.6 Load and strength of parts
Planning maintenance activities, determining tools and process materials.	4.1.3 Process materials and energy 5.6 Drive units 5.5 Functional units for power transmission 7.3.6 Inspection 7.3.7 Repair
Documenting and presenting work results.	10.5 Documenting technical projects
Complying with health and safety and environmental protection regulations.	3.1 Safety at work 3.11 Manufacturing operations and environmental protection 4.12 Environmental issues of materials and process materials

Subject area	Factual information in the book (examples)
Manufacturing individual parts using machine tools	**Project: Hydraulic clamping fixture** 646
Manufacturing workpieces made from various materials on machine tools.	3.7 Manufacturing with machine tools 4.4.3 The designation system for steels 2.4 Quality features and defects 2.7.1 Inspection planning
Selecting appropriate manufacturing processes and clamps for tools and workpieces.	1.2 Principles of metrology 1.3 Length-measuring devices 1.4 Surface testing 1.5 Tolerances and fits 1.6 Checking of form and positions
Annealing, hardening, quenching and tempering. Developing inspection plans based on quality management.	4.4 Steels and iron casting alloys 2.4 Quality features and defects 2.7.1 Inspection planning 4.8 Heat treatment of steels
Installing and commissioning control systems	**Project: Separating and identifying different metal balls** 648
Installing and starting up control systems.	5.1 Classifying machines 10.3 Develop a project in phases using the hoist as an example project
Identifying components and functional processes from controls in different equipment technology. Construction and commissioning of various controls.	5.6 Drive units 8.2 Principles and basic elements of controls 8.3 Pneumatic controls 8.4 Electropneumatic controls 8.5 Hydraulic controls
Assembling technical systems	**Project: Bevel gear** 650
Planning the assembly of technical subsystems and preparing assembly plans. Assembling components. Performing function controls and preparing inspection records. Strength properties.	1.5 Tolerances and fits 1.6 Checking of form and positions 3.8 Joining 5.4 Functional units for bracing and support 4.11 Material testing
Documenting and presenting work results.	10.5 Documenting technical projects
Programming and manufacturing on numerically controlled machine tools	**Project: Gear shaft and bearing cap** 652
Manufacturing components on numerically controlled machine tools. Preparing work and tool plans.	9.1 Computerised numerical controls 9.1.2 Coordinates, zero and reference points 9.1.3 Control modes, corrections 9.1.4 Creating CNC programs 9.1.5 Cycles and subroutines 9.1.6 Programming CNC lathes 9.1.7 Programming CNC milling machines 9.2 Automatic manufacturing equipment 2.3 Quality requirements 2.4 Quality features and defects
Setting up the machine tool. Developing CNC programs.	9.1.2 Coordinates, zero and reference points 9.1.3 Control modes, corrections 9.1.4 Creating CNC programs 9.1.5 Cycles and subroutines 9.1.6 Programming CNC lathes 9.1.7 Programming CNC milling machines
Developing inspection plans based on quality management.	2.7.1 Inspection planning 1.2 Principles of metrology 1.4 Surface testing 1.5 Tolerances and fits 1.6 Checking of form and positions

Subject area	Factual information in the book (examples)
Repairing technical systems	**Project: Motor spindle of a CNC milling machine . . . 654**
Planning repair measures.	7.5 Failure analysis and failure prevention 7.6 Load and strength of parts 3.8 Joining
Dismantling subsystems. Analysing and documenting defects. Replacing and assembling defective components.	4.8 Heat treatment of steels 4.11 Material testing 5.4.1 Friction and lubricants 7.3.6 Inspection 7.3.8 Improvements 7.3.9 Locating sources of faults and errors 10.5 Documenting technical projects
Manufacturing and commissioning technical subsystems	**Project: Feed drive of a CNC milling machine 656**
Describing functions relationships between devices and components. Selecting appropriate manufacturing processes and assembly equipment. Assembling subsystems to form a complete system and commissioning. Recording the transfer.	3.7.10 Broaching 3.7.11 Precision machining 3.8 Joining 7.2 Commissioning 10.5 Documenting technical projects
Monitoring product and process quality	**Project: Spirit level 658**
Performing machine and process capability inspections. Recording process data and evaluating parameters. Distinguishing between systematic and random influencing variables. Monitoring the production process in mass and series production using quality assurance methods, documenting the progress and identifying corrective measures.	2.5 Quality management tools 2.6 Quality control 2.7 Quality assurance 2.8 Machine capability 2.9 Process capability 2.10 Statistical process control with quality control cards 2.12 Continuous improvement process 10.5 Documenting technical projects
Maintaining technical systems	**Project: Bottling plant 660**
Maintaining technical systems. Investigating causes of defects. Performing weakness analyses and selecting appropriate inspection processes and measuring instruments. Transferring technical systems.	2.12 Continuous improvement process 2.5 Quality management tools 7.3 Maintenance 7.5 Failure analysis and failure prevention 7.6 Load and strength of parts 7.2.3 Acceptance of machinery or equipment 10.3.3.1 Plan the project organisation 10.3.5 Completion and closing of the project
Ensuring the operability of automatic systems	**Project: Automating a manual workplace 662**
Analysing and ensuring the operability of automatic systems. Eliminating operating faults, developing fault isolation strategies and optimising processes. Complying with occupational health and safety when working with manufacturing and handling systems.	2.12 Continuous improvement process 8.6 Programmable logic controls 8.7 Handling technology in automation 10.3.2 The definition phase 10.3.3.1 Plan the project organisation 10.3.5 Completion and closing of the project

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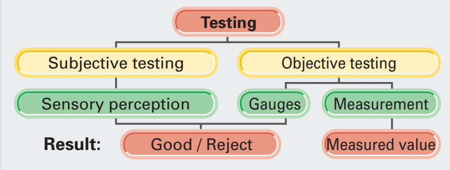

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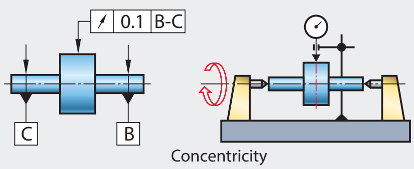

2 Quality Management

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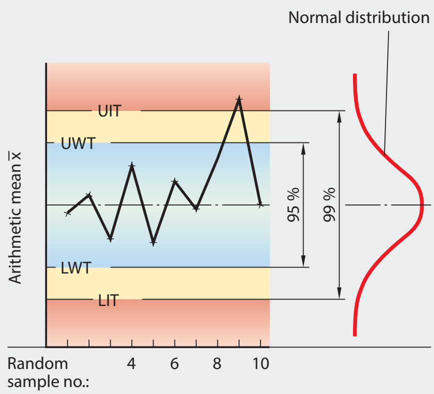


1 Inspection technology

1.1 Quantities and units

Quantities describe properties, e.g. length, time, temperature or current strength **(Figure 1)**.

Base quantities and units are defined in the International System of Units, **SI**, **(Table 1)**.

Decimal multiples or decimal fractions are used to prefix the names of units, e.g. millimetres, in order to avoid the use of very large or very small numbers **(Table 2)**.

Length

> The base unit of length is the metre. One metre is the distance that light travels in a vacuum in one 299,729,458th of a second.

A few prefixes that provide information on large or small distances are useful in connection with the use of the metre unit **(Table 3)**.

Besides the metric system, some countries still use the imperial / US inch system.

Conversion: 1 inch (in) = 25.4 mm

Angles

The units used for angles refer to central angles that are measured relative to a full circle.

One **degree (1°)** is one 360th of a full circle **(Figure 2)**. 1° can be subdivided into minutes ('), seconds (") or into decimal fractions.

The **radian (rad)** is the angle subtended by an arc of 1 m in length for a circle with a radius of 1 m (Figure 2). One radian is equal to an angle of 57.29577951°.

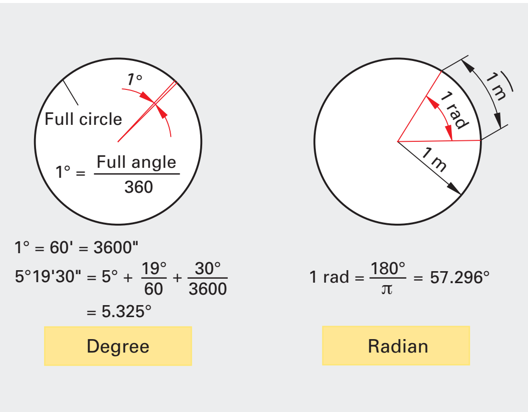


Figure 2: Angle units

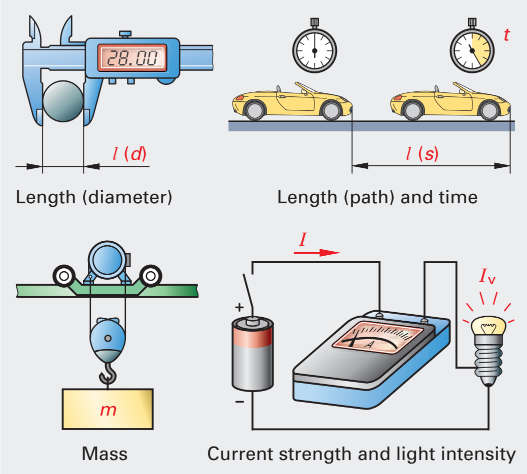


Figure 1: Basic quantities

Table 1: International System of Units

Base quantities and symbols	Base units	
	Name	Symbol
Length l	Metre	m
Mass m	Kilogram	kg
Time t	Second	s
Thermodynamic temperature T	Kelvin	K
Electrical current strength I	Ampere	A
Luminous intensity I_v	Candela	cd

Table 2: Prefixes to define decimal multiples and fractions of units

Prefix		Factor		
M	Mega	Millionfold	10^6	= 1,000,000
k	Kilo	Thousandfold	10^3	= 1,000
h	Hecto	Hundredfold	10^2	= 100
da	Deca	Tenfold	10^1	= 10
d	Deci	Tenth	10^{-1}	= 0.1
c	Centi	Hundredth	10^{-2}	= 0.01
m	Milli	Thousandth	10^{-3}	= 0.001
µ	Micro	Millionth	10^{-6}	= 0.000001

Table 3: Conventional units of length

Metric system	
1 kilometre (km)	= 1000 m
1 decimetre (dm)	= 0.1 m
1 centimetre (cm)	= 0.01 m
1 millimetre (mm)	= 0.001 m
1 micrometer (µm)	= 0.000001 m = 0.001 mm
1 nanometre (nm)	= 0.000000001 m = 0.001 µm

Mass, force and pressure

The **mass *m*** of a solid depends on the quantity of material it contains. It is independent of the location at which the solid is located. The base unit of mass is the kilogram. Frequently used units also include the gram and the tonne: 1 g = 0.001 kg, 1 t = 1,000 kg.

A platinum-iridium cylinder that is stored in Paris is the international standard for the mass of 1 kg. It is the only base unit that has not been able to be defined using a natural constant.

> A solid with a mass of one kilogram is pulled towards the earth (standard location Zurich) with a **force F_W** (weight force) of 9.81 N on its mount or restraint **(Figure 1).**

Pressure *p* refers to the force per unit area **(Figure 2)** measured in Pascal (Pa) or bar (bar).

Units: 1 Pa = 1 N/m² = 0.00001 bar; 1 bar = 10^5 Pa = 10 N/cm²

Temperature

The temperature describes the thermal state of solids, liquids or gases. One **Kelvin (K)** equals 1/273.15 of the temperature difference between absolute zero and the freezing point of water **(Figure 3).** The most common unit of temperature is the **degree Celsius (°C).** The freezing point of water is equal to 0 °C, while the boiling point of water is 100 °C.

Conversion: 0 °C = 273.15 K; 0 K = –273.15 °C

Time, frequency and speed

The second (s) is defined as the base unit of **time *t*.**

Units: 1 s = 1,000 ms; 1 h = 60 min = 3,600 s

The **period *T*,** also referred to as the period of oscillation, is the time in seconds in which a process is regularly repeated, e.g. the full oscillation of a pendulum or the rotation of a grinding wheel **(Figure 4).**

Frequency *f* is the inverse of the period T ($f = 1/T$). It indicates how many processes occur every second. It is measured in 1/s or Hertz (Hz).

Units: 1/s = 1 Hz; 10^3 Hz = 1 kHz; 10^6 Hz = 1 MHz

The **frequency of rotation *n* (speed)** is the number of rotations per second or minute.

For example: A grinding wheel with a diameter of 200 mm rotates 6,000 times in 2 minutes.
What is its speed?

Solution: Speed (frequency of rotation) $n = \frac{6{,}000}{2\ \text{min}} = \mathbf{3000/min}$

Dimensional equations (formulae)

Formulae represent relationships between quantities.

For example: Pressure p is the force F per unit of area A.

$$p = \frac{F}{A};\quad p = \frac{100\ \text{N}}{1\ \text{cm}^2} = 100\ \frac{\text{N}}{\text{cm}^2} = \mathbf{10\ bar}$$

In calculations, quantities are expressed by symbols. The value of a quantity is indicated as the product of the numerical value and the unit, e.g. F = 100 N or A = 1 cm². Unit equations indicate the relationship between units, e.g. 1 bar = 10^5 Pa.

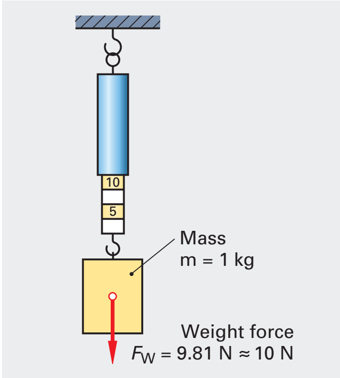


Figure 1: Mass and force

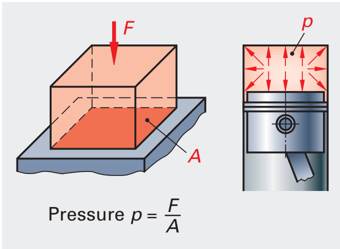


Figure 2: Pressure

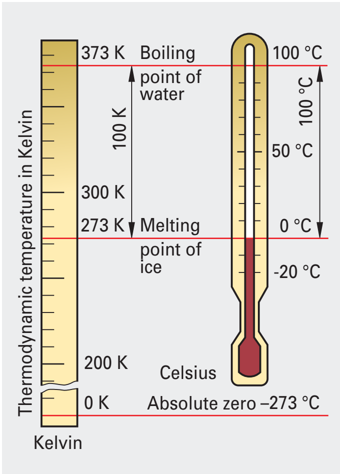


Figure 3: Temperature scales

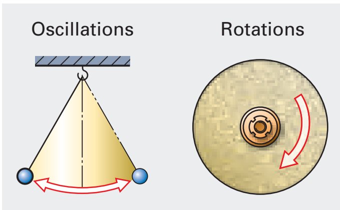


Figure 4: Periodic processes

1.2 Principles of metrology

1.2.1 Basic terms

Testing involves the comparison of actual product characteristics, such as the dimensions, form or surface quality with the required properties.

> Performing tests on a test object determines whether it displays the required features, e.g. dimensions, form or surface quality.

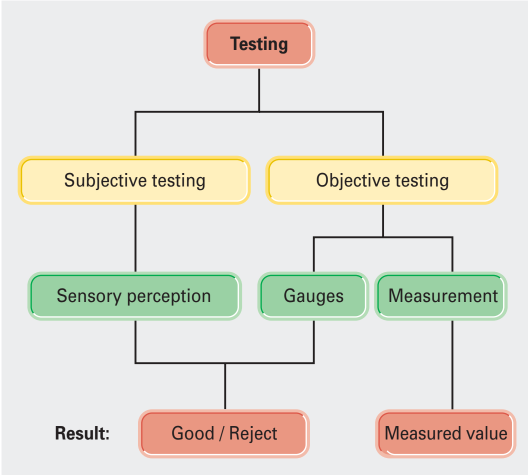


Figure 1: Test methods and test results

Test methods

Subjective testing is performed by way of the tester's sensory perception without the use of tools **(Figure 1).** for example, the tester determines whether the burr formation and peak-to-valley height on the workpiece are allowable (visual and tactile inspection).

Objective testing is performed using measuring instruments, i.e. measuring devices and gauges **(Figure 1 and Figure 2).**

> **Measurement** is the comparison of a length or angle using a measuring device. The result is a measured value.
>
> **Gauging** is the comparison of the test object with a gauge. This does not provide a numerical value; it only determines whether the test object is OK (go) or a reject (no-go).

Measuring instruments

Measuring instruments are divided into three groups: **Measuring devices, gauges and tools.**

All measuring devices and gauges are based on **material measures.** They represent the measured quantity, e.g. by the spacing of dashes (graduated gauge), by the fixed distances of surfaces (gauge block, gauge) or by the angle position of surfaces (angle gauge block).

Indicating measuring devices have movable marks (pointer, vernier line), movable scales or counters. The measured value can be read directly off the device.

Gauges represent either the dimensions or the dimensions **and** form of the test object.

Tools include measuring stands and prisms.

Metrological terms

Clear basic terms are essential in order to avoid misunderstandings when describing measurement methods or evaluation procedures **(tables on the following page).**

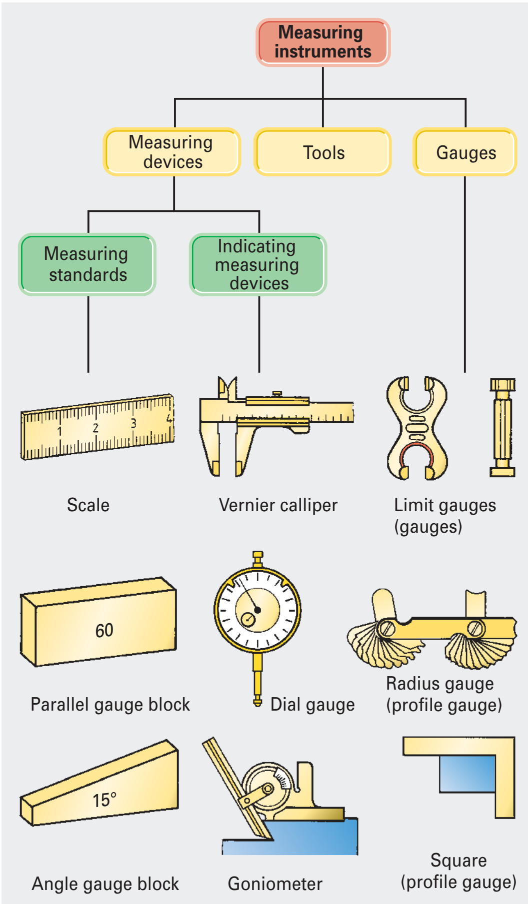
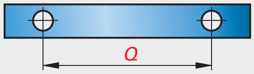
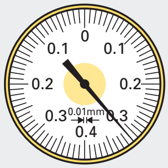


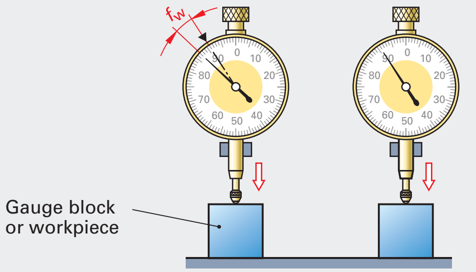
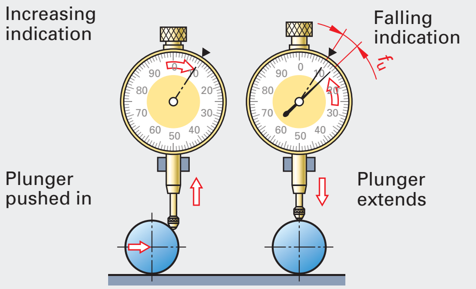
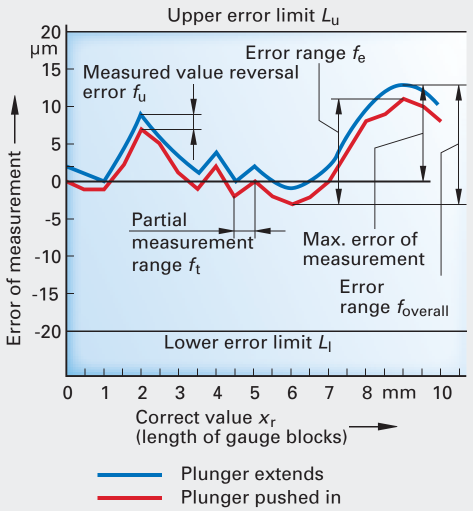
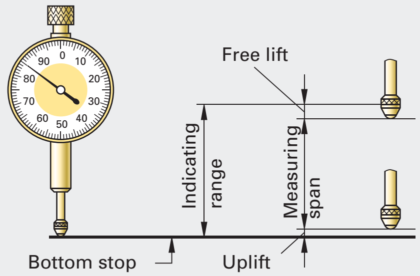
Figure 2: Measuring instruments

Table 1: Metrological terms

Term	Symbol	Definition, explanation	Example, formulae
Measured quantity	Q	The length or angle to be measured, e.g. a hole spacing or a diameter.	
Display	–	The displayed numerical value of the measured value without units (depends on the measuring range). For material measures, the inscription corresponds to the indication.	
Scale indication	–	Continuous indication on a line scale	
Digital indication	–	Digital indication on a numerical scale	Scale indication GI = 0.01 mm
Graduation interval*	GI or →I←	Difference between two measured values that correspond to two consecutive graduation lines. The graduation interval GI is indicated in the scale units.	
Numerical increment	NI	The numerical increment corresponds to the graduation of a line scale.	Digital indication NI = 0.01 mm
Displayed measured value	x_a $x_1, x_2 \ldots$	Individual measured values or arithmetic means are comprised of the correct value and the random and systematic measurement errors.	
Arithmetic mean	$\bar{x}$	The arithmetic mean $\bar{x}$ is generally determined from five repeated measurements.	
True value	x_w	The true value would only be obtained in the case of an ideal measurement. The true value x_w is an "estimate" determined from numerous repeated measurements and corrected for the known systematic errors.	
Correct value	x_r	In the case of material measures the correct value x_r is determined by calibration. It generally has a negligible deviation from the true value. For the case of a comparison measurement, e.g. with a gauge block, its dimension can be regarded as the correct value	
Uncorrected measuring result	x_a $x_1, x_2 \ldots$ $\bar{x}$	Measured value of a measured quantity, e.g. an uncorrected individual measured value or a measured value determined based on repeated measurements, which has not yet been corrected for the systematic errors E_s. Single measurements are generally performed in production engineering due to the known errors from earlier measurement series or capability investigations. The measuring result remains uncertain due to the random as well as the unknown systematic errors of measurement in the case of individual measurements.	
Systematic error of measurement	E_s	An error of measurement is identified by comparing the displayed measured value x_a or the arithmetic mean $\bar{x}_a$ with the correct value x_r (Page 20).	$\boldsymbol{E_s = x_a - x_r}$ $(E_s = \bar{x}_a - x_r)$
Correction value	C	Compensation of known, systematic errors, e.g. temperature error.	$\boldsymbol{C = -E_s}$ $(C = C_1 + C_2 \ldots + C_n)$
Measurement uncertainty*	u	Measurement uncertainty includes all random errors as well as the unknown and uncorrected systematic errors of measurement.	
Combined standard uncertainty	u_c	Combined effect of multiple uncertainty contributions to the scatter of measured values, e.g. due to temperature, measuring equipment, tester and measurement method.	$\boldsymbol{u_c = \sqrt{u^2_{x1} + u^2_{x2} + \ldots u^2_{xn}}}$
Expanded uncertainty	U	The expanded uncertainty indicates the range $y - U$ to $y + U$ about the measuring result in which a measurement's "true value" is expected to lie.	$\boldsymbol{U = 2 \cdot u_c}$ (factor 2 for a 95 % confidence level)
Corrected measuring result	y	Measured value, corrected for the known systematic errors of measurement (C – correction).	$\boldsymbol{y = x + C}$ $(y = \bar{x} + C)$
Complete measuring result	Y	The measuring result Y is the true value for the measured quantity Q. It includes the expanded uncertainty U.	$\boldsymbol{Y = y \pm U}$ $(Y = \bar{x} + C \pm U)$

* Characteristics of measuring devices that are indicated in the catalogues.

Table 1: Metrological terms

Term	Symbol	Definition, explanation	For example
Repeatability*	f_w	Repeatability is the ability of a measuring device to achieve similar readings for no more than 5 measurements of the same measured quantity in the same direction of measurement under the same measurement conditions. The lower the scatter, the "more precise" the method of measurement.	
Repeatability limit* (repeatability)	r	The repeatability limit is the difference for two individual measured values with a probability of 95 %.	
Measured value reversal error*	f_u	The measured value reversal error of a measuring device is the difference in the reading for the same measured quantity in the case of a measurement with an increasing indication (plunger pushed in) and a measurement with a falling indication (plunger extends). The measured value reversal error can be determined by individual measurements at any values within the measuring range, or it can be taken from the error diagram.	
Error range*	f_e	The error range f_e is the difference between the highest and lowest errors of measurement across the entire measuring range. It is determined using dial gauges and precision dial gauges when the plunger is being pushed in.	
Overall error range	$f_{overall}$	The overall error range $f_{overall}$ for dial gauges is determined by performing measurements when the plunger is being pushed in and extended across the entire measuring range.	
Error limit*	L	Error limits are agreed error of measurement limits, or limits specified by the manufacturer, for the errors of measurement of a measuring device. The errors are deemed to be faults if these amounts are exceeded. If the upper and lower error limit are the same, the indicated value applies for each of the two error limits, e.g. L_u = L_l = 20 µm	
Measuring range*	*Mer*	The measuring range is the range of measured values in which the measuring device's error limits are not exceeded.	
Measuring span	*Mes*	The measuring span is the difference between the end value and the starting value of the measuring range.	
Indicating range	*Ir*	The indicating range is the range between the largest and smallest reading.	

* Features of measuring devices that are indicated in the catalogues.

1.2.2 Errors of measurement

Sources of errors of measurement

(Table 1, following page)

A **deviation from the reference temperature of** 20 °C always results in errors of measurement if the workpieces and the controlling measuring devices and gauges are not made from the same material and do not have the same temperature **(Figure 1).**

A change in temperature of as little as 4 °C, e.g. caused by the warmth of a hand, results in a change in length of 4.6 µm in a 100 mm steel gauge block.

> The workpieces, measuring devices and gauges should lie within the prescribed tolerances at the **reference temperature of 20 °C**.

Changes in shape due to the measuring force occur for elastic workpieces, measuring devices and measuring stands.

The elastic bending of a measuring stand does not effect the measured value if the same measuring force is used for the measurement as is applied in the zero position with gauge blocks **(Figure 2).**

> Errors of measurement are reduced if the indication of a measuring device is adjusted under the same conditions under which the workpiece is measured.

Errors of measurement due to parallax arise if readings are taken from an oblique viewing angle **(Figure 3).**

Types of errors

Systematic errors of measurement are caused by constant errors: temperature, measuring force, radius of the probe or imprecise scales.

Random errors of measurement cannot be determined with regard to size and direction. For example, they may be caused by unknown fluctuations in the measuring force and temperature.

> **Systematic errors of measurement** render the measured value inaccurate. The amplitude and algebraic sign (+ or –) of the errors can be compensated if they are known.
>
> **Random errors of measurement** introduce uncertainty into the measured value. Unknown random errors cannot be compensated.

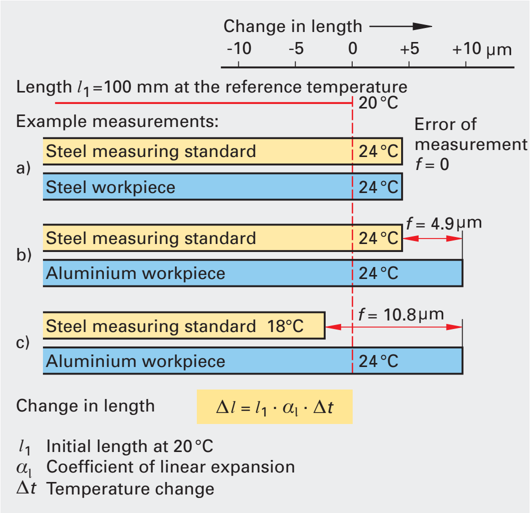


Figure 1: Errors of measurement caused by temperature

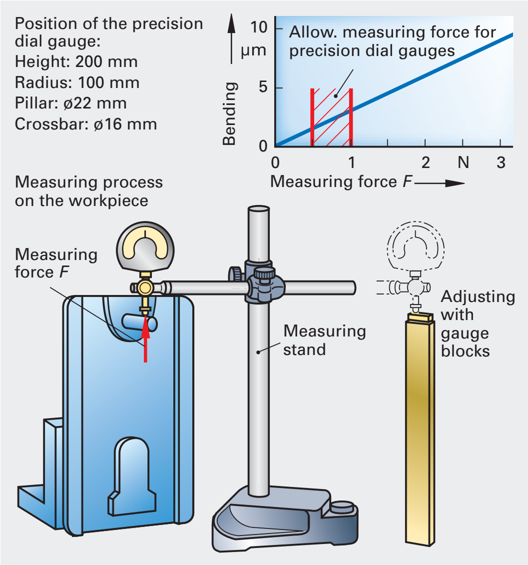


Figure 2: Errors of measurement caused by elastic changes of shape to the measuring stand due to the measuring force

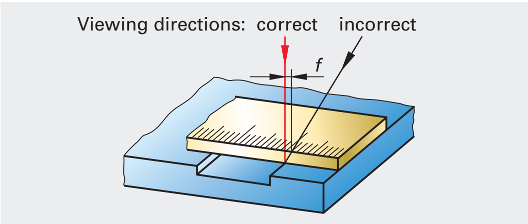
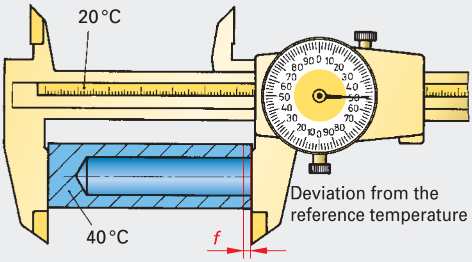


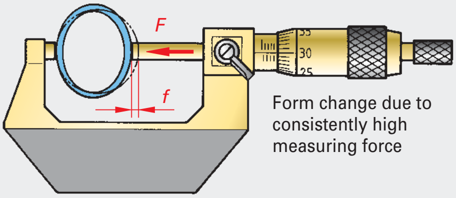
Figure 3: Error of measurement due to parallax

Table 1: Sources and types of errors of measurement

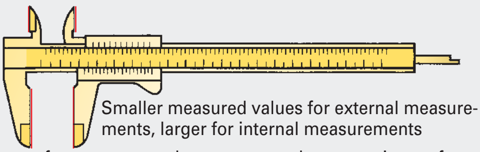
Systematic errors of measurement



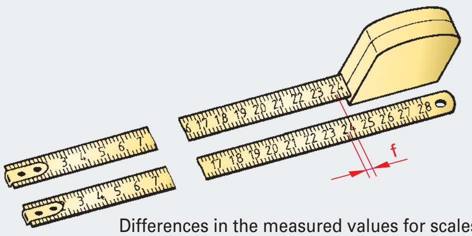
Measured value too high due to high workpiece temperature



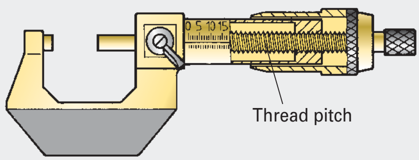
Measured value too low due to the influence of measuring force



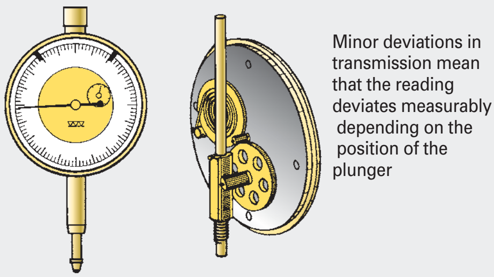
Errors of measurement due to wear on the measuring surfaces



Differences in the measured values for scales

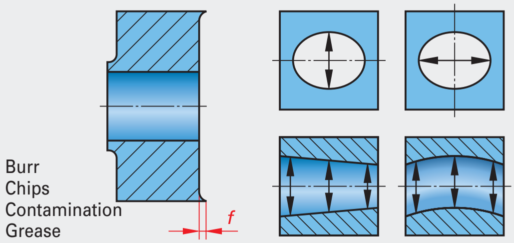


Influence of pitch deviations on the measured values

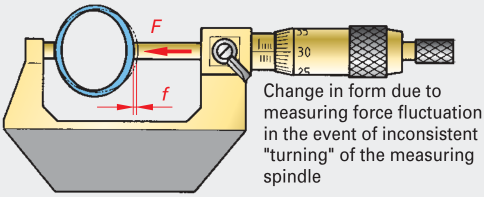


Inconsistent transmission of the movement of the plunger

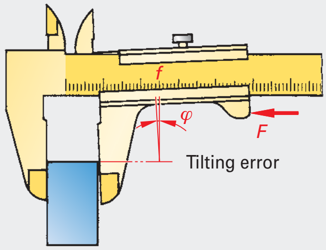
Random errors of measurement



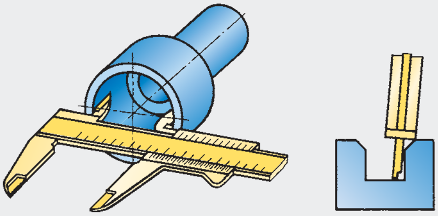
Uncertainties due to unclean surfaces and form deviations

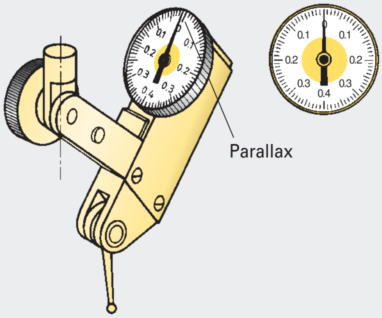


Scattering of the measured values due to fluctuations in the measuring force



"Tilting error" depending on the measuring force and guide play


Imprecise application of the vernier calliper for internal measurements



Reading error due to slanted viewing angle (parallax)

Systematic errors can be identified by a **comparison measurement** using accurate measuring devices or gauge blocks.

Using the example of testing a micrometer, the indication is compared with a gauge block **(Figure 1)**. The nominal value of the gauge block (inscription) can be taken as the correct value. The systematic **error E_s** of an individual measured value is equal to the difference between the displayed value x_a and the correct value x_r.

Testing the errors of measurement of an outside micrometer in the measuring range between 0 mm and 25 mm results in the errors of measurement diagram **(Figure 1)**. For micrometers, the comparison measurement is performed for various angles of rotation of the measuring spindle using specific gauge blocks.

Error limits and tolerances

- The error limit L must not be exceeded at any point of the measuring range.
- The standard case in metrology is symmetrical error limits. The error limits incorporate the errors of the measuring element, e.g. deviations in surface flatness.
- Compliance with the error limit L can be checked using gauge blocks of tolerance class 1 in accordance with DIN EN ISO 3650.

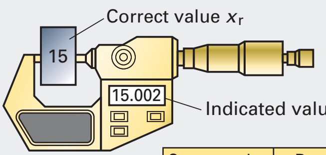
Systematic errors of measurement can be reduced by **zero adjustment of the display (Figure 2)**. The zero adjustment is performed using gauge blocks that correspond to the workpiece test dimension. The random scatter can be determined by **measurements under repeat conditions (Figure 3)**:

Working rules for measurements under repeatability conditions

- The repeated measurements of the same measured quantity on the same workpiece must be performed in succession.
- The measuring equipment, method of measurement, tester and the ambient conditions must not change during the repeat measurement.
- Measurements must always be taken at the same point if roundness deviations are not to influence the measurement scatter.

Systematic errors of measurement are identified by a comparison measurement.

Random errors can be identified by repeat measurements.



Correct value x_r	Deviation E_s	Correction C
7.700 mm	−2 µm	+2 µm
10.300 mm	0	0
15.000 mm	+2 µm	−2 µm
17.600 mm	+3 µm	−3 µm

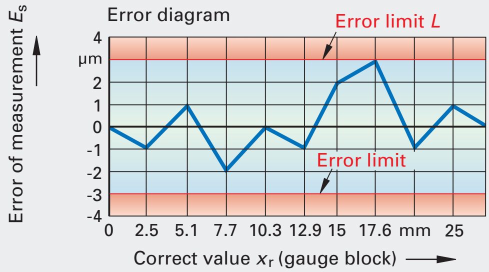


Figure 1: Systematic errors of an outside micrometer

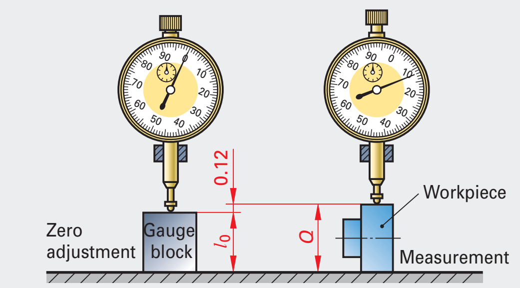
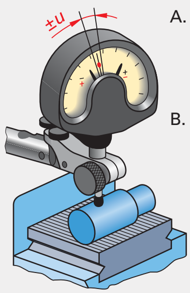


Figure 2: Zero adjustment of the indication and differential measurement



A. Zero adjustment of the precision dial gauge on the turned part diameter of nominal dimension 30.0 mm using a gauge block.

B. 10 **repeat measurements**
Range of the indicated values
$R = x_{a\,max} - x_{a\,min}$
$= 6\,\mu m - 2\,\mu m = 4\,\mu m$

Arithmetic mean of the 10 indicated values

$$x_a = \frac{+40\,\mu m}{10} = +4\,\mu m$$

Indicated values in µm			
+3	+4	+5	+4
+5	+4	+6	+3
+4	+2		

C. **Measurement result**
Arithmetic mean of the diameter
x = 30.0 mm + 0.004 mm
x = 30.004 mm

Figure 3: Random errors of a precision dial gauge for measurements under repeatability conditions