Teaching Material

PT 104 Dimensional Metrology I:
Training Kit 4

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 104** training kit is part of the G.U.N.T. learning concept for dimensional metrology. The test kit includes test equipment and ten test objects. An angle piece 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 universal goniometer and its function
- Measuring specified angles
- Calculating angles
- 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 104** 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 training kit PT 104

The components of the **PT 104** training kit are outlined here. It outlines the structure of the measuring instrument 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 104** 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 104** 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.

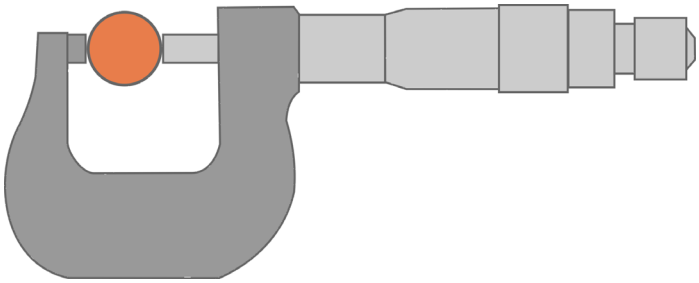


Fig. 3.1 Measuring instrument in line with Abbe's comparator principle

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).

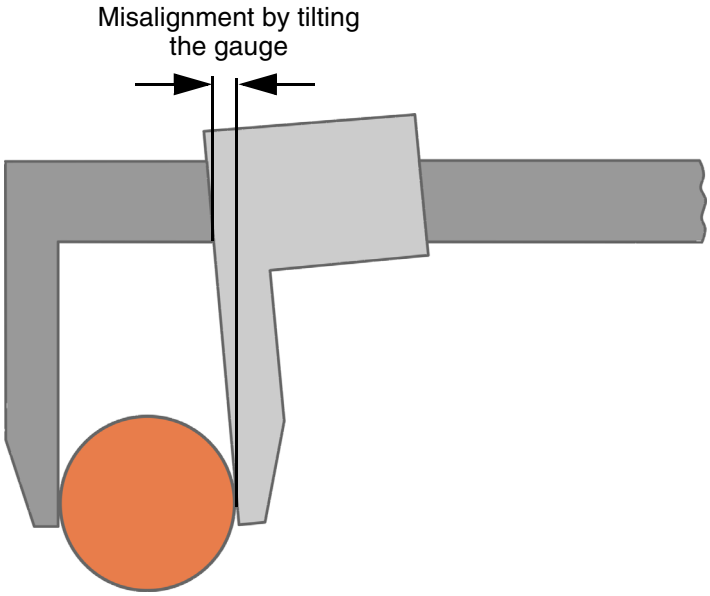


Fig. 3.2 Measuring error by tilting the gauge

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.

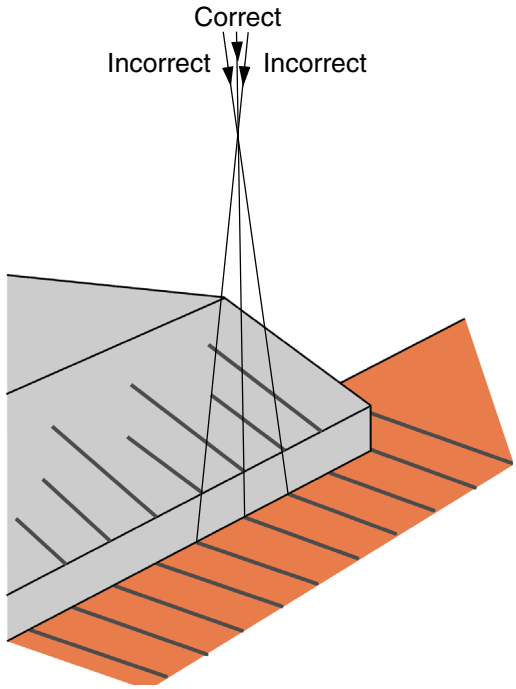


Fig. 3.3 Reading error due to parallax

Random measuring variations are reduced by:

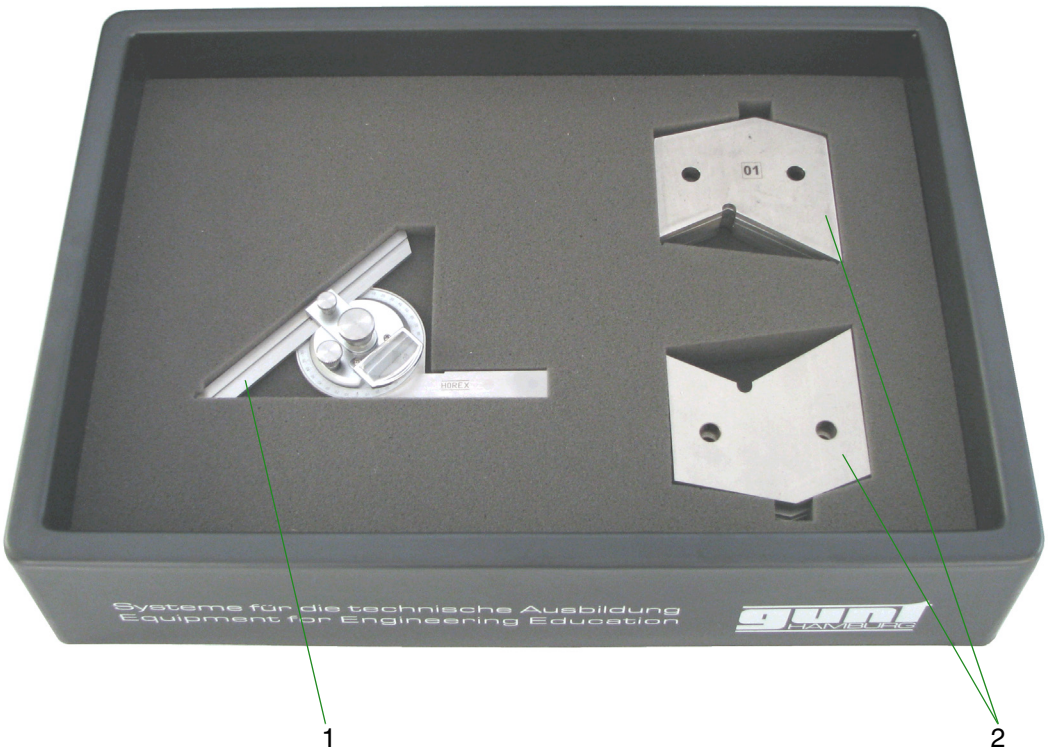
- Careful and calm working
- Multiple measurements

  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 training kit PT 104

4.1 Components



Item	Designation	Measuring range	Additional specifications
1	Universal goniometer	0...360°	Reading accuracy: 5'
2	Angle pieces 01 to 10	–	Manufacturing dimensions: See Chapter 4.3, Page 18

Fig. 4.1 PT 104 training kit

4.2 Test equipment

4.2.1 Universal goniometer

The universal goniometer is used to check angles.

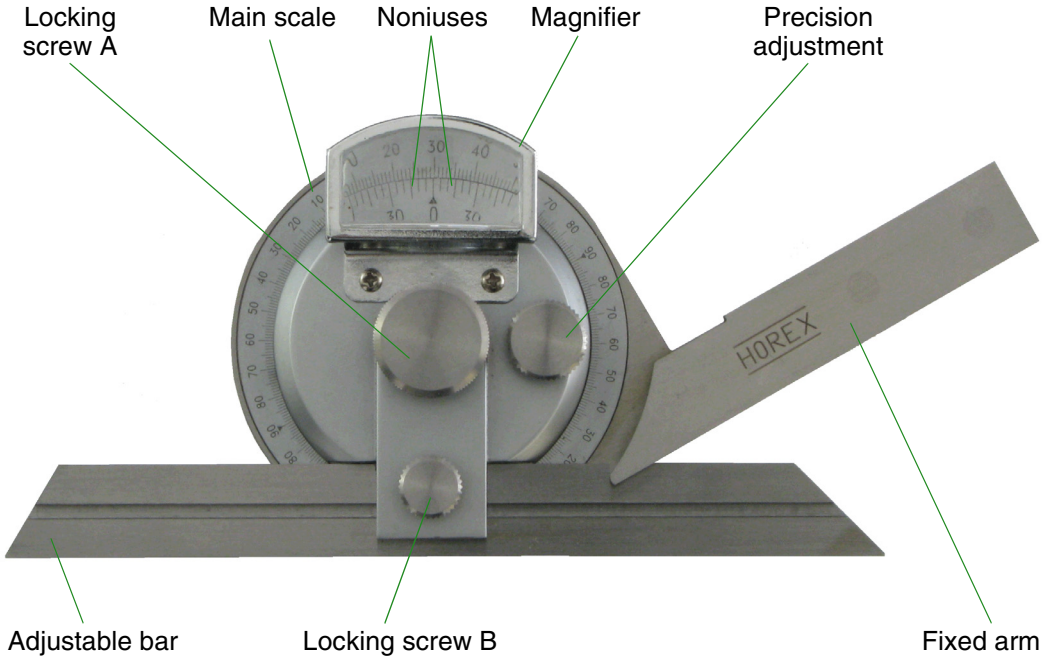


Fig. 4.2 Universal goniometer

The universal goniometer is made up of a fixed arm and an adjustable bar with a main scale, two noniuses and a magnifier.

Locking screw A allows the universal goniometer to be set to a particular angle and used as a gauge.

The universal goniometer is used as follows:

- The length and angle of the adjustable bar are adjusted until the test object is located between the fixed arm and the adjustable bar.
- The bar is then fixed in place with locking screw B, so that the bar forms a right angle with the noniuses.
- The precision adjustment mechanism is then used to move the adjustable bar towards the test object.
- The value on the main scale and one of the noniuses is then read.

When positioning the test object and reading the angle, it is important to note whether it the test object has an acute angle (< 90°) or an obtuse angle (> 90°). Both of these are explained on the following pages.

- **Acute angled test object**

  For an acute angled test object, the main scale and nonius are read *to the right*.

  – View the zero line of the nonius as the decimal point. Read off the full degrees (°) on the main scale 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 main scale. Each graduation corresponds to 5 minutes of angle ('). Read off the minutes here.

  – Add the two values together. This gives you the angle in degrees and minutes.

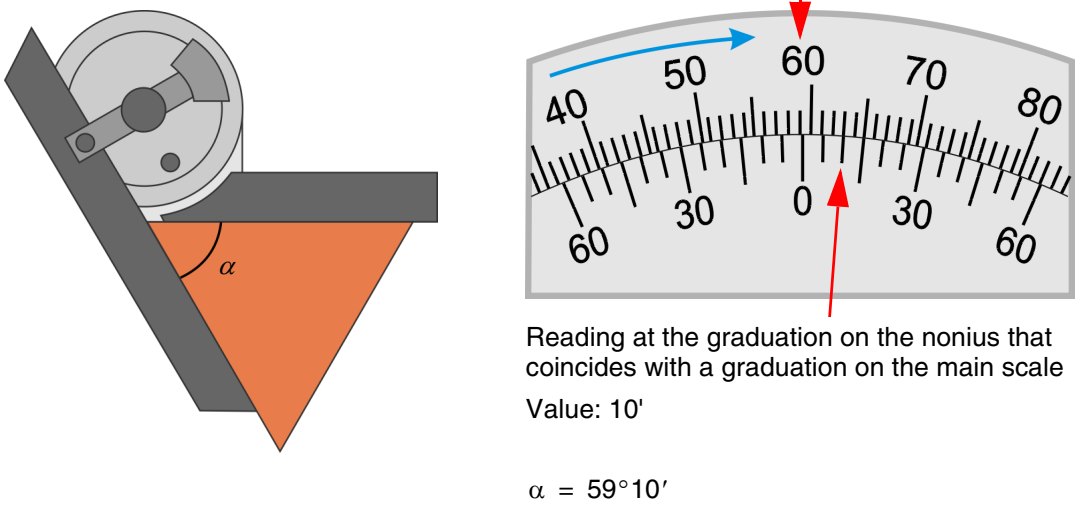


Fig. 4.3 Universal goniometer with acute angled test object

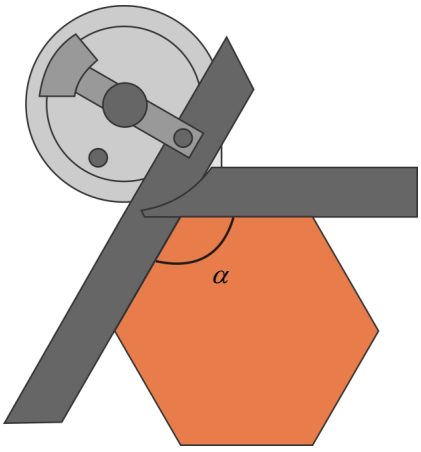
- **Obtuse angled test object**

  For an obtuse angled test object, the main scale and nonius are read *to the left*.

  – View the zero line of the nonius as the decimal point. Read off the full degrees (°) on the main scale at the zero line of the nonius.

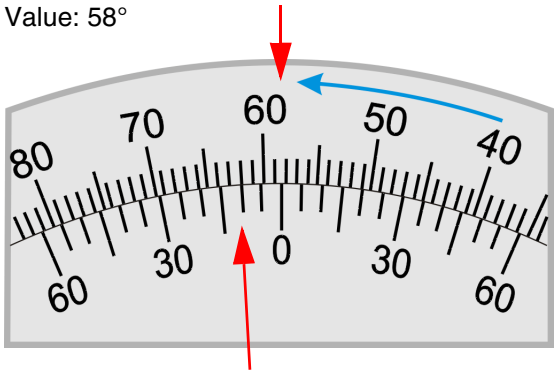
  – Then look to the left of the zero line for the graduation on the nonius that coincides with a graduation on the main scale. Each graduation corresponds to 5 minutes of angle (′). Read off the minutes here.

  – Add the two values together.
  Then subtract the total from 180°.
  This gives you the angle in degrees and minutes.



Reading at zero line

Value: 58°



Reading at the graduation on the nonius that coincides with a graduation on the main scale

Value: 10'

$\alpha = 180° - 58°10' = 121°50'$

Fig. 4.4 Universal goniometer with obtuse angled test object

4.3 Test objects

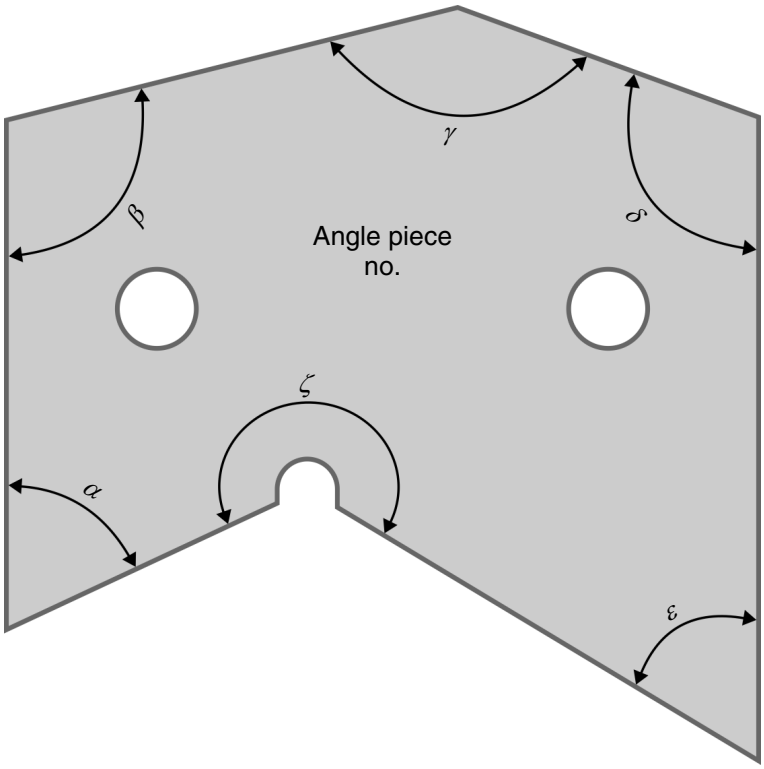


Fig. 4.5 Dimension drawing of angle pieces, scale 1 : 1

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

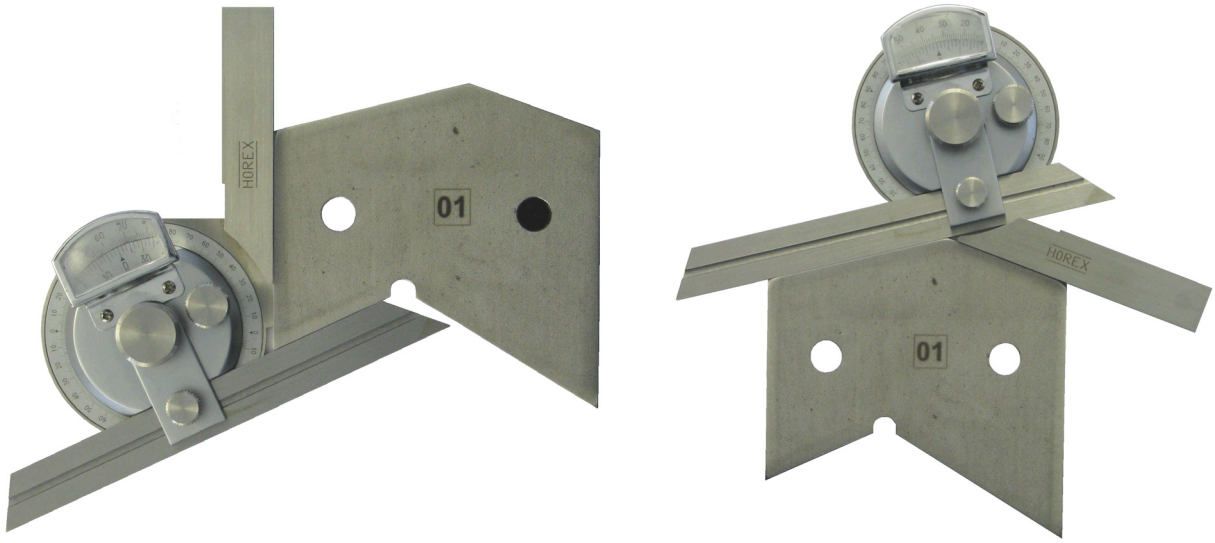
Dimension name	Tolerance	Angle piece 01	02	03	04	05	06	07	08	09	10
Angle											
α	**A**	65° 00'	66° 00'	66° 30'	64° 00'	65° 00'	66° 00'	67° 00'	66° 00'	64° 00'	64° 30'
β	**A**	104° 00'	103° 00'	102° 00'	105° 00'	103° 00'	105° 00'	105° 00'	104° 00'	103° 00'	103° 00'
γ	**B**	146° 00'	148° 00'	150° 00'	144° 00'	148° 00'	145° 00'	146° 00'	148° 00'	148° 00'	146° 00'
δ	**A**	110° 00'	109° 00'	108° 00'	111° 00'	109° 00'	110° 00'	109° 00'	108° 00'	109° 00'	111° 00'
ε	**A**	59° 00'	60° 00'	61° 00'	62° 00'	60° 00'	58° 00'	60° 00'	58° 00'	59° 00'	61° 00
ζ	**B**	236° 00'	234° 00'	232° 30'	234° 00'	235° 00'	236° 00'	233° 00'	236° 00'	237° 00'	234° 30'

Tab. 4.1 Selected angle piece dimensions
Tolerance A: ± 3', production tolerance
Tolerance B: Calculated, tolerances not taken into account

4.4 Examples for testing the test objects

The **PT 104** training kit contains a universal goniometer for checking the angles on the angle pieces specified in Fig. 4.5, Page 18.

Fig. 4.6 shows examples of measurements on an angle piece.



Acute angle Obtuse angle

Fig. 4.6 Measurements using the universal goniometer

5 Tasks

5.1 Worksheet A – Metrology

Page 1

1. Explain the difference between "testing" and "measuring".

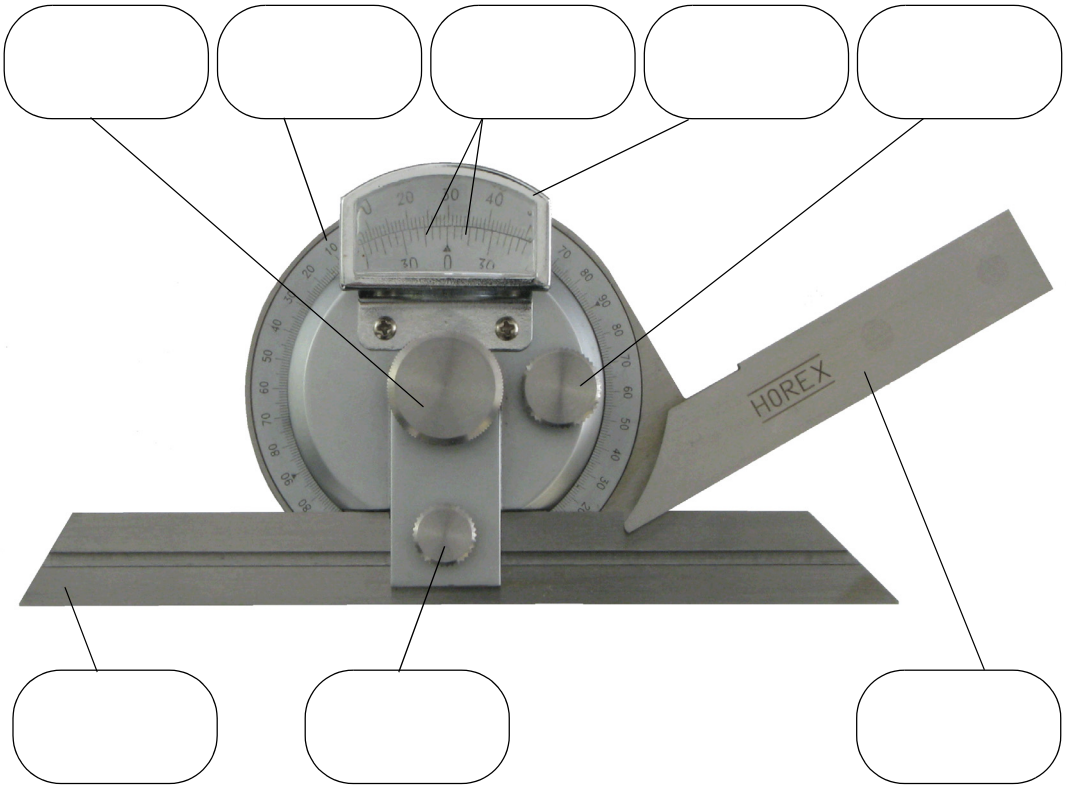
2. State possible causes of random measuring variations.

3. How do you avoid random measuring variations?

5.2 Worksheet B – Universal goniometer

Page 1

1. Name the parts of the universal goniometer.



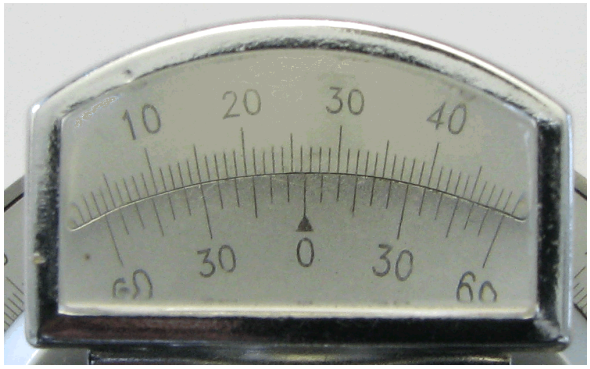
2. How is the angle of an obtuse angled test object determined?

5.3 Worksheet C – Reading measured values

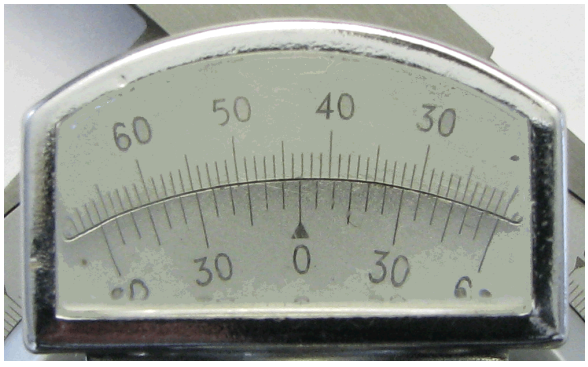
Page 2

1. The figures below show the main scale and nonius on a universal goniometer.

   In each case, note the value read and the measured angle.



Value read:	
Measured angle:	

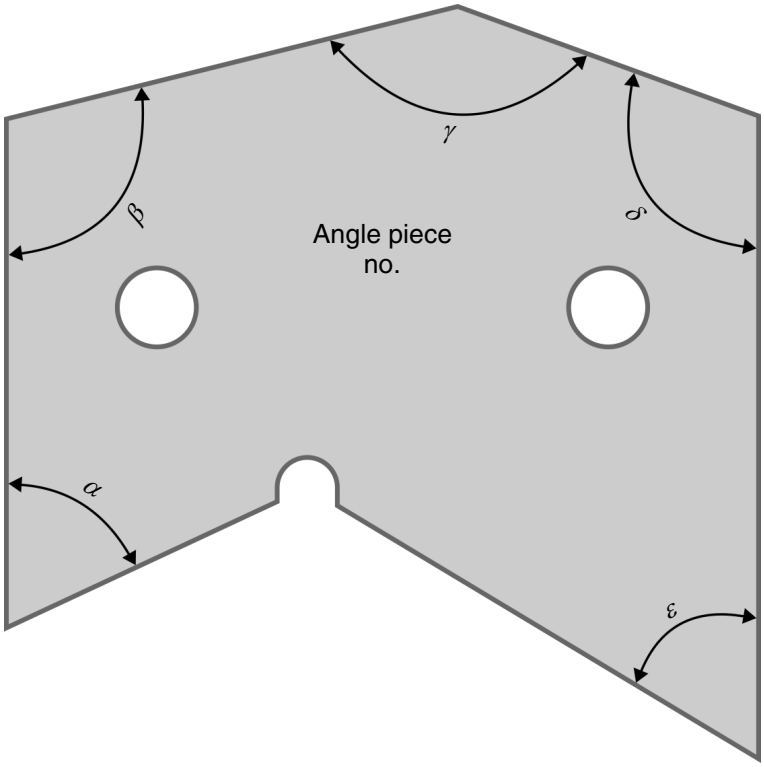


Value read:	
Measured angle:	

5.4 Worksheet D – Measuring angles on an angle piece

Page 1

1. Determine the dimensions α, β, γ, δ and ε on an angle piece and enter the values in the test report.



Worksheet D – Measuring angles on an angle piece

Page 2

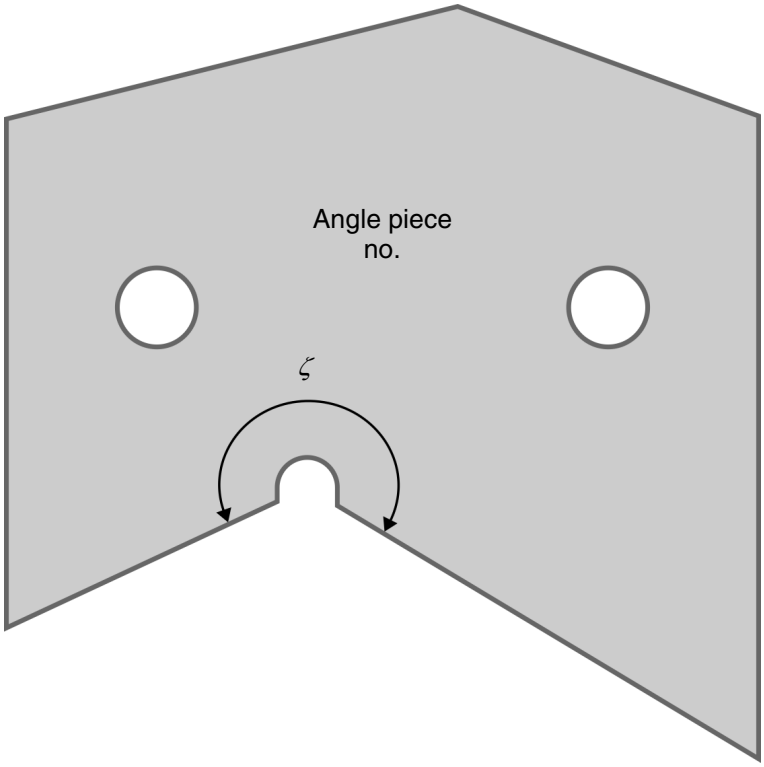
Test report	
Test object: Angle piece no. ____	
Date: _____	
Dimension name	**Measured dimension in ° and '**
α	
β	
γ	
δ	
ε	

5.5 Worksheet E – Determining angles that cannot be measured

Page 1

You need to determine the dimension ζ on an angle piece. This angle cannot be measured using the universal goniometer.

1. Which dimension do you have to measure? Identify the dimension and enter it in the drawing.



2. Which formula is used to calculate the angle ζ?

Worksheet E – Determining angles that cannot be measured

Page 2

3. Enter the measured value and your calculation of the angle ζ in the test report.

Test report		
Test object: Angle piece no. ____		
Date: _____		
	Dimension name	**Value in ° and '**
Measured dimension		
Calculated dimension	Angle ζ	

6 Solutions

6.1 Worksheet A – Metrology

Page 1

1. Explain the difference between "testing" and "measuring".

Testing involves using test equipment to establish whether a test object meets the specified requirements. The test equipment can be a measuring instrument or a gauge.

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

2. State possible causes of random measuring variations.

- Dirty measuring instruments.
- Reading the scale at an angle (parallax error).

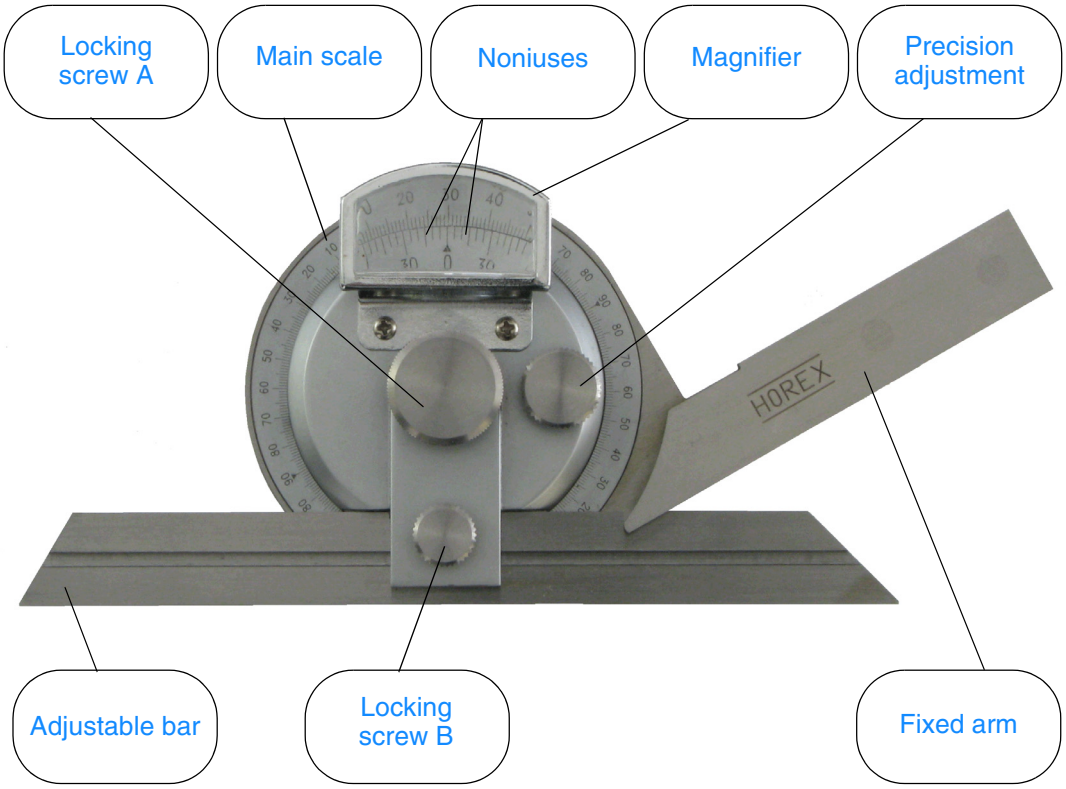
3. How do you avoid random measuring variations?

- By carrying out the measurements carefully and calmly.
- By carrying out the measurements several times and then calculating the mean value.

6.2 Worksheet B – Universal goniometer

Page 1

1. Name the parts of the universal goniometer.



2. How is the angle of an obtuse angled test object determined?

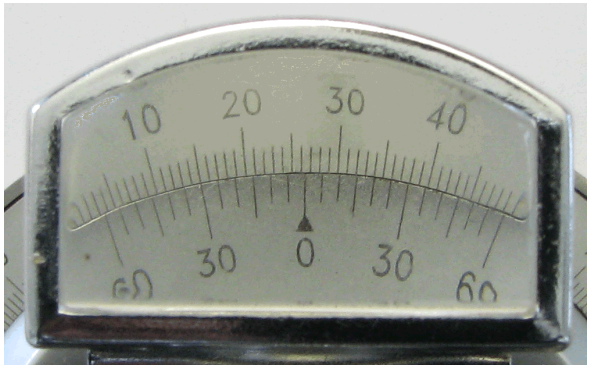
For an obtuse angled test object, the main scale and the nonius are first read to the left. The value read is then subtracted from 180°.

6.3 Worksheet C – Reading measured values

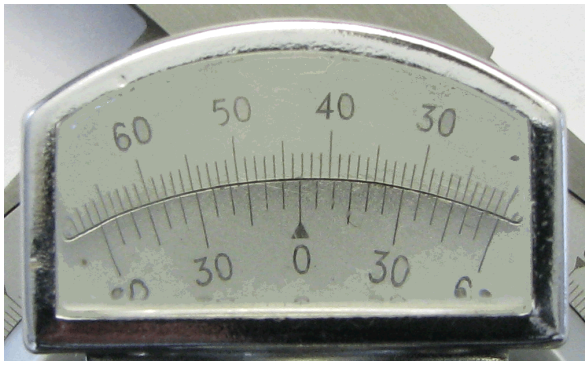
Page 2

1. The figures below show the main scale and nonius on a universal goniometer.

   In each case, note the value read and the measured angle.



Value read:	26° 25'
Measured angle:	26° 25'

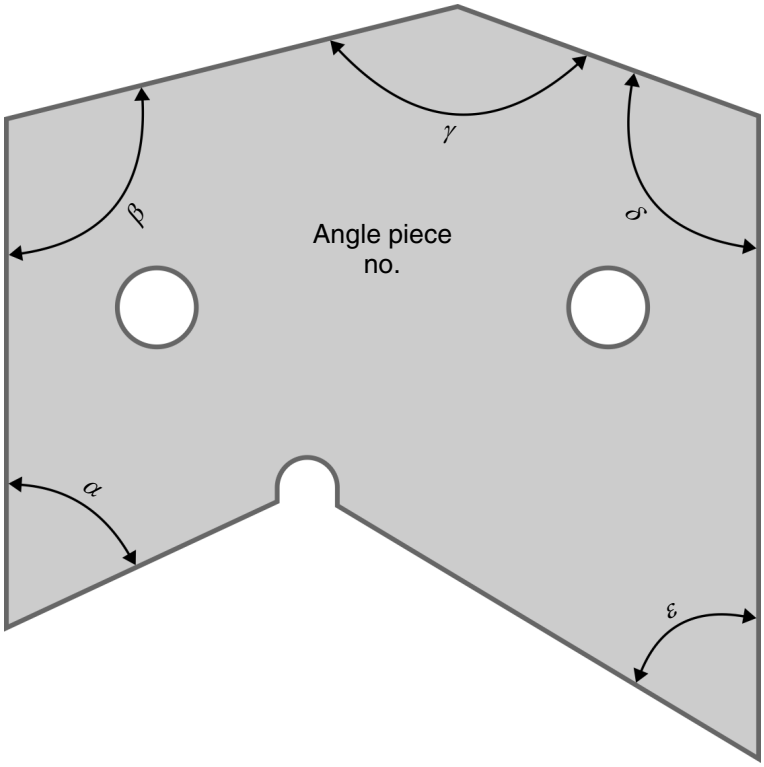


Value read:	43° 10'
Measured angle:	136° 50'

6.4 Worksheet D – Measuring angles on an angle piece

Page 1

1. Determine the dimensions α, β, γ, δ and ε on an angle piece and enter the values in the test report.



Worksheet D – Measuring angles on an angle piece

Page 2

Test report	
Test object: Angle piece no. ____	
Date: _____	
Dimension name	**Measured dimension in ° and '**
α	*
β	*
γ	*
δ	*
ε	*

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

Worksheet D – Measuring angles on an angle piece

Page 3

For the teacher only

Dimension name	Tolerance	Angle piece 01	02	03	04	05	06	07	08	09	10
Angle											
α	A	65° 00'	66° 00'	66° 30'	64° 00'	65° 00'	66° 00'	67° 00'	66° 00'	64° 00'	64° 30'
β	A	104° 00'	103° 00'	102° 00'	105° 00'	103° 00'	105° 00'	105° 00'	104° 00'	103° 00'	103° 00'
γ	B	146° 00'	148° 00'	150° 00'	144° 00'	148° 00'	145° 00'	146° 00'	148° 00'	148° 00'	146° 00'
δ	A	110° 00'	109° 00'	108° 00'	111° 00'	109° 00'	110° 00'	109° 00'	108° 00'	109° 00'	111° 00'
ε	A	59° 00'	60° 00'	61° 00'	62° 00'	60° 00'	58° 00'	60° 00'	58° 00'	59° 00'	61° 00

Tab. 6.1 Selected angle piece dimensions
Tolerance A: ± 3'
Tolerance B: Calculated, tolerances not taken into account

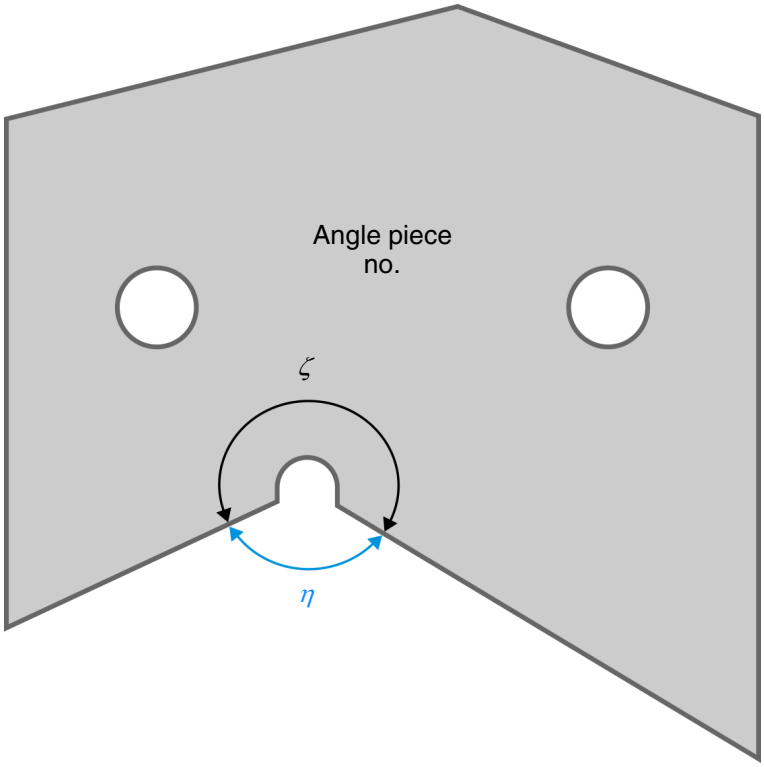
6.5 Worksheet E – Determining angles that cannot be measured

Page 1

You need to determine the dimension ζ on an angle piece. This angle cannot be measured using the universal goniometer.

1. Which dimension do you have to measure? Identify the dimension and enter it in the drawing.

   The angle η has to be measured.



2. Which formula is used to calculate the angle ζ?

   $\zeta = 360° - \eta$

Worksheet E – Determining angles that cannot be measured

Page 2

3. Enter the measured value and your calculation of the angle ζ in the test report.

Test report		
Test object: Angle piece no. ____		
Date: _____		
	Dimension name	**Value in ° and '**
Measured dimension	Angle η	*
Calculated dimension	Angle ζ	*

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

Worksheet E – Determining angles that cannot be measured

Page 3

For the teacher only

Dimension name	Tolerance	Angle piece 01	02	03	04	05	06	07	08	09	10
Angle											
η	B	124° 00'	126° 00'	127° 30'	126° 00'	125° 00'	124° 00'	127° 00'	124° 00'	123° 00'	125° 30'
ζ	B	236° 00'	234° 00'	232° 30'	234° 00'	235° 00'	236° 00'	233° 00'	236° 00'	237° 00'	234° 30'

Tab. 6.2 Selected angle piece dimensions
Tolerance B: Calculated, tolerances not taken into account