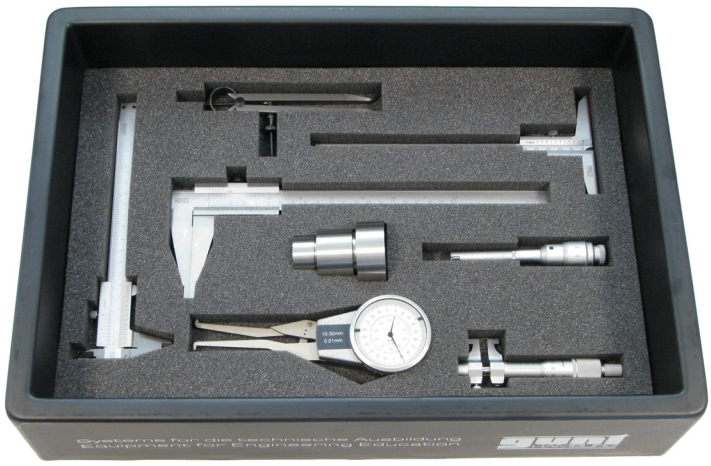
Teaching Material

PT 103 Dimensional Metrology I:
Training Kit 3



Teaching Material

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This manual must be kept by the unit.

Before operating the unit:
- Read this manual.
- All participants must be instructed on handling of the unit and, where appropriate, on the necessary safety precautions.

Table of Contents

1 Introduction

1.1 Subject, target group and learning objectives

The **PT 103** training kit is part of the G.U.N.T. learning concept for dimensional metrology. The training kit includes various items of test equipment and test objects. A sleeve is used as an example to perform, document and evaluate measuring exercises.

The main application of the training kit is in the training of specialist technicians.

The learning content includes:

- Familiarisation with various measuring instruments
- Measuring specified lengths and diameters
- Using an inside spring calliper as a gauge
- Keeping a measurement log
- Estimating measurement variations
- Identifying typical errors

1.2 Didactic information for the tutor

This teaching material is designed to assist you in preparing your lessons. You can put together sections of the material as information for your students and use them in their lessons.

The teaching material also includes prepared worksheets for the students, along with the corresponding solutions.

To support your teaching, we also provide this material in PDF format on a CD. We grant you unrestricted rights to reproduce the teaching material for the purposes of your teaching work.

1.3 Structure of teaching material

Chapter 2 – Safety

This chapter contains safety information, which must be taken into account when using the **PT 103** training kit.

Chapter 3 – Principles of metrology

Explains the difference between testing, measuring and gauging, and between calibration, adjustment and official calibration. Systematic and random measuring variations and actions to avoid these are also dealt with in this chapter.

Chapter 4 – Dimension check with the PT 103 training kit

The components of the **PT 103** training kit are outlined here. It outlines the structure of the measuring instruments and how to read off measured values. A dimension drawing illustrates the dimensions that can be measured on the test objects. There is an explanation of how the dimensions are recorded on the test objects using measuring instruments.

Chapter 5 – Tasks

This chapter contains worksheets for the students. These include questions on metrology and exercises in measuring and using the test equipment and objects in the **PT 103** training kit.

Chapter 6 – Solutions

This chapter contains the solutions to the exercises for the teacher.

2 Safety

2.1 Intended use

The unit is to be used only for teaching purposes.

2.2 Structure of the safety instructions

The signal words DANGER, WARNING or CAUTION indicate the probability and potential severity of injury.

An additional symbol indicates the nature of the hazard or a required action.

Signal word	Explanation
⚠ DANGER	Indicates a situation which, if not avoided, **will** result in **death or serious injury**.
⚠ WARNING	Indicates a situation which, if not avoided, **may** result in **death or serious injury**.
⚠ CAUTION	Indicates a situation which, if not avoided, may result in **minor or moderately serious injury**.
NOTICE	Indicates a situation which may result in **damage to equipment**, or provides instructions on **operation of the equipment**.

Symbol	Explanation
	Notice

2.3 Safety instructions

NOTICE

Test equipment and test objects are sensitive.

- Handle all components of the **PT 103** training kit with great care.

3 Principles of metrology

3.1 Testing – measuring – gauging

In general, testing means comparing an actual value with a set or specified value. We can differentiate between testing, measuring and gauging.

Testing

Testing involves using **test equipment** to establish whether a **test object** meets the specified requirements.

Measuring

Measuring involves using a measuring instrument with a scale, on which the measured variable can be **read off**.

The **measuring instrument** has a scale. It can be fixed (solid measure, e.g. ruler) or adjustable (indicating measuring instrument, e.g. calliper gauge).

The result is a **measured value**, consisting of a numerical value and a unit.

Examples:

- Calliper gauge
- Micrometer
- Dial gauge

Gauging

Gauging involves **comparing** a dimension or shape with a gauge that has the specified dimension or shape.

The **gauge** represents the negative shape, i.e. it is the counterpart to the test object. It is fixed, has no scale and, in general, no moving parts. There are dimension gauges, form gauges and limit gauges.

The result is a **conclusion** as to whether the test object lies within specified limits.

Examples:

- Radius gauge
- Taper gauge

3.2 Calibration – adjustment – official calibration

Operational or legal regulations may stipulate that test equipment has to be compared with a reference. We differentiate between calibration, adjustment and official calibration depending on the test equipment and the activity.

Calibration

Comparison of the values measured using an item of test equipment (measuring instrument or gauge) with a reference.

This identifies the level of variation between two values (measuring instrument) or whether the variation between two values lies within certain limits (gauge).

This variation is noted.

Calibration does not involve any modification of the test equipment.

Adjustment

Changing the display on a measuring instrument due to a variation identified during calibration.

Gauges cannot be adjusted.

Official calibration

Calibration and adjustment of a measuring instrument by a **statutory body**, for example the state calibration authority.

Examples:

- A calliper gauge is calibrated by measuring and noting the difference from a reference.
- An example of adjustment would be changing the zero indicator on a pressure gauge so that it corresponds to the zero indicator on a reference pressure gauge.
- Equipment such as scales used in food shops are officially calibrated. The statutory body thus confirms that adjustment has been carried out in accordance with the regulations.

In general, all objects that have a greater accuracy than the test equipment can be used as a reference.

3.3 Measuring variations

3.3.1 Systematic measuring variations

Systematic measuring variations can be identified by calibration. The measured value is then corrected by the amount of the variation to give the measuring result.

Measuring result = Measured value ± Variation

The sign is crucial here.

Significant systematic measuring variations include:

- Reference temperature

  The reference temperature for test equipment and test objects is 20 °C, i.e. test equipment and test objects should have this temperature.

  If the temperatures differ from this, the measured length must be corrected using the temperature and material-specific coefficient of linear expansion.

- Abbe's comparator principle for measuring instruments

  This principle was established in 1893 by Ernst Abbe, the former owner of the Carl Zeiss company (optical industry). It states that the length to be measured and the scale of the measuring instrument must be positioned flush to one another.

The micrometer conforms to this principle.

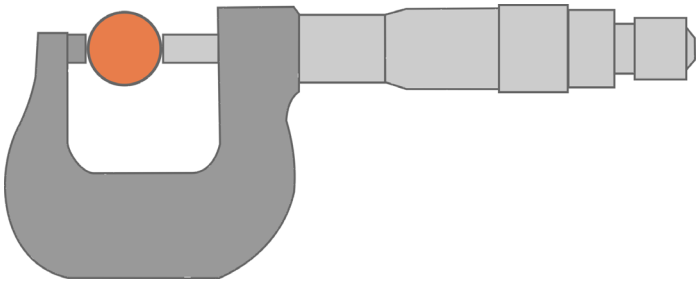


Fig. 3.1 Measuring instrument in line with Abbe's comparator principle

The calliper gauge does not conform to Abbe's comparator principle – as the scale and the measuring object do not lie on an axis. Therefore, measuring errors can occur by tilting the gauge (see Fig. 3.2).

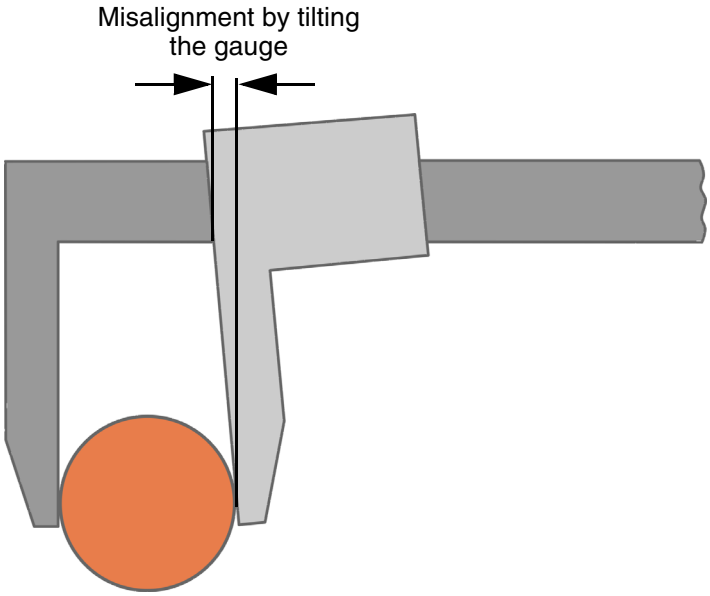


Fig. 3.2 Measuring error by tilting the gauge

3.3.2 Random measuring variations

Random measuring variations are different for each measurement. They cannot be identified by calibration and thus cannot be corrected.

Examples of random measuring variations include:

- Contamination

  Test equipment must always be stored separately from test objects. In the laboratory or workshop, test equipment is stored in particular locations where they will be protected from contamination, severe temperature fluctuations and moisture.

- Reading error due to parallax

  Look at the scale from a right angle when reading the measured value. An inclined view can falsify the reading.

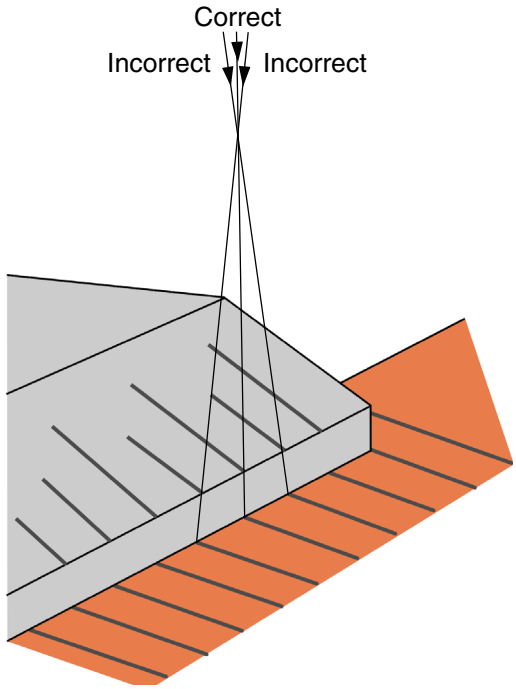


Fig. 3.3 Reading error due to parallax

Random measuring variations are reduced by:

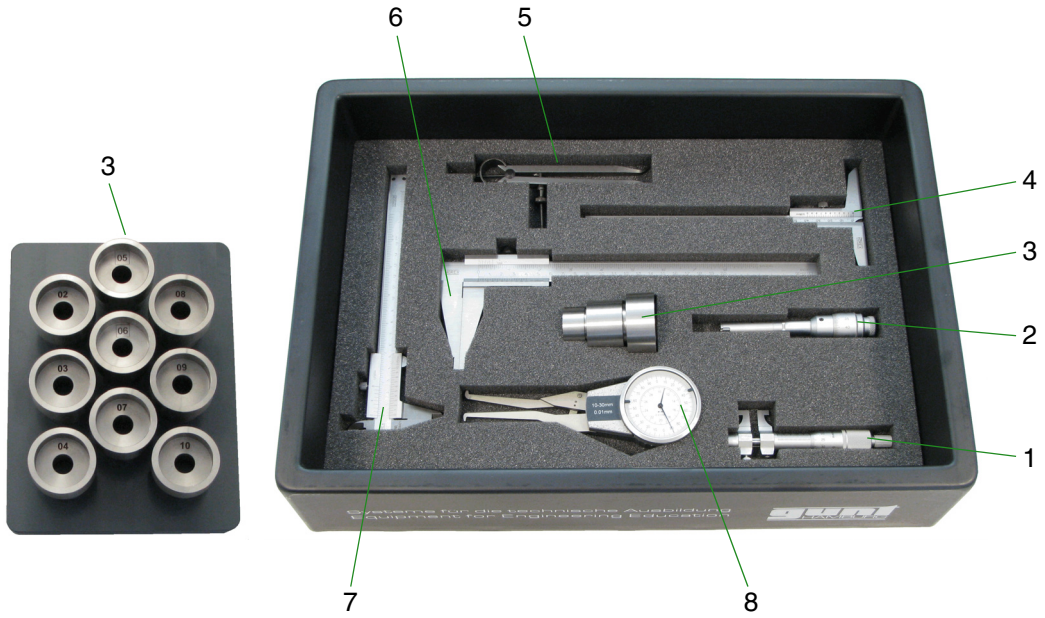
- Careful and calm working
- Multiple measurements

  Measure each dimension several times, if possible with the measuring object at different positions. For example, measure round measuring objects three times, turning the object by 120° each time.

  Then calculate the mean value of your measurements.

4 Dimension check with the PT 103 training kit

4.1 Components



Item	Designation	Measuring range	Additional specifications
1	Internal micrometer	25...50 mm	Reading accuracy: 0,01 mm
2	Three-point internal micrometer	12...16 mm	Reading accuracy: 0,005 mm
3	Sleeves 01 to 10		Manufacturing dimensions: See Chapter 4.3, Page 22
4	Depth calliper gauge	0...150 mm	Reading accuracy: 0,05 mm
5	Inside spring calliper		
6	Calliper gauge	0...200 mm	Reading accuracy: 0,05 mm
7	Pocket calliper gauge	0...150 mm	Reading accuracy: 0,05 mm
8	Internal quick calliper	10...30 mm	Reading accuracy: 0,01 mm

Fig. 4.1 PT 103 training kit

4.2 Test equipment

4.2.1 Calliper gauge

Because of its versatility for different measuring tasks, ease of use and handling, the calliper gauge is the most important length measuring instrument in metalworking. The **PT 103** training kit includes:

- a calliper gauge for external and internal measurements
- a pocket calliper gauge for external, internal and depth measurements
- a depth calliper gauge for depth measurements.

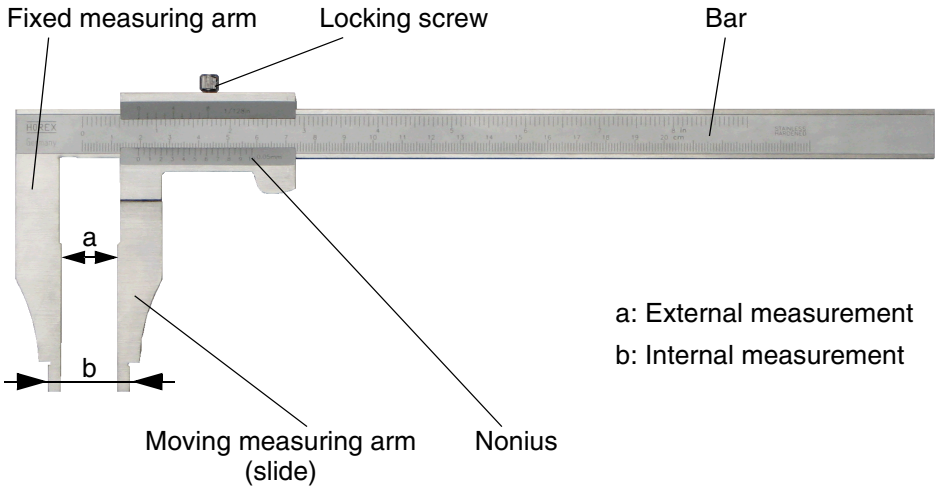


Fig. 4.2 Calliper gauge

The calliper gauge consists of a bar with millimetre graduations and a fixed measuring arm, which makes a right angle with the bar. The moving measuring arm or slider also has a scale, known as the nonius.

The calliper gauge shown in Fig. 4.2 can be used to perform the following measurements:

- External measurement using inner sides of measuring arm.
- Internal measurement using outer sides of measuring arm. In this case, 10mm (length of two measuring arms) must be added to the measured dimension.

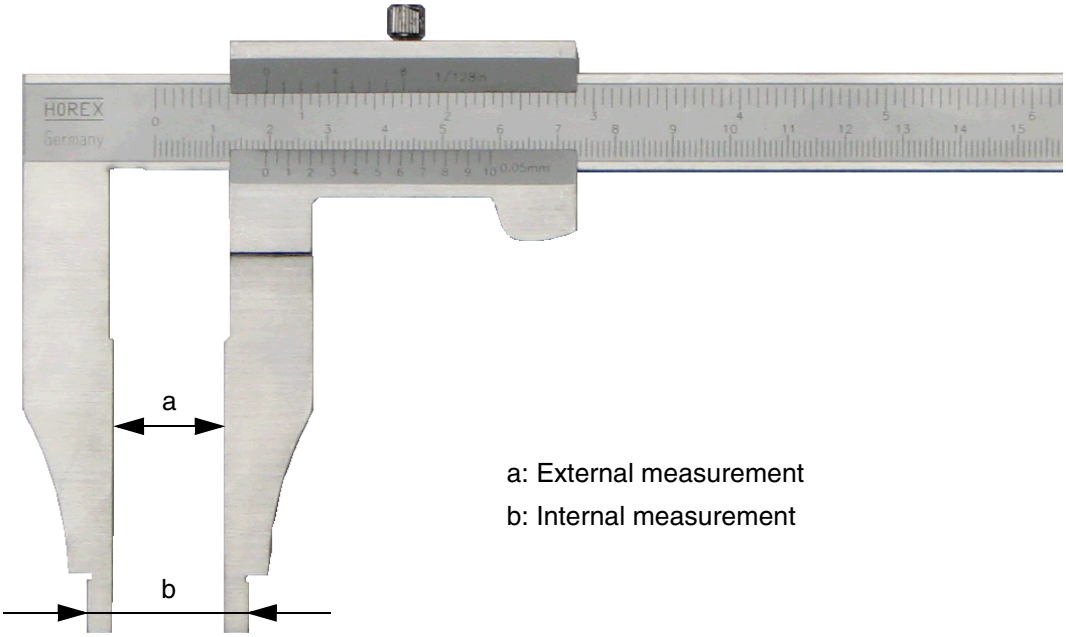
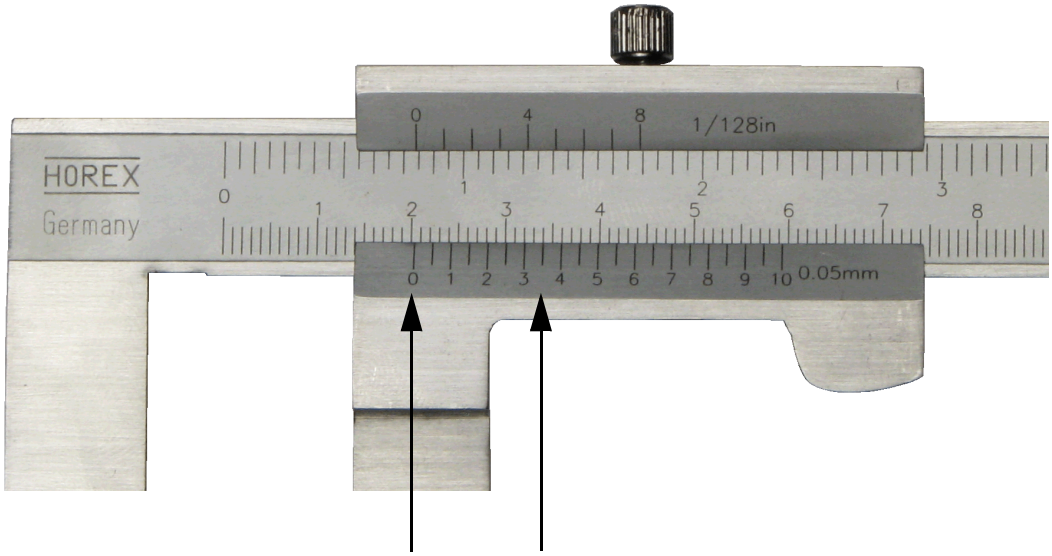


Fig. 4.3 External and internal measurement with calliper gauge

The locking screw also allows the calliper gauge to be used as an adjustable gauge.

The calliper gauge is read as follows:

- View the zero line of the nonius as the decimal point. Read off the full millimetres at the zero line of the nonius.
- Then look to the right of the zero line for the graduation on the nonius that coincides with a graduation on the scale. Read off the tenths of millimetres there.



Reading at the zero line of the nonius
Value: 20

Reading at the graduation on the nonius that coincides with a graduation on the scale
Value: 0,35

Value read: 20,35mm

Fig. 4.4 Reading a calliper gauge

4.2.2 Micrometers

The **PT 103** training kit contains an internal micrometer and a three-point internal micrometer.

With a micrometer, the rotational movement of the scale barrel creates a longitudinal movement.

The measuring accuracy and measuring range are specified on the micrometer. The measuring accuracy of the micrometer is normally greater than that of a calliper gauge. However, the measuring range of the micrometer is smaller than that of a calliper gauge.

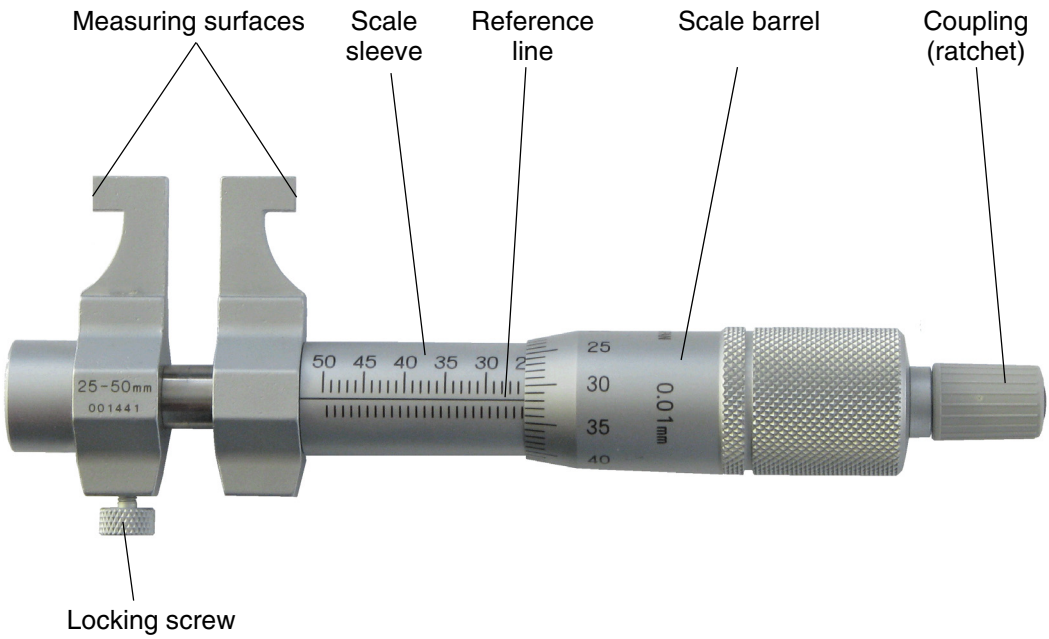


Fig. 4.5 Internal micrometer

The test object is positioned between the two measuring surfaces. The coupling (ratchet) limits the pressure applied to the test object via the thread, thus preventing deformation and measuring variations.

The locking screw allows the micrometer to be fixed and used as a gauge.

The spindle thread normally has a pitch of 0,5 mm, i.e. a complete rotation moves the spindle 0,5 mm in a longitudinal direction. The scale barrel is divided into 50 equal intervals by graduation marks. Rotation from one graduation mark to another corresponds to spindle longitudinal movement of

$$\frac{0{,}5\,\text{mm pitch}}{50\ \text{graduation}} = 0{,}01\,\text{mm}$$

Reading the micrometer:

- Read the full millimetres from the scale on the scale sleeve with numbers (first reading).
- Decimal places:
  - On the scale on the barrel that does not have numbers, each graduation mark divides the full millimetre scale into 0,5 mm. If a graduation mark on this scale is visible between the edge of the barrel and the graduation mark read for the full millimetres, the value is 0,0 mm (second reading). If no graduation mark is visible, the value is 0,5 mm.
  - Each graduation mark on the scale barrel represents 0,01 mm. Read off this value at the reference line (third reading).
  - Add the values from the second and third reading, which give the tenths and hundredths of millimetres respectively.

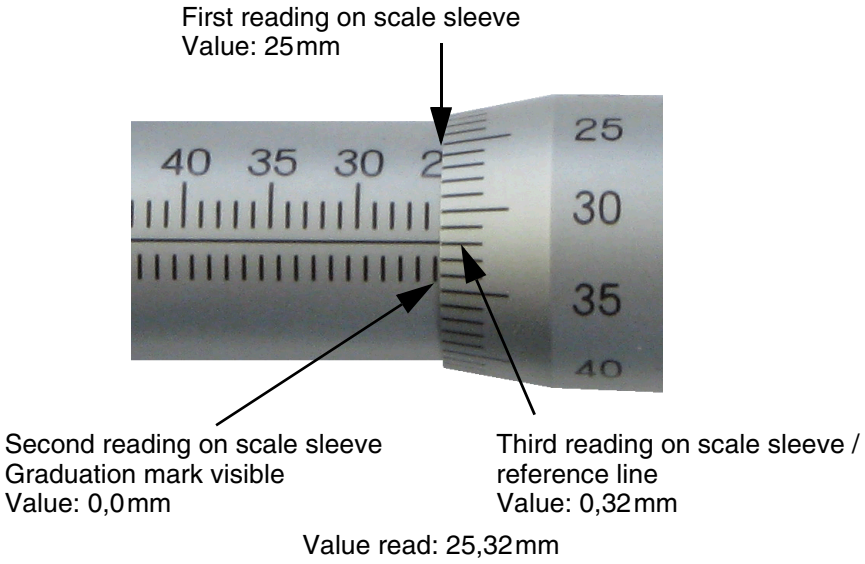


Fig. 4.6 Reading a micrometer

4.2.3 Quick calliper

Quick callipers are used to measure external and internal dimensions at locations that cannot be reached with a calliper gauge or a micrometer. The **PT 103** training kit contains an internal quick calliper.

The measuring range and measuring accuracy are specified on the housing of the quick calliper. The measuring accuracy of the quick calliper is normally greater than that of a calliper gauge. However, the measuring range of the quick calliper is smaller than that of a calliper gauge.

The internal quick calliper is fed into a hole so that the measuring surfaces are in contact with the inner sides of the hole. The longitudinal movement of the measuring arm is transmitted to two pointers and the measured value is read on the scale.

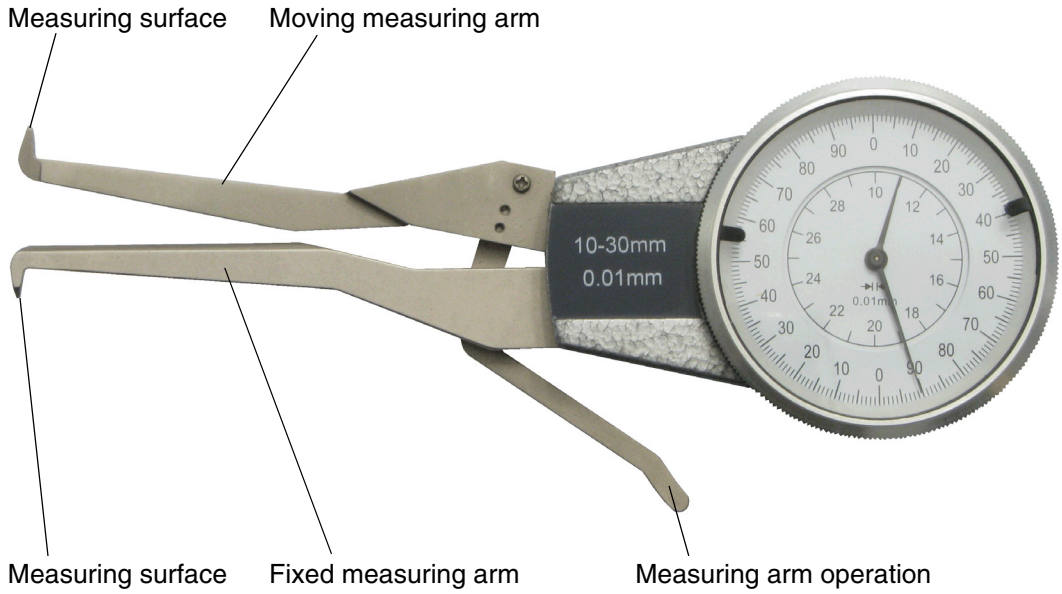


Fig. 4.7 Internal quick calliper

4.2.4 Spring calliper

The spring calliper is fixed using the locking screw and used as a gauge to verify the roundness of test objects.

The **PT 103** training kit contains an inside spring calliper for testing holes.

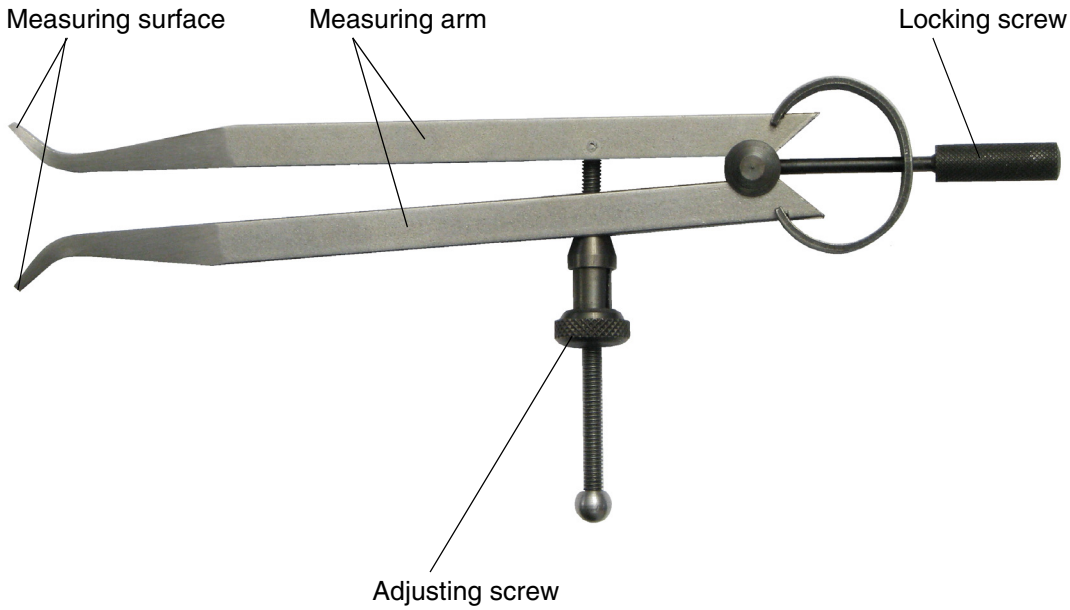


Fig. 4.8 Inside spring calliper

4.3 Test objects

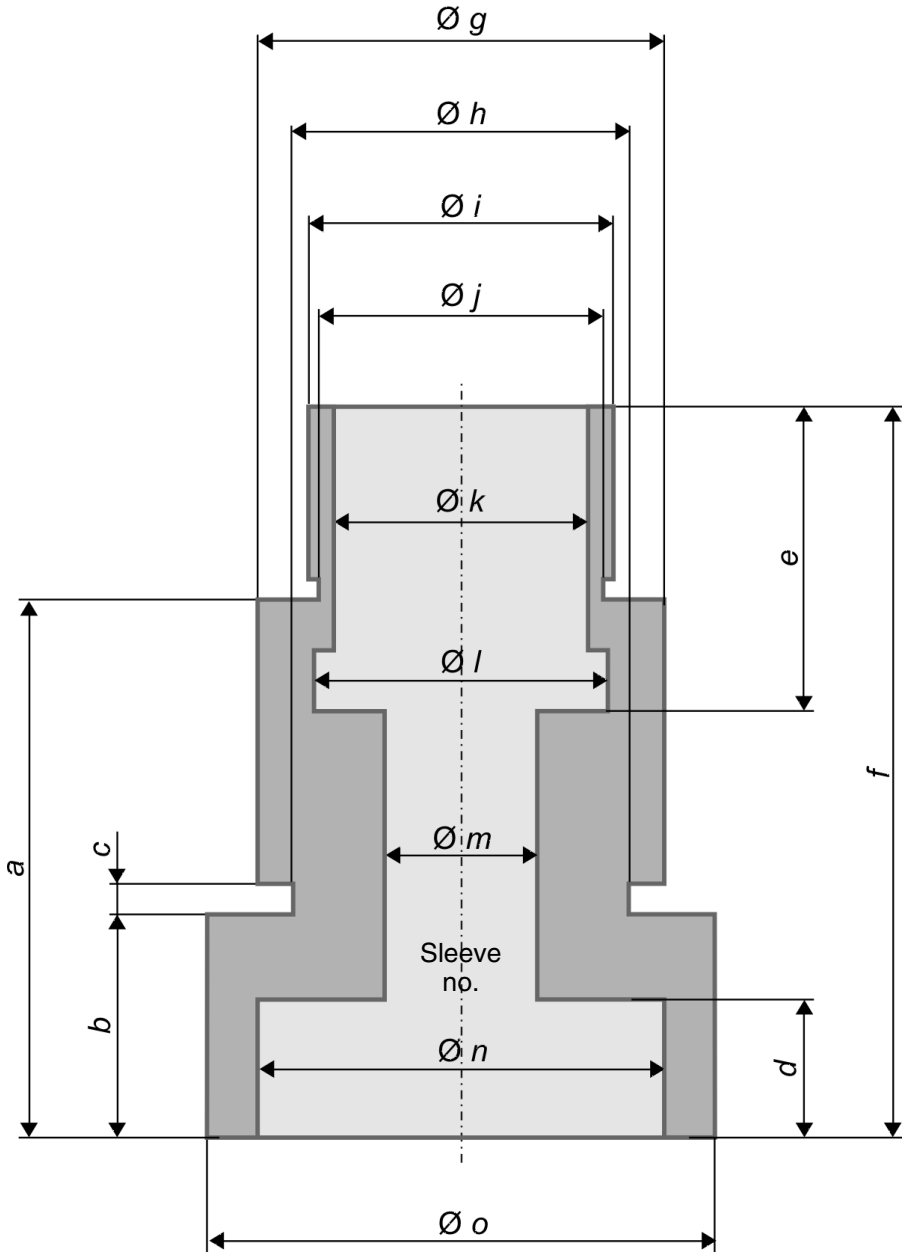


Fig. 4.9 Dimension drawing of sleeves

Ten sleeves are used as the test objects. They are produced to the accuracy of CNC parts and differ due to slight variations in the manufacturing dimensions.

Dimension name	Tolerance	Sleeve 01	02	03	04	05	06	07	08	09	10
Lengths in mm											
a	**A**	53,0	53,8	53,6	53,0	52,9	53,7	52,8	53,0	53,4	52,6
b	**A**	22,0	22,3	22,1	22,0	21,8	22,4	22,3	22,0	22,5	21,2
c	**A**	3,0	3,2	3,5	3,1	3,0	3,4	3,3	3,5	3,0	3,2
d	**A**	13,6	14,0	13,4	13,5	13,3	13,6	14,0	13,2	13,1	13,6
e	**A**	30,0	29,9	30,1	29,8	30,2	30,5	29,6	29,6	29,8	30,1
f	**A**	72,0	72,2	72,5	72,0	71,8	72,7	72,0	71,5	72,3	72,0
Diameter in mm											
Ø g	**B**	40,02	39,99	39,95	40,06	39,99	39,99	39,90	40,10	39,90	40,00
Ø h	**A**	33,00	33,10	33,50	33,00	33,50	34,00	33,20	33,40	33,00	34,00
Ø i	**B**	30,00	29,89	29,81	29,92	29,89	29,96	29,82	29,90	29,70	29,94
Ø j	**A**	28,00	28,20	27,90	27,80	27,80	27,90	28,10	28,00	27,60	28,10
Ø k	**B**	25,10	25,28	24,95	25,18	25,20	24,95	25,03	25,15	25,15	24,90
Ø l	**A**	28,90	29,00	29,10	28,80	28,70	28,90	29,10	28,20	28,60	28,90
Ø m	**B**	15,01	15,15	15,08	15,05	15,07	15,12	15,08	15,09	15,01	15,05
Ø n	**B**	40,00	39,80	40,50	40,10	40,70	39,60	40,30	40,80	40,60	39,90
Ø o	**B**	49,80	50,00	49,50	49,85	49,79	49,65	50,01	49,83	49,65	49,98

Tab. 4.1 Selected sleeve dimensions
Tolerance A: General tolerances in compliance with DIN 7168 medium, production tolerance
Tolerance B: ± 0.05 mm, production tolerance

4.4 Examples for testing the test objects

The **PT 103** training kit contains various items of length measuring equipment for testing the lengths and diameters of the sleeves specified in Fig. 4.9.

Fig. 4.10 to Fig. 4.13 show examples of measurements on a sleeve.

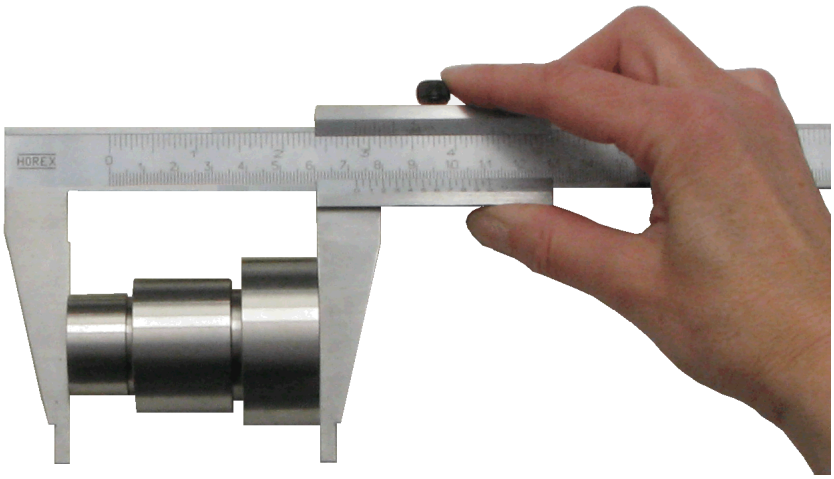


Fig. 4.10 Measuring an external length with the calliper gauge

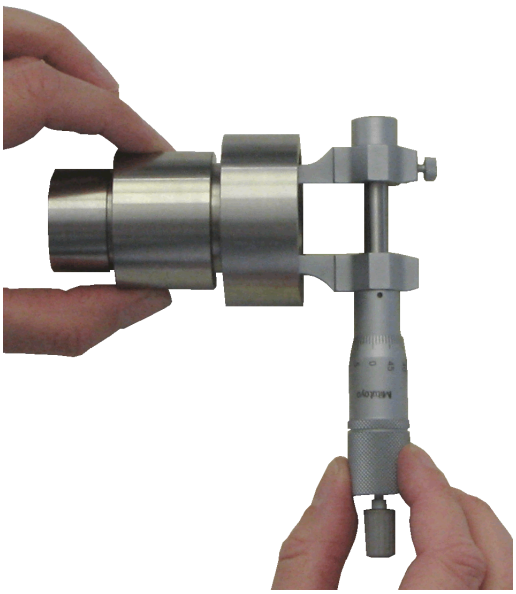


Fig. 4.11 Measuring an internal diameter with the internal micrometer

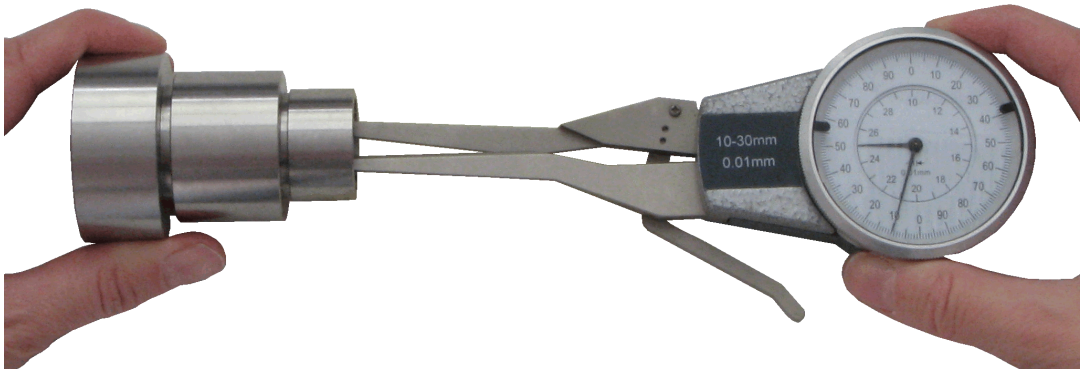


Fig. 4.12 Measuring an internal diameter with the internal quick calliper

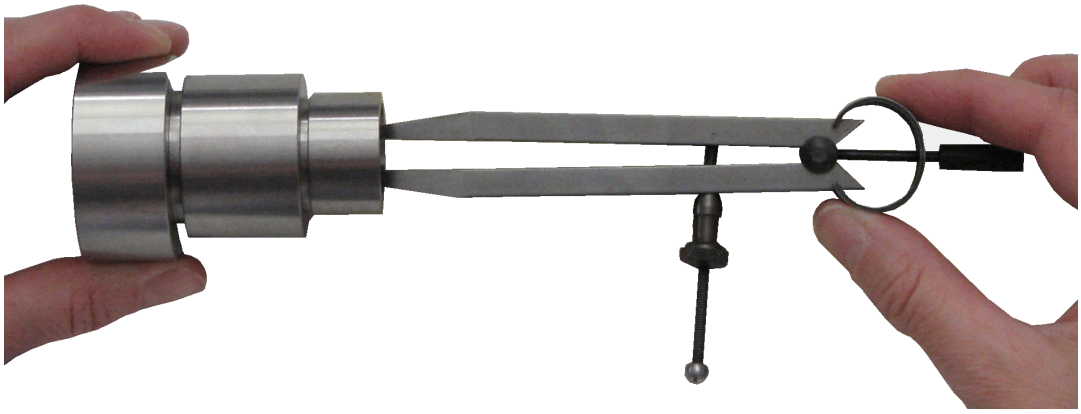


Fig. 4.13 Checking the roundness of a hole with the inside spring calliper

5 Tasks

5.1 Worksheet A – Metrology

Page 1

1. You want to measure the diameter of a round test object.

   How do you avoid random measuring variations?

2. What do you need to consider when storing test equipment?

3. You read a measured value on a scale.

   What do you need to consider when reading, and why?

5.2 Worksheet B – Quick calliper

Page 1

1. What are the advantages of a quick calliper compared to a calliper gauge?

2. And what are the disadvantages of the quick calliper compared to a calliper gauge?

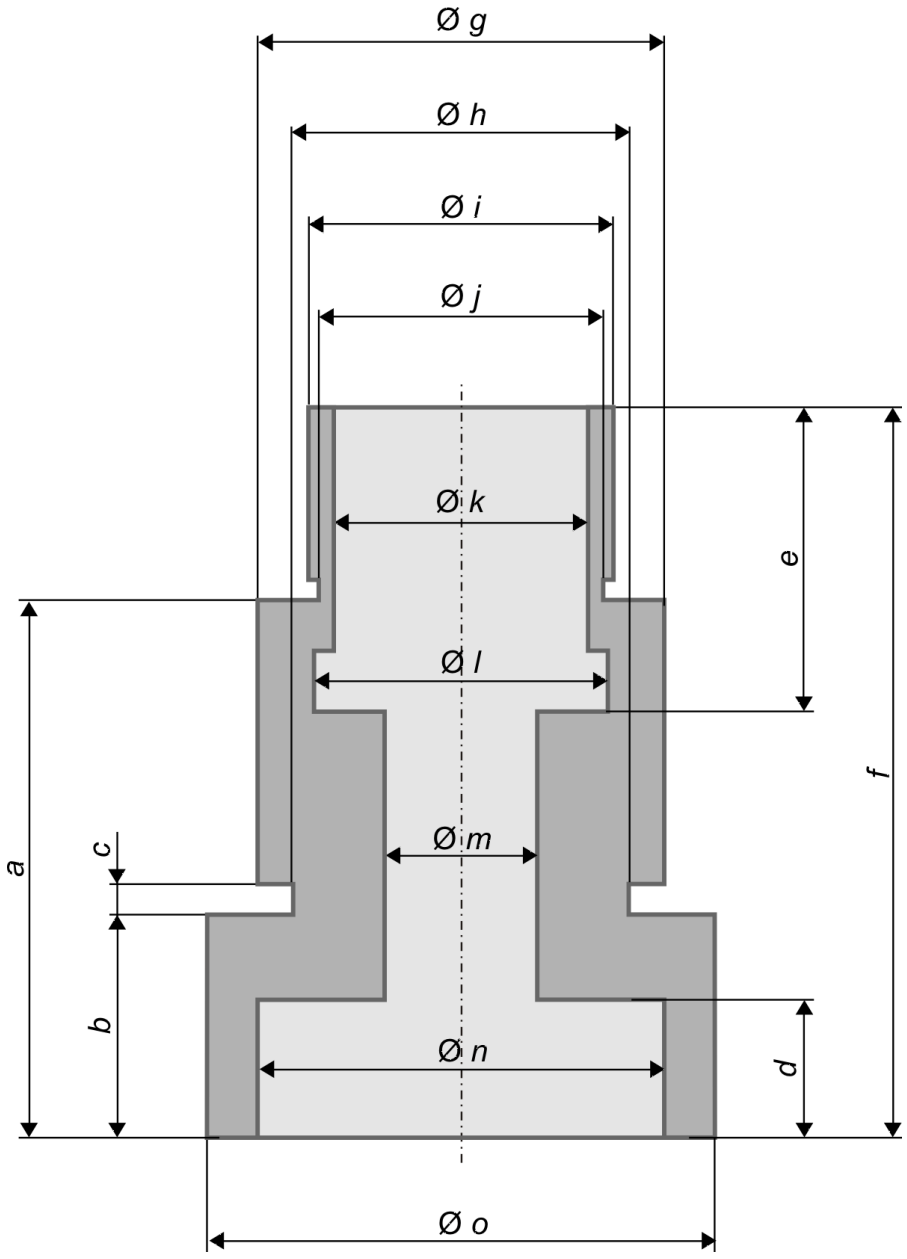
3. Read off the measured value in the figure below and note it.

Measured value:

5.3 Worksheet C – Performing measurements on a sleeve

Page 1

1. Determine the dimensions of a sleeve and enter the values in the test report.



Worksheet C – Performing measurements on a sleeve

Page 2

Test report	
Test object: Sleeve no. ____	
Date: _____	
Dimension name	**Measured dimension in mm**
Lengths	
a	
b	
d	
e	
f	
Diameter	
Ø g	
Ø i	
Ø j	
Ø k	
Ø l	
Ø m	
Ø n	
Ø o	

5.4 Worksheet D – Determining dimensions that cannot be measured

Page 1

You want to determine the length *p* for a sleeve. You cannot measure this length using the measuring instruments from the PT 103 training kit. Therefore, you must measure other dimensions and use them to calculate the length *p*.

1. Which dimensions do you have to measure?

   Name the dimensions and, if not already indicated, add them to the drawing on the next page.

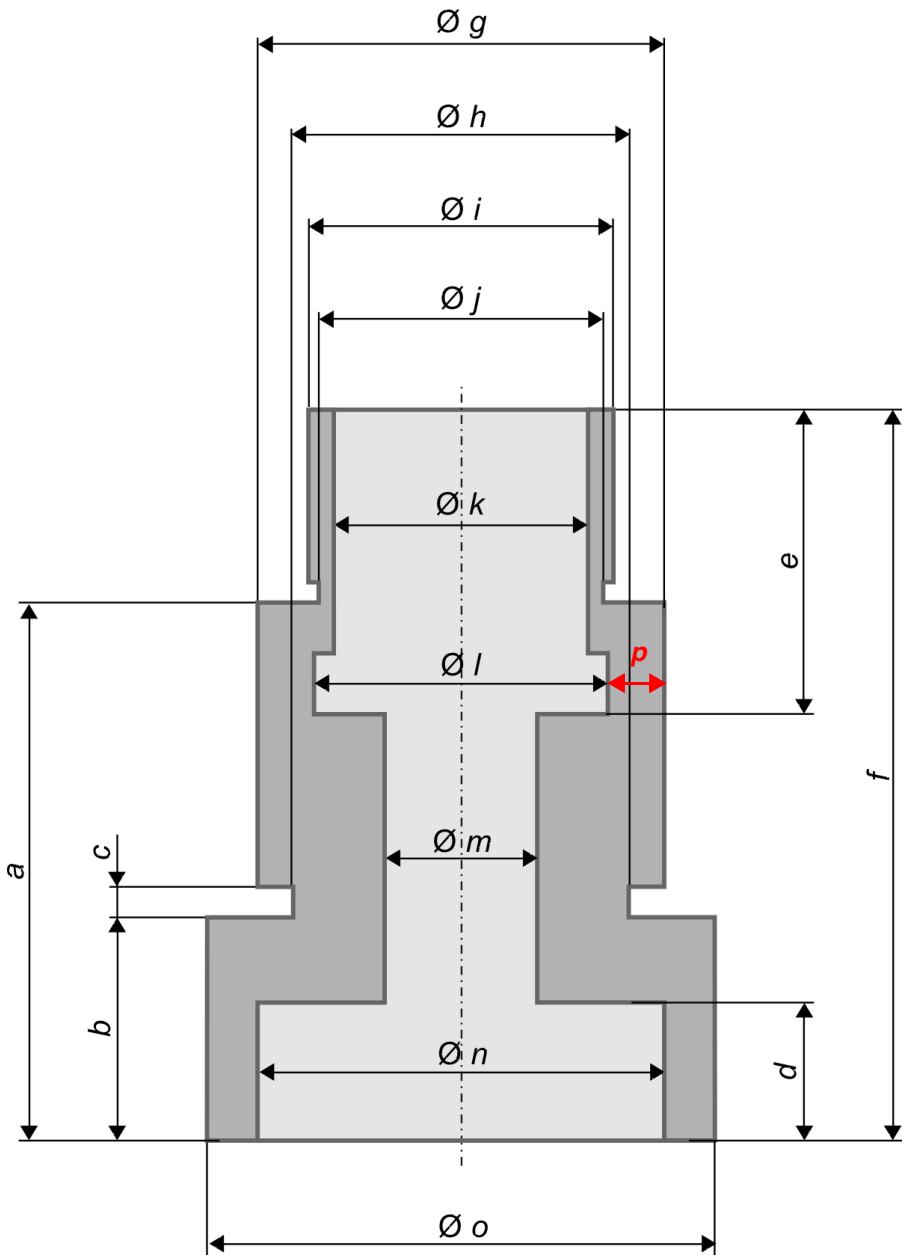
2. Which formula do you use to calculate the length *p*?

3. Enter the measured values and your calculation of the length *p* in the table.

Dimension		Value in mm
Measured dimensions		
Calculated dimension	*p*	

Worksheet D – Determining dimensions that cannot be measured

Page 2



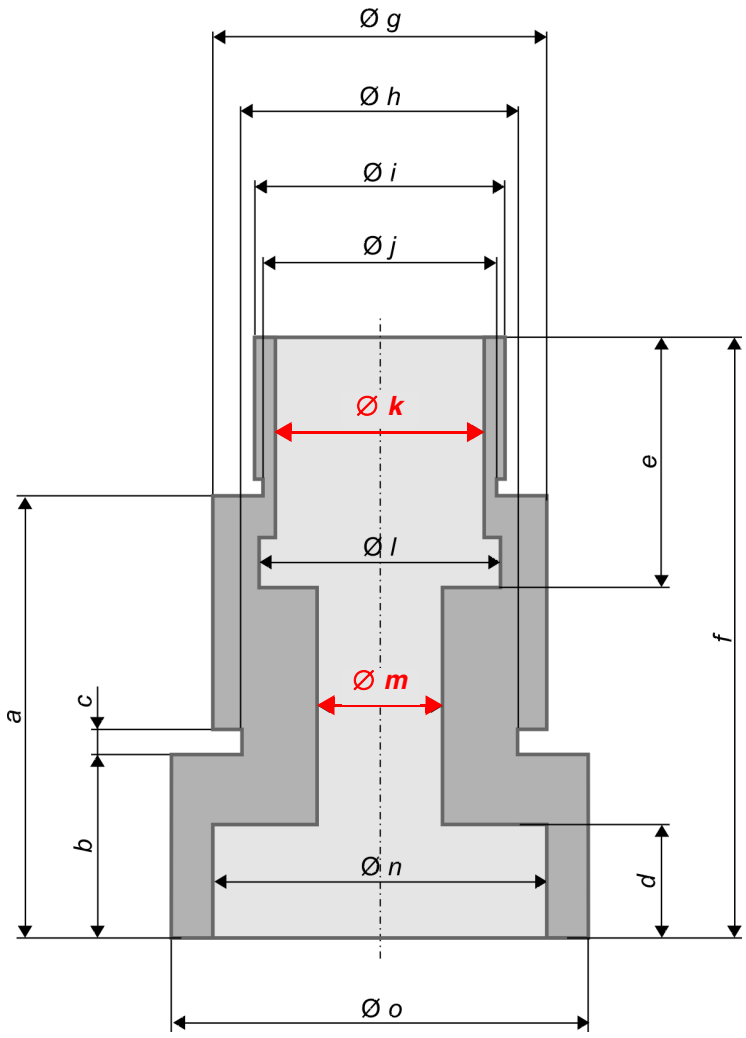
5.5 Worksheet E – Determining dimensions with different measuring instruments

Page 1

1. On a sleeve, measure:
   - the dimension *k* with the calliper gauge, the internal quick calliper and the internal micrometer

   the dimension *m* with the calliper gauge, the internal quick calliper and the three-point internal micrometer.

   Enter the measured values in the test report.



Worksheet E – Determining dimensions with different measuring instruments

Page 2

Test report			
Test object: Sleeve no. ____			
Date: _____			
Measuring instrument	**Calliper gauge**	**Internal quick calliper**	**Internal micrometer**
Dimension name	**Measured dimension in mm**		
Ø k			

Test report			
Test object: Sleeve no. ____			
Date: _____			
Measuring instrument	**Calliper gauge**	**Internal quick calliper**	**Three-point internal micrometer**
Dimension name	**Measured dimension in mm**		
Ø m			

6 Solutions

6.1 Worksheet A – Metrology

Page 1

1. You want to measure the diameter of a round test object.

   How do you avoid random measuring variations?

   I carry out the measurements carefully and calmly.
   I measure three times, turning the test object by 120° for each measurement.
   I then calculate the average value from the measurements.

2. What do you need to consider when storing test equipment?

   Test equipment must be protected from contamination, moisture and significant temperature fluctuations.

3. You read a measured value on a scale.

   What do you need to consider when reading, and why?

   I am looking at the scale at a right angle.
   Viewing from an angle would falsify the reading.

6.2 Worksheet B – Quick calliper

Page 1

1. What are the advantages of a quick calliper compared to a calliper gauge?
   - The quick calliper can be used to measure dimensions at locations that cannot be reached with a calliper gauge.
   - The measuring accuracy of the quick calliper is higher than that of the calliper gauge.

2. And what are the disadvantages of the quick calliper compared to a calliper gauge?

   The measuring range of the quick calliper is smaller than that of the calliper gauge.

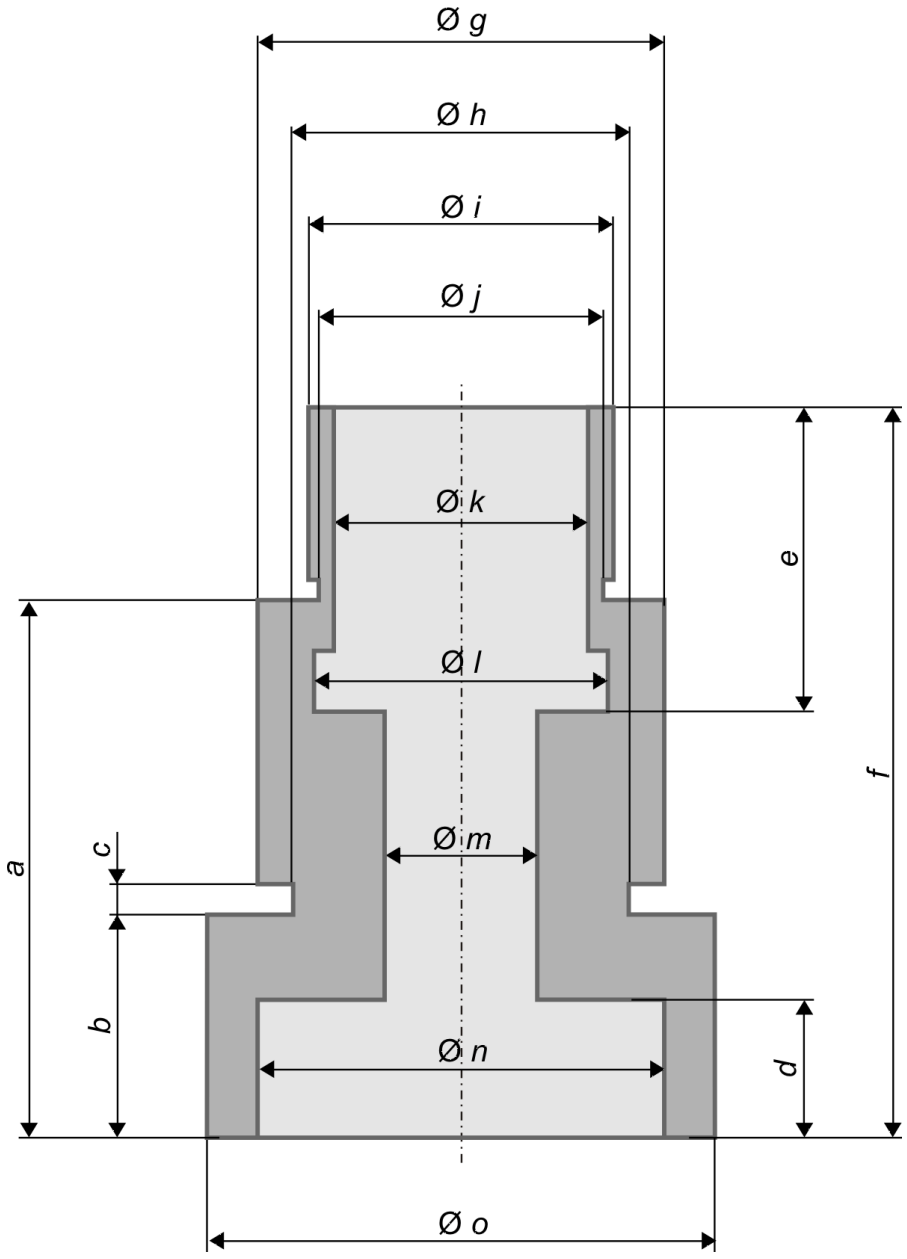
3. Read off the measured value in the figure below and note it.

Measured value: 10,90 mm

6.3 Worksheet C – Performing measurements on a sleeve

Page 1

1. Determine the dimensions of a sleeve and enter the values in the test report.



Worksheet C – Performing measurements on a sleeve

Page 2

Test report	
Test object: Sleeve no. ____	
Date: _____	
Dimension name	**Measured dimension in mm**
Lengths	
a	*
b	*
d	*
e	*
f	*
Diameter	
Ø g	*
Ø i	*
Ø j	*
Ø k	*
Ø l	*
Ø m	*
Ø n	*
Ø o	*

* Information for the teacher: The values depend on the sleeve and the measuring instrument and are therefore not specified here. For comparison, the manufacturing dimensions of all sleeves are specified in a table on the next page.

Worksheet C – Performing measurements on a sleeve

Page 3

For the teacher only

Dimension name	Tolerance	Sleeve 01	02	03	04	05	06	07	08	09	10
Lengths in mm											
a	A	53,0	53,8	53,6	53,0	52,9	53,7	52,8	53,0	53,4	52,6
b	A	22,0	22,3	22,1	22,0	21,8	22,4	22,3	22,0	22,5	21,2
d	A	13,6	14,0	13,4	13,5	13,3	13,6	14,0	13,2	13,1	13,6
e	A	30,0	29,9	30,1	29,8	30,2	30,5	29,6	29,6	29,8	30,1
f	A	72,0	72,2	72,5	72,0	71,8	72,7	72,0	71,5	72,3	72,0
Diameter in mm											
Ø *g*	B	40,02	39,99	39,95	40,06	39,99	39,99	39,90	40,10	39,90	40,00
Ø *i*	B	30,00	29,89	29,81	29,92	29,89	29,96	29,82	29,90	29,70	29,94
Ø *j*	A	28,00	28,20	27,90	27,80	27,80	27,90	28,10	28,00	27,60	28,10
Ø *k*	B	25,10	25,28	24,95	25,18	25,20	24,95	25,03	25,15	25,15	24,90
Ø *l*	A	28,90	29,00	29,10	28,80	28,70	28,90	29,10	28,20	28,60	28,90
Ø *m*	B	15,01	15,15	15,08	15,05	15,07	15,12	15,08	15,09	15,01	15,05
Ø *n*	B	40,00	39,80	40,50	40,10	40,70	39,60	40,30	40,80	40,60	39,90
Ø *o*	B	49,80	50,00	49,50	49,85	49,79	49,65	50,01	49,83	49,65	49,98

Tab. 6.1 Selected sleeve dimensions
Tolerance A: General tolerances in compliance with DIN 7168 medium, production tolerance
Tolerance B: ± 0,05 mm, production tolerance

6.4 Worksheet D – Determining dimensions that cannot be measured

Page 1

You want to determine the length *p* for a sleeve. You cannot measure this length using the measuring instruments from the PT 103 training kit. Therefore, you must measure other dimensions and use them to calculate the length *p*.

1. Which dimensions do you have to measure?

   Name the dimensions and, if not already indicated, add them to the drawing on the next page.

   The lengths *g* and *l* have to be measured.

2. Which formula do you use to calculate the length *p*?

   $p = \frac{g - l}{2}$

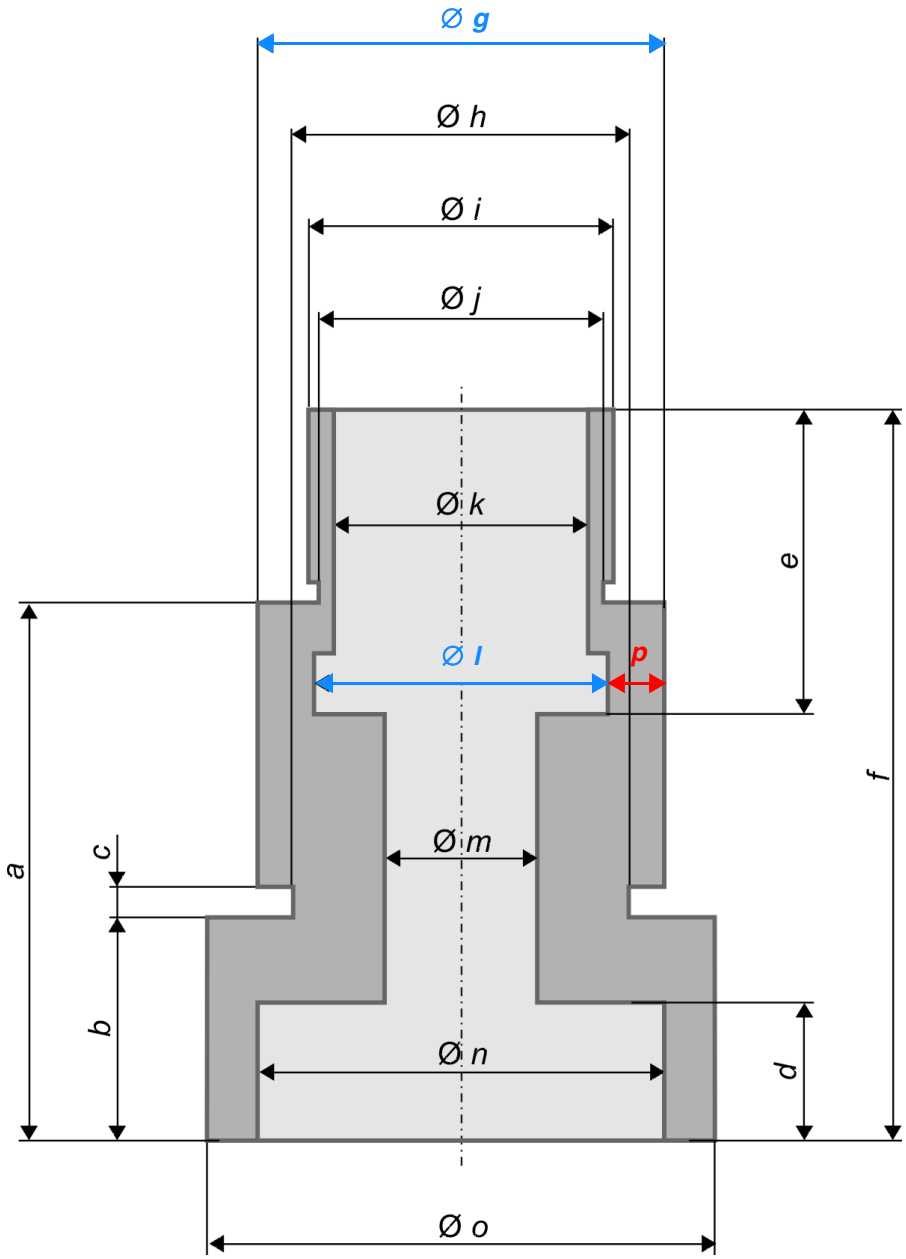
3. Enter the measured values and your calculation of the length *p* in the table.

Dimension		Value in mm
Measured dimensions	*g*	*
	l	*
Calculated dimension	*p*	*

* Information for the teacher: The values depend on the sleeve and the measuring instrument and are therefore not specified here. For comparison, the manufacturing dimensions of all sleeves required here are specified on page 3 of this worksheet.

Worksheet D – Determining dimensions that cannot be measured

Page 2



Worksheet D – Determining dimensions that cannot be measured

Page 3

For the teacher only

Dimension name	Tolerance	Sleeve 01	02	03	04	05	06	07	08	09	10
Lengths in mm											
p	**C**	5,56	5,50	5,43	5,63	5,65	5,55	5,40	5,95	5,65	5,55
Diameter in mm											
Ø *g*	**B**	40,02	39,99	39,95	40,06	39,99	39,99	39,90	40,10	39,90	40,00
Ø *l*	**A**	28,90	29,00	29,10	28,80	28,70	28,90	29,10	28,20	28,60	28,90

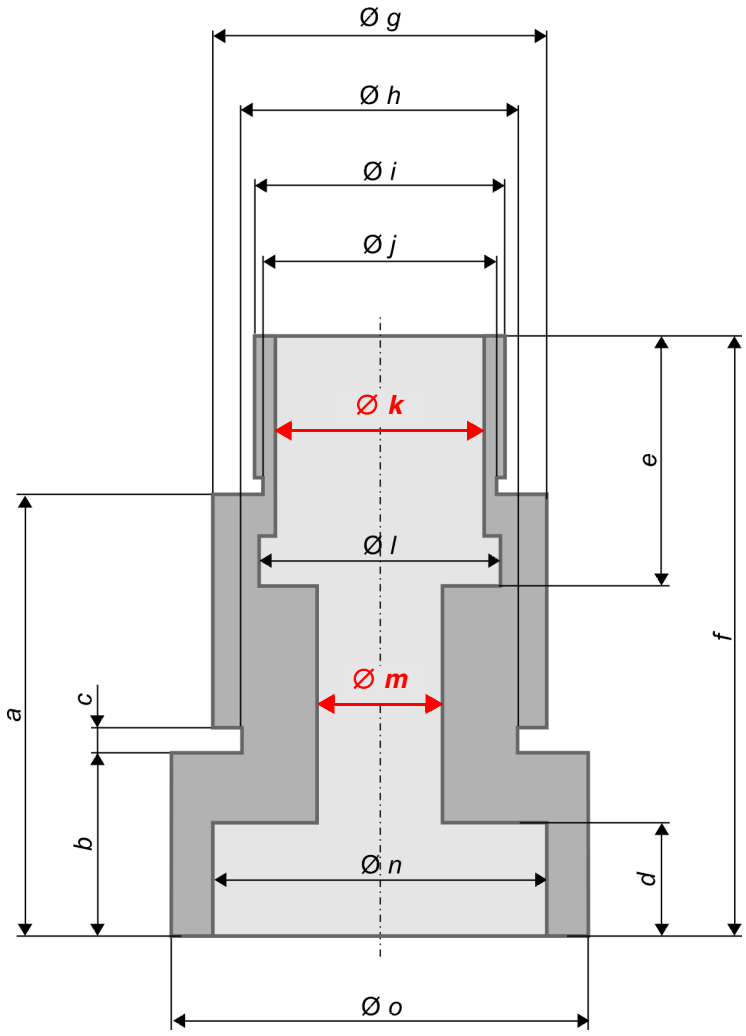
Tab. 6.2 Selected sleeve dimensions
Tolerance A: General tolerances in compliance with DIN 7168 medium, production tolerance
Tolerance B: ± 0,05 mm, production tolerance
Tolerance C: Calculated, other tolerances not taken into account

6.5 Worksheet E – Determining dimensions with different measuring instruments

Page 1

1. On a sleeve, measure:
   - the dimension *k* with the calliper gauge, the internal quick calliper and the internal micrometer
   - the dimension *m* with the calliper gauge, the internal quick calliper and the three-point internal micrometer

   Enter the measured values in the test report.



Worksheet E – Determining dimensions with different measuring instruments

Page 2

Test report			
Test object: Sleeve no. ____			
Date: _____			
Measuring instrument	**Calliper gauge**	**Internal quick calliper**	**Internal micrometer**
Dimension name	**Measured dimension in mm**		
Ø k	*	*	*

Test report			
Test object: Sleeve no. ____			
Date: _____			
Measuring instrument	**Calliper gauge**	**Internal quick calliper**	**Three-point internal micrometer**
Dimension name	**Measured dimension in mm**		
Ø m	*	*	*

* Information for the teacher: The values depend on the sleeve and the measuring instrument and are therefore not specified here. For comparison, the manufacturing dimensions of all sleeves required here are specified on page 3 of this worksheet.

Worksheet E – Determining dimensions with different measuring instruments

Page 3

For the teacher only

Dimension name	Tolerance	Sleeve 01	02	03	04	05	06	07	08	09	10
Diameter in mm											
Ø *k*	**B**	25,10	25,28	24,95	25,18	25,20	24,95	25,03	25,15	25,15	24,90
Ø *m*	**B**	15,01	15,15	15,08	15,05	15,07	15,12	15,08	15,09	15,01	15,05

Tab. 6.3 Selected sleeve dimensions
Tolerance B: ± 0,05 mm, production tolerance