

Good Practice Guide No. 40

Callipers and micrometers

David Flack



Measurement Good Practice Guide No. 40

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ABSTRACT

This guide covers the use of callipers and micrometers for internal, external and depth measurements. The issues covered include the effect of measurement force, both when a ratchet is present (*e.g.*, micrometers) and when it is not, particularly when measuring soft materials; use and general care, support and handling of micrometers and callipers; guidance on choosing the most appropriate equipment type for the measurement; advice on calibration and verification methods and how to generate an uncertainty budget for a measurement; use of electronic instruments, fault awareness, temperature effects; awareness of errors introduced into internal knife edge jaws as external/internal jaws wear; and standard calibration methods and reporting of results.

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July 2001
Updated September 2014

ISSN 1368-6550

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Acknowledgements

The author acknowledges the following contributions to this guide. Alan Hatcher and Keith Bevan of Mitutoyo for providing useful technical input; Dr. Graham Peggs, Dr. Robert Angus and Brian Shipp for reviewing this document; UKAS for their valuable input to the project; All lead users who reviewed early drafts of this guide and last but not least the Department of Trade and Industry (DTI) for funding production of this guide as part of the 1999-2002 Length Program (Project MPU 8/61.3). The latest updates were funded by the UK National Measurement System Programme for Engineering & Flow Metrology.

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Callipers and Micrometers

Preface

The author hopes that after reading this Good Practice Guide you will be able to understand the correct way to make measurements with popular measuring hand tools. The content is written at a simpler technical level than many of the standard textbooks so that a wider audience can understand it. I am not trying to replace a whole raft of good textbooks, operator's manuals, specifications and standards, rather present an overview of good practice and techniques.

GOOD MEASUREMENT PRACTICE

There are six guiding principles to good measurement practice that have been defined by NPL. They are:

The Right Measurements: *Measurements should only be made to satisfy agreed and well-specified requirements.*

The Right Tools: *Measurements should be made using equipment and methods that have been demonstrated to be fit for purpose.*

The Right People: *Measurement staff should be competent, properly qualified and well informed.*

Regular Review: *There should be both internal and independent assessment of the technical performance of all measurement facilities and procedures.*

Demonstrable Consistency: *Measurements made in one location should be consistent with those made elsewhere.*

The Right Procedures: *Well-defined procedures consistent with national or international standards should be in place for all measurements.*

Introduction

1

IN THIS CHAPTER

- What this guide is about and what it is not
- Callipers and micrometers
- Units of measurement

This measurement good practice guide provides an overview of the use of callipers and micrometers. It is an update to a guide first published in 2001 and has been updated to reflect changes in the specification standards over the last ten years.

What this guide is about and what it is not

It is intended that this guide should give enough information so that the metrologist can make best use of micrometers and callipers. The guide also covers good practice regarding storage and care of micrometers and callipers. This good practice guide is not intended to be an authoritative guide to the standards and the primary reference should always be the standards themselves.

Callipers and micrometers

This guide covers the use of callipers and micrometers for internal, external and depth measurements.

Issues covered in this guide include the effect of measurement force, both when a ratchet is present (for example, micrometers) and when it is not, particularly when measuring soft materials; use and general care, support and handling of micrometers and callipers; guidance on choosing the most appropriate equipment type for the measurement; advice on calibration and verification methods and how to generate an uncertainty budget for a measurement; use of electronic instruments, fault awareness, temperature effects, comparison of usage with non-electronic instruments; awareness of errors introduced into internal knife edge jaws as external/internal jaws wear and standard calibration methods and reporting of results.

Callipers are covered in chapter 2 of this guide and micrometers in chapter 3.

BSI Implementation of ISO standards

ISO standards have replaced many of the British Standards relating to micrometers and callipers since the last issue of this guide. These new standards cover the design and metrological characteristics of the instrument but do not specify values for these characteristics. The manufacturer's datasheet now specifies these values and will need to be referred to in conjunction with the standard.

Who made this decision?

Development of the new standards was the responsibility of working group 6 of ISO technical committee 213. Members of the UK national committee TDW4/4 were involved in the discussions that led to these standards. BSI is obliged to adopt all European standards (ENs) developed by CEN, CENELEC and ETSI and to withdraw any existing British Standards that conflict with them. That was the procedure followed in the case of the instrument standards.

In addition, with changes to BS0 (A standard for standards) the option of giving the existing standards the status obsolescent was removed.

Standards such as BS 870:2008 have been withdrawn but will remain applicable for the foreseeable future as they can be used as guidance to specify the metrological characteristics when completing the data sheet presented in, for instance, Annex B of EN ISO 3611.

What does this mean for the consumer? It means that in the past when specifying, for instance, that a micrometer should comply with BS870 you knew exactly what to expect from its performance. However, with the new standards you will have to carefully examine each manufacturers' specification to see which micrometer is suitable for your application. This may seem like more work. However, it will also mean that you do not buy an instrument that is over specified for the task. Section 6.2 of ISO 14978 gives some guidance, as does Annex B.

There will also be implications for calibration laboratories. When a calibration laboratory receives an instrument made to one of these new standards they will need to contact the manufacturer of the instrument to source the appropriate technical specification.

For the user, ISO 14978 states

The metrological characteristics necessary for the intended use of the instrument shall be chosen and shall be verified by calibration (or verification tests). The calibrated value(s) of the metrological characteristic(s) shall be stated with the related measurement uncertainty/uncertainties, and/or the calibrated values of the metrological characteristic shall be proven to be in conformance with the actual MPE value(s).

This statement puts the onus on the user to understand fully the measurement process and to base the calibration procedure on those metrological characteristics that are important to the process.

Why has it changed?

If we look at ISO 14978 it states:

Standards for specific measuring equipment, with the exception of a few examples (that is to say, ISO 1938 and ISO 3650), shall not include any numerical values for MPEs and MPLs, but shall include empty tables for MPE or MPL values as a guidance for the user of the standard. Numeric values for MPEs (and MPLs) will normally be specified by the manufacturer, in the case of acceptance tests, and by the user, in the case of verification tests.

The key phrase is; shall not include any numerical values for maximum permissible errors (MPEs) and maximum permissible limits (MPLs).

Units of measurement

Parts of this guide cover the use of instruments calibrated in imperial units. European Directives cover units of measurement. The directives that are currently in force are Council

Directive 80/181/EEC as amended by Directives 85/1/EEC and 89/617/EEC. These directives apply in the United Kingdom. The principal purpose of the Directives is the phase out of the use of non-metric units of measurements in the favour of metric ones. The Directives have been implemented in general in Great Britain by the Units of Measurement Regulations 1986, SI 1986/1082, as amended by SI1994/2867. For further information contact BIS.

Website: www.bis.gov.uk/assets/nmo/docs/legislation/legislation/units-of-measurement/gnotes-for-public-sector-on-use-of-metric.pdf

In general, always use SI units for length measurement unless there is a very good reason to use imperial units.

Callipers

2

IN THIS CHAPTER

- Operating Principles
- Examples of types of measurement
- Reading vernier callipers
- Set-Up, Preparation And Measurements
- Factors affecting calliper performance
- Handling and storage of callipers
- Special purpose callipers
- Sources of measurement uncertainties and error
- Uncertainties when making measurements with callipers
- A note regarding the purchasing of callipers
- Chapter summary

The purpose of chapter 2 is to give the reader an introduction to some of the considerations necessary when using callipers for measurement. The operating principles of callipers will be discussed along with factors affecting performance and sources of measurement uncertainty and error. Finally, handling and storage of callipers will be discussed.

Operating principles

Introduction

The vernier calliper (figure 1) is a measuring instrument that incorporates a main scale, a vernier scale and a fixed and sliding jaw. Other types of calliper may employ other types of readout such as, a dial for least count readout or an electronic digital readout. Three types of measurement can be made with a typical calliper, that is to say, outside, inside and depth (figure 10 to figure 12).

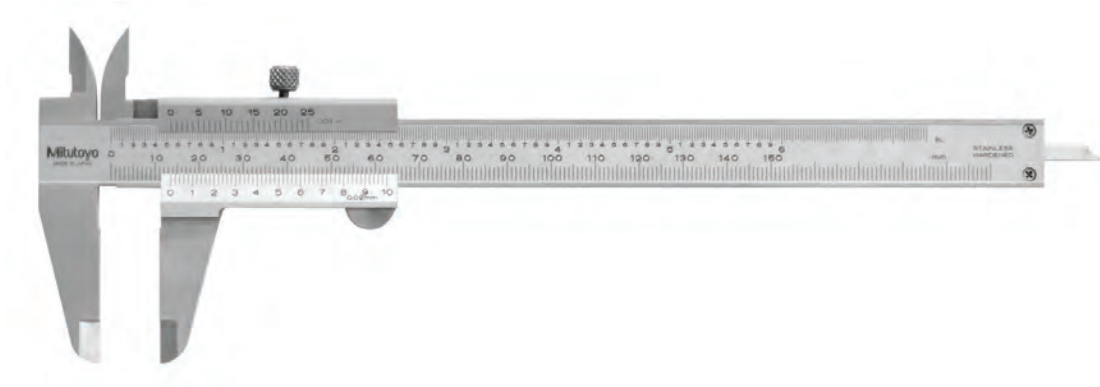


Figure 1 M type vernier callipers

Callipers are available in various sizes, with measuring ranges from 100 mm to 3000 mm (4 in. to 120 in. for inch callipers). Generally, callipers that have a measuring range of 300 mm (12 in.) or less are classified as small callipers and ones with larger ranges are classified as large callipers.

Typical measurement resolutions are 0.05 mm for a vernier calliper, 0.02 mm for dial callipers and 0.01 mm for digital callipers.

The standard specifications relevant to callipers are listed below.

ISO 3599:1976 *Vernier callipers reading to 0,1 and 0,05 mm**

ISO 6906:1984 *Vernier callipers reading to 0,02 mm**

BS EN ISO 13385-1:2011 *Geometrical product specifications (GPS) — Dimensional measuring equipment — Part 1: Callipers; Design and metrological characteristics;*

BS EN ISO 13385-2:2011 *Geometrical product specifications (GPS) — Dimensional measuring equipment — Part 2: Calliper depth gauges; Design and metrological characteristics*

BS 887:2008 *Precision vernier callipers. Requirements and test methods**

JIS B 7502 *Micrometer callipers*

JIS B 7507:1993 *Vernier, dial and digital callipers*

*** Note: These standards have now been withdrawn**

Types of vernier callipers

JIS B 7507:1993 *Vernier, dial and digital callipers* specifies two types of standard vernier callipers, the M-Type and the CM-Type. The M type (figure 2) has independent jaws for internal and external measurement. With the CM type (figure 3), the faces for internal and external measurement are on the same jaws.

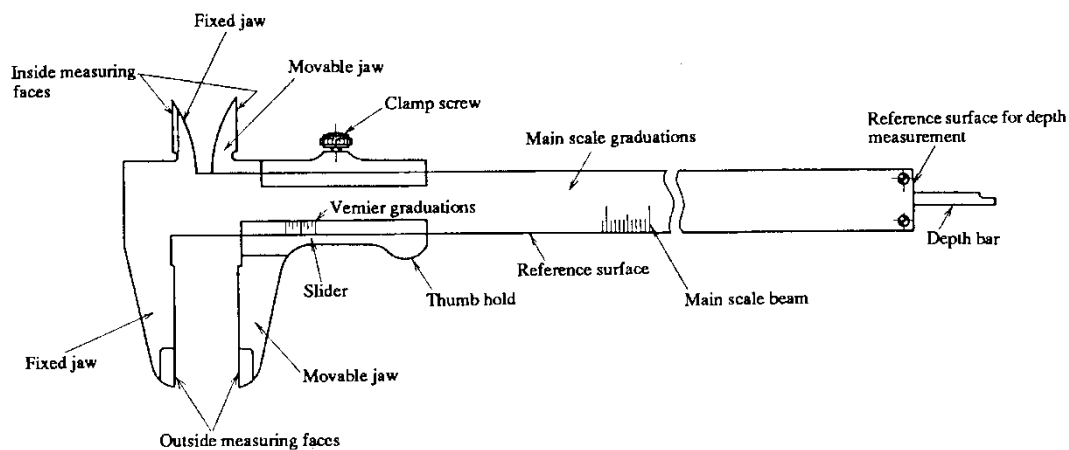


Figure 2 M type vernier calliper for external, internal and depth measurement (slider with locking screw or clamping device)

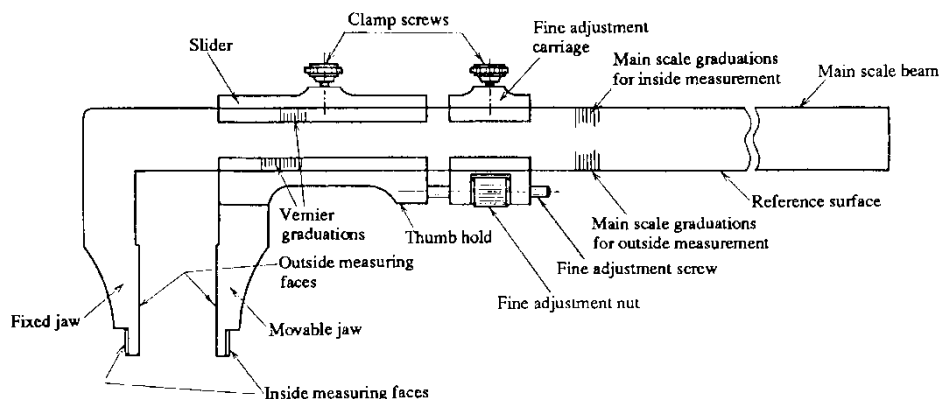


Figure 3 CM Type Precision vernier calliper a design of callipers for external and internal measurement with a fine adjustment device

The CM type is the type of calliper covered by ISO 6906 and ISO 3599. The M type is covered by ISO 3599. Both types are covered in BS EN ISO 13385. Other types of calliper include the dial calliper (figure 4) and the electronic calliper (figure 5), also covered in BS EN ISO 13385.

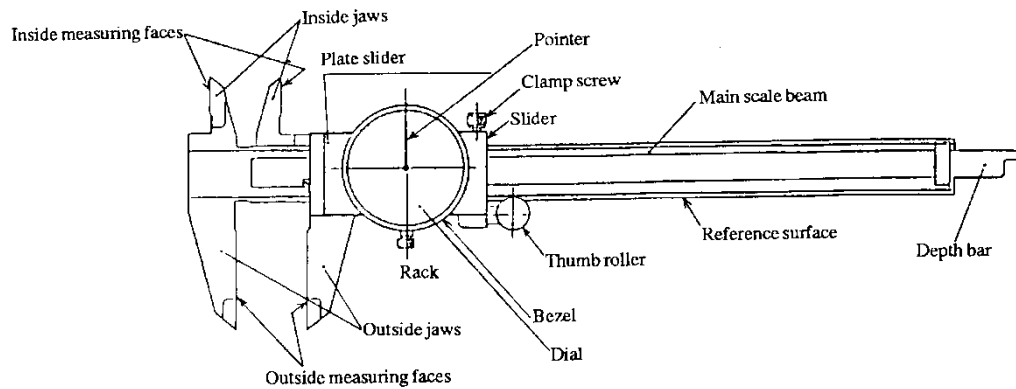


Figure 4 Dial calliper (analogue indicating device with circular scale)

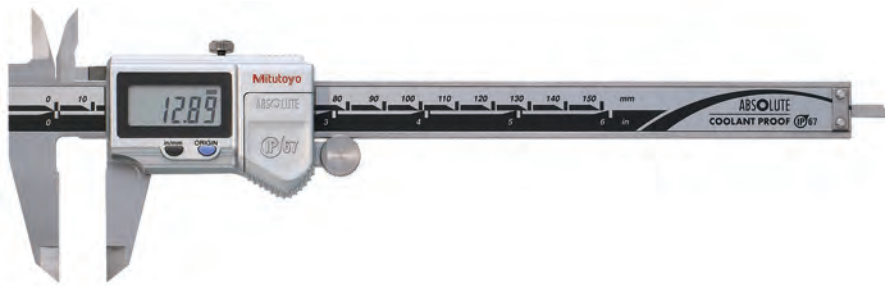


Figure 5 Electronic (digital) calliper (digital indicating device with digital display)

Standard vernier calliper

Making a measurement with a vernier calliper involves the use of two scales, one being the main scale on the beam and the other the vernier scale (figure 6).

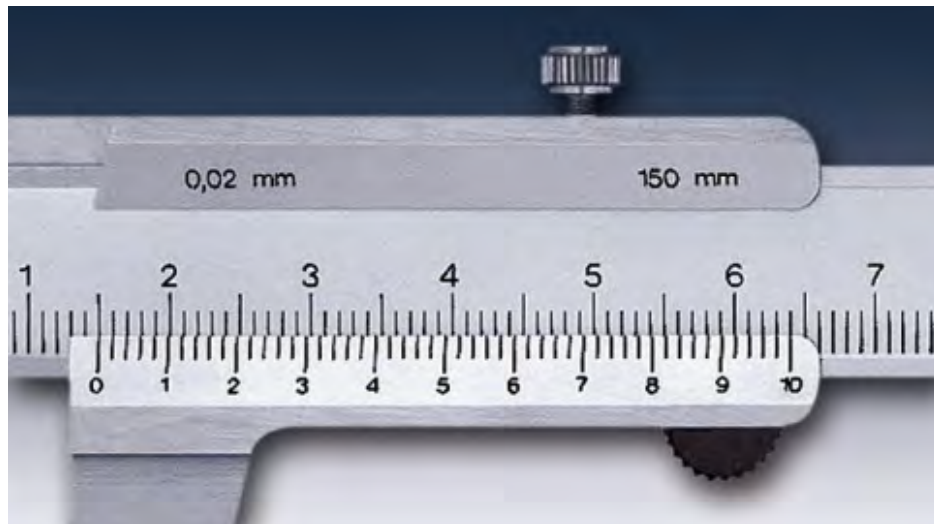


Figure 6 Image showing main (1 mm divisions) and vernier (0.02 mm resolution, 50 vernier divisions in 49 mm) scales.

The vernier scale allows measurements to be taken which are smaller than the intervals between the main scale graduations. This is achieved with a vernier scale graduation spacing that is shorter than that on the main scale for example 20 vernier divisions occupy 19 divisions on the main scale. The measurement result is obtained by finding the graduation on the vernier scale that is most closely aligned with a graduation on the main scale (see the section on reading vernier callipers).

Examples of main and vernier scale graduations are listed in table 1 (metric) and table 2 (imperial).

Table 1 Graduations of main and vernier scales (metric)

Metric		
Main scale divisions	Vernier graduations	Vernier resolution
0.5 mm	25 divisions in 12 mm	0.02 mm
	25 divisions in 24.5 mm	0.02 mm
1.0 mm	50 divisions in 49 mm	0.02 mm
	20 divisions in 19 mm	0.05 mm
	20 divisions in 39 mm	0.05 mm

Table 2 Graduations of main and vernier scales (imperial)

Inch		
Main scale divisions	Vernier graduations	Vernier resolution
1/16 in	8 divisions in 7/16 in	1/128 in
1/40 in	25 divisions in 1.225 in	1/1000 in
1/20 in	50 divisions in 2.45 in	1/1000 in

Dial callipers

Extensive use is made of dial callipers (figure 7) because they provide an easier method of reading when compared with vernier callipers thus allowing quicker measurement. The dial calliper uses the amplification mechanism of a dial gauge. To take a measurement, simply add the position of the pointer on the dial to the reading on the main scale. Before using dial callipers, clean the jaws. The jaws should then be closed and the zero adjusted by rotating the scale bezel. With dial callipers, it is essential to keep the toothed rack clean. Contamination can cause the pinion gear to jump and lead to the pointer not returning to zero. Dial graduations are listed in table 3 and figure 8 illustrates a specific example.

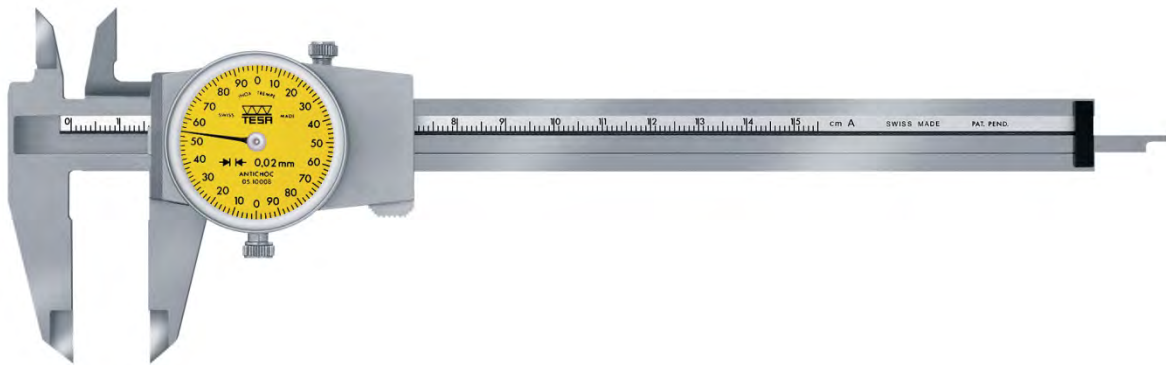
**Figure 7 Dial calliper (courtesy Tesa Group)**

Table 3 lists dial calliper graduations.

Table 3 Dial calliper graduations

Type	Metric			Inch		
	Division	Dial Graduations	Displacement/ Revolution	Division	Dial Graduations	Displacement/ Revolution
D-type	0.05 mm	100 divisions around circumference	5 mm/rev	0.001 in	100 divisions around circumference	0.1 in/rev
DT-type	0.02 mm	100 divisions around circumference	2 mm/rev	0.001 in	200 divisions around circumference	0.2 in/rev
DE-type	0.01 mm	100 divisions around circumference	1 mm/rev			



Figure 8 Close up of the dial. Note that there are 100 divisions in one revolution. The resolution is 0.001 inch (courtesy Tesa group).

Electronic calliper

The electronic calliper (figure 9) has a digital display and generally uses a linear encoder as its displacement detection system. This linear encoder may be capacitive, inductive or magnetic. The advantages of this type of instrument are ease of reading and operation and enhanced functionality. Before electronic callipers are used, clean the jaws. After cleaning, close the jaws and set the zero.

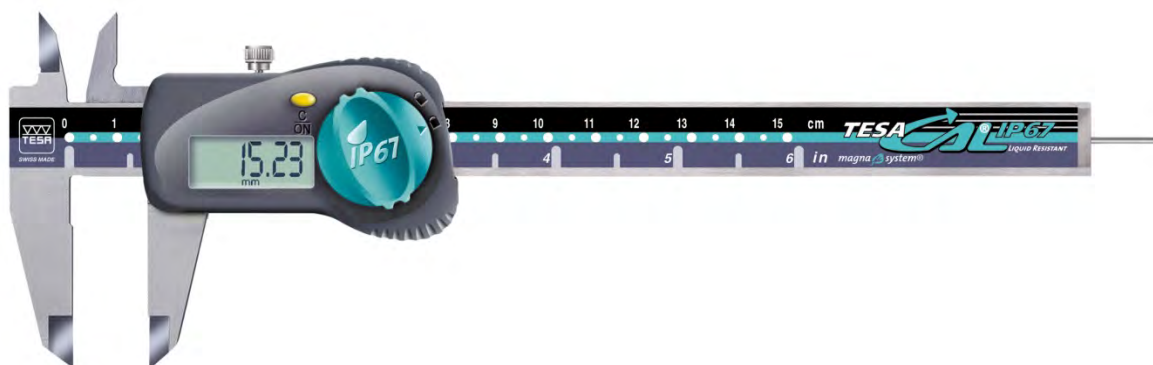


Figure 9 Electronic calliper with digital display (courtesy Tesa Group)

Examples of types of measurement

Callipers are versatile instruments and a number of different types of measurement can be made using callipers. Some examples are given below in figure 10, figure 11 and figure 12 (adapted from Annex D of ISO 13385-1). Figure 10 shows callipers being used for external measurements. Figure 11 shows callipers being used for internal measurements. Figure 12 shows step and depth measurements being performed with callipers.



Figure 10 External measurement (courtesy Tesa Group).



Figure 11 Internal measurements (courtesy Tesa group).

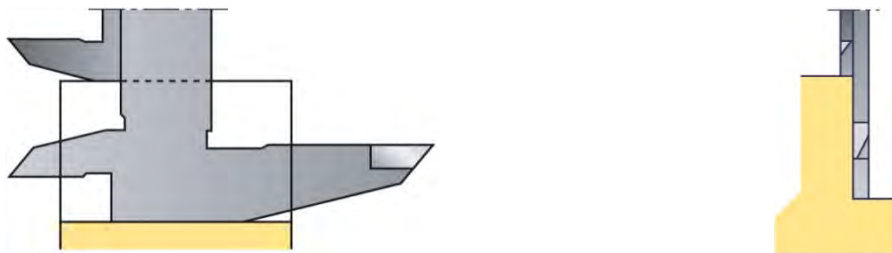


Figure 12 Step or depth measurements (courtesy Tesa group).

Reading vernier callipers

The following example explains how a reading is taken using a metric vernier calliper. Figure 13 illustrates the case where the zero graduation on the vernier scale aligns perfectly with a graduation on the main scale.

MAIN AND VERNIER SCALE

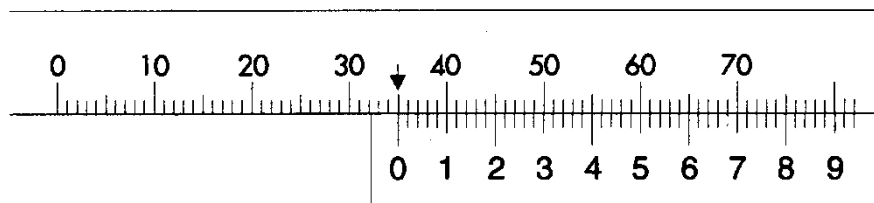


Figure 13 An integer reading

In this case, the zero on the vernier scale and the 35 mm graduation on the main scale align. The correct calliper reading is therefore 35.00 mm.

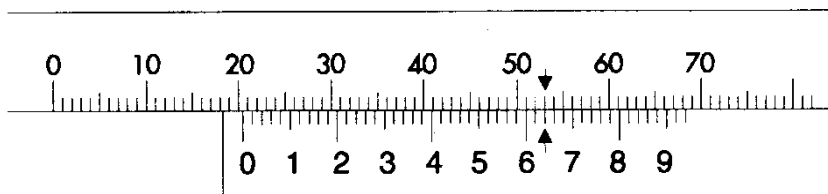


Figure 14 A non-integer reading on the main scale

Figure 14 illustrates the case where the zero on the vernier scale does not line up with a graduation on the main scale. In this case the procedure for finding the correct reading is as follows.

1. Look along the main scale and determine the smaller of the two graduation numbers that most closely line up with the zero on the vernier scale. In the example above (figure 14) the zero on the vernier scale lies between 20 and 21 on the main scale. The correct main scale reading to use is therefore 20.
2. Now look along the vernier or sliding scale and see which graduation lines up with a main scale division. In figure 14 this is 64 on the vernier scale.
3. The correct reading in the above example is therefore $20 \text{ mm} + 0.64 \text{ mm} = 20.64 \text{ mm}$

Figure 15 and figure 16 show further examples for callipers with 0.05 mm and 0.02 mm discrimination.

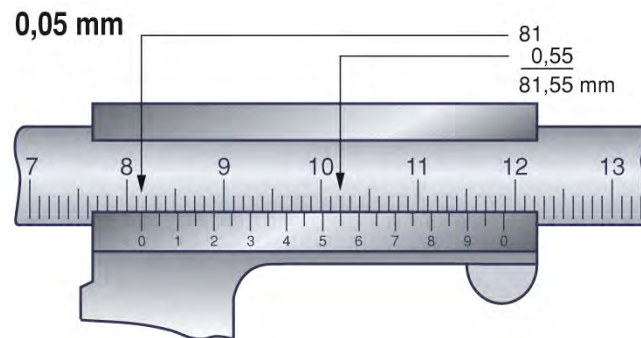


Figure 15 A further example (courtesy Tesa group)

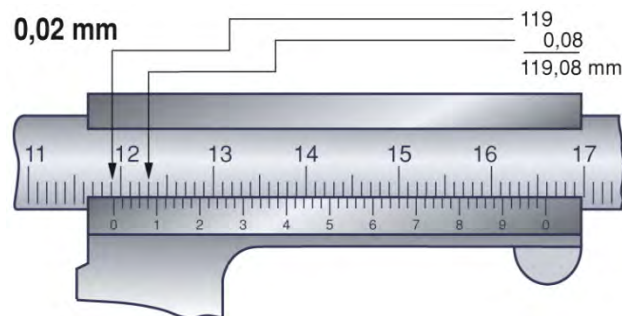


Figure 16 A further example (courtesy Tesa group)

Set-up, preparation and measurements

Now we know how to read the callipers it's now time to make a measurement. It is good practice to observe the following list of steps and precautions when making external measurements with callipers. British standard BS 887:2008 *Precision vernier callipers – Requirements and test methods* Appendix C contains notes on the use of precision callipers. ISO 13385-1 contains further information in its Annex B.

Set-up and preparation

1. Select the calliper that best suits the application by ensuring that the type, measuring range, graduation and other specifications of the calliper are appropriate for the measurement to be made.
2. Check that the calliper calibration has not expired. If the calibration has expired, use another calliper whose calibration is valid.
3. Inspect the calliper measurement faces for signs of damage. Do not use damaged callipers.
4. Before taking a measurement, remove cutting chips, dust, burrs, *etc.* from the workpiece. Make sure that the workpiece is at room temperature.
5. Wipe off any dust and oil from the calliper before use. Thoroughly wipe the sliding surfaces and measuring faces, using only clean lint free paper or cloth.
6. When measuring, slowly move the slider while lightly pressing the finger hold against the main scale. The slider should not feel loose or have any play. If any problems are found they should be corrected by adjusting the pressing screw and setscrew on the slider (if fitted). Tighten the pressing screw and setscrew, then loosen them in a counter clockwise direction about 1/8 of a turn (45°). Check the sliding action again. Repeat the procedure

while adjusting the angular position of the screws until an appropriate sliding smoothness is obtained.

7. Check the zero reading.

Measurements

The procedure to make measurements is as follows

1. Close the jaws and set the calliper zero.
2. Open the callipers to a length larger than the size of the object to be measured.
3. Placed the fixed jaw in contact with the workpiece. The workpiece should be as close as possible to the main scale.
4. Align the beam of the calliper to be parallel with dimension to be measured and bring the sliding jaw into contact with the workpiece ensuring that the measuring faces are in even contact. Do not use excessive force to avoid distorting either the work piece or instrument frame. If a clamping screw is fitted, use this to reduce angularity error. Do not regard the clamping screw as a memory device.
5. Record the calliper reading.
6. Recheck the zero reading. If the zero is incorrect, this may be a sign that a piece of dirt has transferred from the work piece to the calliper faces. Clean the faces and work piece, and repeat the measurements from step 1.

Consistency of measurement may be gained by first using the calliper on a standard length bar assembly. This is particularly useful when the operator is required to 'feel' the jaws in contact with the item to be measured.

Taking several measurements on any one dimension and recording the mean can give extra confidence in measurements and is necessary for estimating the uncertainty of measurement.

Factors affecting calliper performance

No measuring instrument can be manufactured to be absolutely free from errors. As the accuracy requirements of a measuring instrument become higher so the difficulty in manufacturing increases, and the manufacturing costs rise accordingly. Therefore, select measuring instruments according to the accuracy requirement of the intended application. Even if a very accurate instrument is used it should be noted that, measurement errors might still occur due to variations in environmental conditions and operator errors.

The instrumental error (deviation of reading) is the error that is inherent to a measuring instrument. In other words, it is the difference between the true value and the measured value, when making a measurement under the standard conditions specified for that instrument. It is important to know the instrument error because by compensating for the error, it is possible to obtain measurements that are more accurate than they would otherwise have been.

Instrumental errors are determined by calibration and are usually given in the inspection certificate or technical specifications that are supplied with the instrument. When compensating a measured value for the instrumental error, you need to change the sign of the instrument error value and add it to the measured value.

Check the performance of a calliper according to the following procedures:

Instrumental error of outside measurement

Insert a gauge block between the two faces used for external measurement (figure 17) and record the reading. Determine the instrumental error by subtracting the calibrated dimension of the gauge block from the reading on the calliper. This test should be performed at a minimum of five approximately equally spaced positions covering the measuring range of the main scale and the vernier scale.

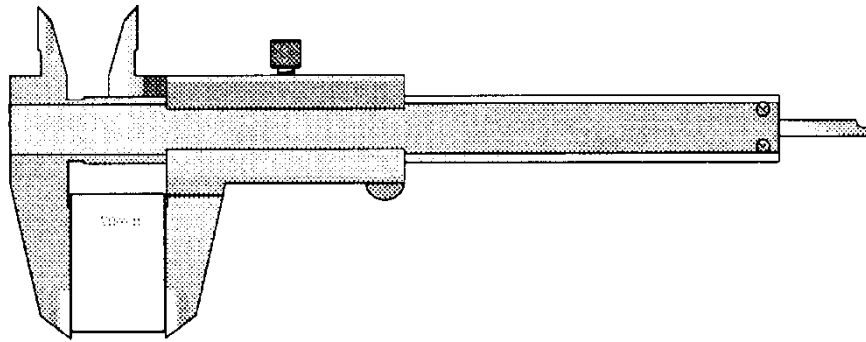


Figure 17 Checking outside measurement capability

Check the parallelism of the faces by inserting a gauge block at different points on the jaw. The use of a second gauge block of different length allows this test to be performed at two positions in the measuring range. One position should be close to zero and the other close to full range. Check that parallelism is not affected by clamping the slider. Check the squareness of the fixed face to the guiding edge with a knife-edge square. Check the flatness of the faces with an optical flat (See *Fundamentals of Dimensional Metrology* Chapter 13 – full details at the end of this guide).

Instrumental error of inside measurement

Produce a known internal dimension using a gauge block and holding device and jaws from an accessory set (figure 18). Measure the dimension between the jaws using the faces for internal measurement and record the reading. Determine the instrumental error by subtracting the dimension of the gauge block from the reading on the calliper.

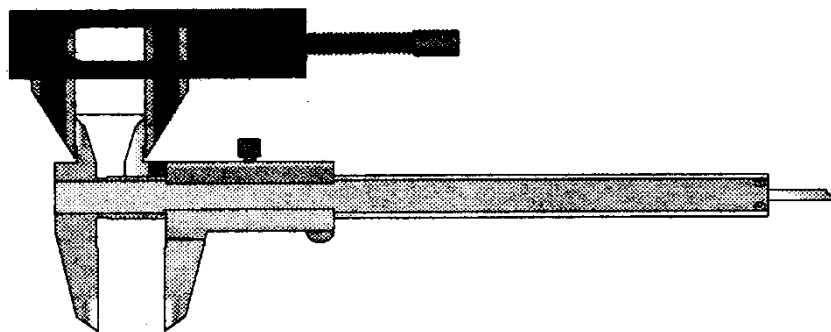


Figure 18 Checking the inside measurement capability

Check the parallelism of the faces for internal measurement with a micrometer with small diameter anvils.

Straightness of inside and outside measuring faces

To check the straightness of the faces set a lever-type dial indicator on a surface plate so that its contact point can move parallel to the outside and inside measuring faces of the calliper. Measure the straightness of the outside and inside measuring faces by sliding the dial indicator stand (see figure 19) and noting the change in reading.

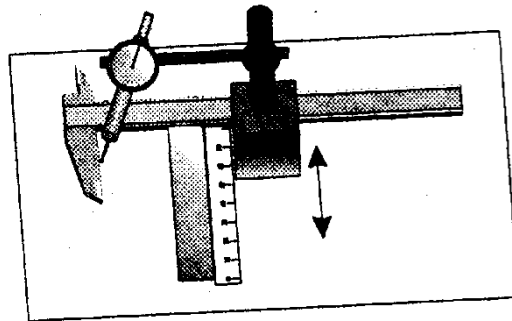


Figure 19 Straightness of inside faces

Further information

Appendix B of BS887:2008 (withdrawn) gives further information of methods of testing precision vernier callipers as does Annex A of BS EN ISO 13385-1.

Handling and storage of callipers

Callipers are often used in hostile environments and their maintenance tends to be overlooked perhaps because of their apparently simple construction and the low accuracy use to which they are often put. However, in order to obtain the best possible performance from callipers and to ensure economical use, it is essential to implement effective maintenance control. As with other types of measuring instruments, companies should have standardised rules that govern purchasing, training, handling, storage, maintenance and periodic inspection of callipers.

Storage of callipers

Observe the following precautions when storing callipers.

1. Select a place where the callipers will not be subject to dust, high humidity or extreme temperature fluctuations. The storage area should not be damp and it is worth taking the extra precaution of placing a bag of silica gel in the tool draw.
2. Lay callipers in a manner such that the main scale beam will not bend and to give adequate protection from damage to the vernier.

3. Leave the measuring faces so that they are not in contact. A gap of about 2 mm is suggested
4. Do not clamp the slider
5. Store the calliper in a case or plastic bag.
6. When storing large size callipers, which are not frequently used, apply a rust preventative to the sliding and measuring faces and separate the two jaws. Avoid rust preventatives that leave a coating on the material being protected. This type of rust preventative material can affect the calibration of dial type callipers.
7. For callipers that kept in storage and are seldom used, at least once a month, check the storage condition and movement of callipers to ensure that no deterioration has occurred.
8. Prevent vapours from chemicals such as hydrochloric or sulphuric acid from permeating storage rooms.
9. Keep a record of callipers that are stored. Maintain detailed information on all callipers in use on the shopfloor.

It is also good practice, during the daily use of a calliper, to wipe it clean of dirt and fingerprints with a clean lint-free cloth and store it with the outside jaws slightly open on completion of measurements.

Never leave callipers unprotected on a swarf-covered bench or in an environment where the graduated face is regularly exposed to cutting chips and dust, since the graduations may become hard to read due to scratches or stains and slider movement may become uneven. Once measurements are complete, clean and properly store the callipers.

Periodic inspection and calibration

It is good practice to carry out periodic inspections of callipers at least once a year, the exact interval depending on the frequency of use. In addition, implement inventory control methods to prevent inadvertent use of callipers known to be in need of repair or are beyond repair and are for disposal. There are two systems of making periodic inspections. One is to inspect the callipers at each work site and the other is to collect all the callipers at predetermined intervals and inspect them all at a central testing site. Inform all personnel who use callipers in the workplace of the inspection process adopted. Closing the jaws tightly and holding the calliper to a light source is a good daily check on jaw wear. If you do not see light breaking through at any point along the jaw boundary the callipers are suitable for continued use. If wear is spotted, make further checks on the jaw faces using optical flats.

Frequency of calibration will depend on frequency of use and on the previous history of the calibration errors. Only perform calibration using traceable standards. Alternatively, use should be made of a UKAS accredited laboratory to perform the calibration. ISO 13385-1 gives methods for evaluating the performance of callipers in its Annex A.

Control of callipers

An effective method of maintenance control for measuring tools, such as callipers, which are frequently used on the shop floor, is to limit the number of tools in the tool room and on the shop floor. Although callipers are relatively cheap, they are not consumables and you should not treat them as such.

Special purpose callipers

Callipers have a wide range of applications. However, some workpieces have complex shapes that are difficult to measure with standard type callipers. This complexity of shape has led to the development of many special purpose callipers to cope with these and other difficult measurement situations. The following sections contain examples of special purpose callipers.

Callipers with carbide measuring faces

The measuring faces of calliper jaws are subject to wear, particularly when used on rough surfaces. Some callipers are therefore fitted with carbide tipped inside and outside jaws to make them suitable for measuring work pieces with rough surfaces, for example castings and grinding stones.

Offset Calliper

The jaw on the head end of the main scale of offset callipers (figure 20) can be vertically adjusted by loosening a clamp. This adjustment makes it possible to measure dimensions on stepped work pieces that cannot be measured with standard types of callipers.

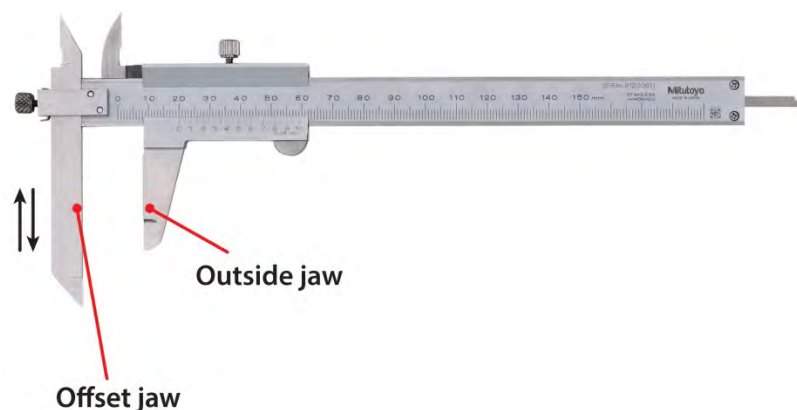


Figure 20 Key features of offset Callipers

Swivel jaw callipers

This type of calliper has a jaw that is rotatable by $\pm 90^\circ$ about an axis that is parallel with the line of measurement (figure 21 and figure 22). This type of calliper can measure stepped work pieces and shafts having off-centred sections that standard types of calliper cannot measure.

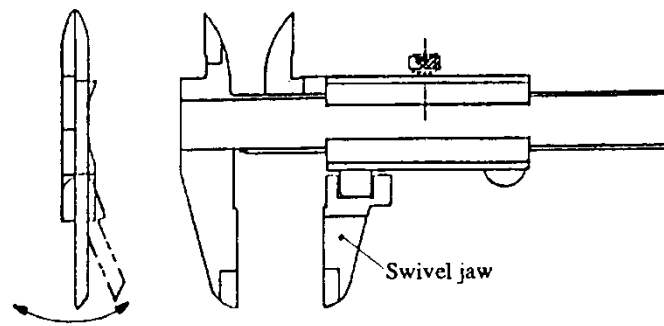


Figure 21 Swivel jaw callipers

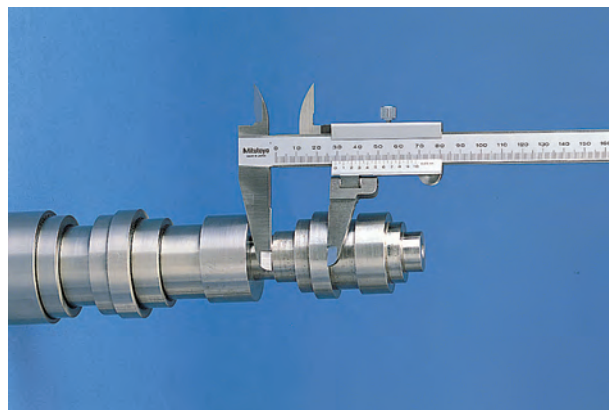


Figure 22 An application of swivel jaw callipers

Long jaw callipers

This type of calliper (figure 23) has longer fixed and sliding jaws than standard types of calliper. It can be used to measure inside diameters of deep holes and large outside diameters that standard type callipers cannot measure. The standard jaw lengths of this type of calliper are 90 mm for a calliper with a measuring range of 300 mm and 200 mm for one with a measuring range of 500 mm.



Figure 23 Long jaw Callipers

Constant force dial callipers

The use of polymer materials for machine parts is extensive and they require accurate dimensional measurement. These materials are often soft and the measuring force applied by

ordinary callipers and micrometers can deform them, resulting in inaccurate measurements. Consequently, this has led to the development of constant force dial callipers (figure 24) that allow the measurement of materials that are easily deformed.

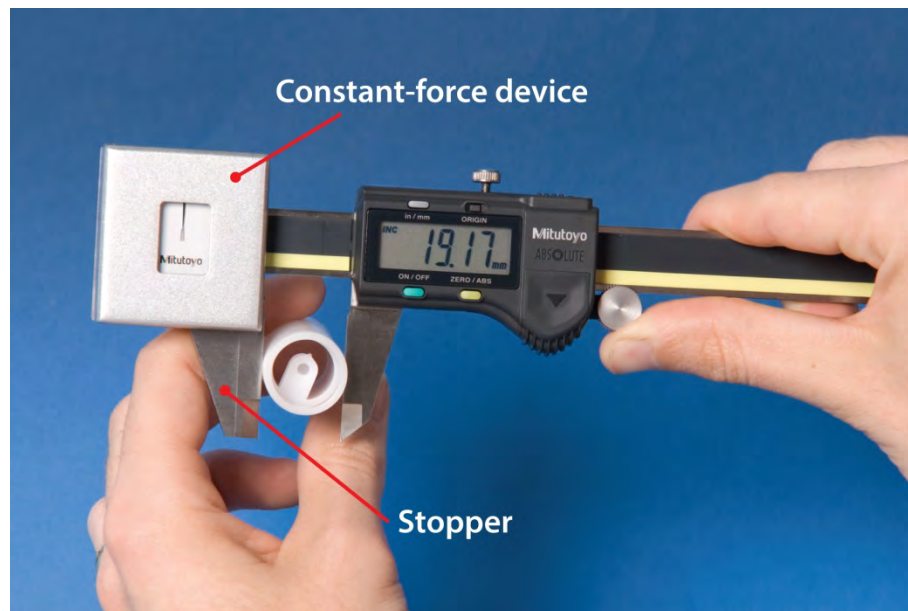


Figure 24 An application of constant force callipers (courtesy Mitutoyo)

Offset callipers for hole distance measurement

This type of calliper (figure 25) has cone shaped jaws (cone angle 40°) to facilitate the measurement of the centreline distances between holes (with the same or different diameters), between holes on different surfaces on a stepped workpiece or the distance from a datum face to the centre of a hole.

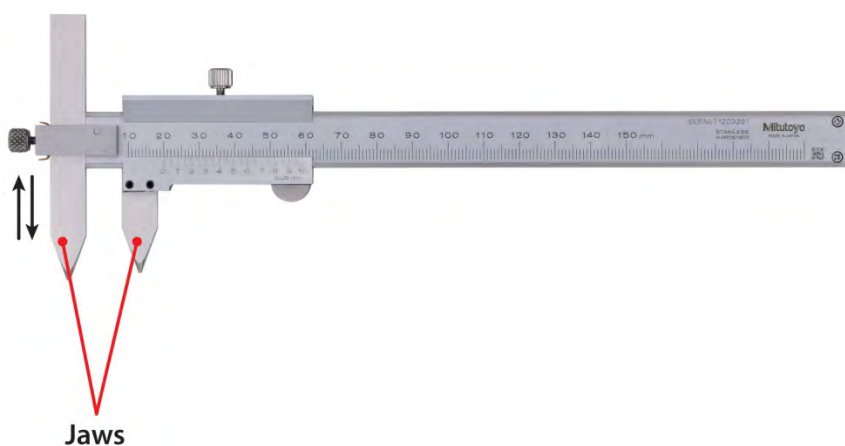


Figure 25 A schematic of offset callipers for hole measurement (courtesy Mitutoyo)

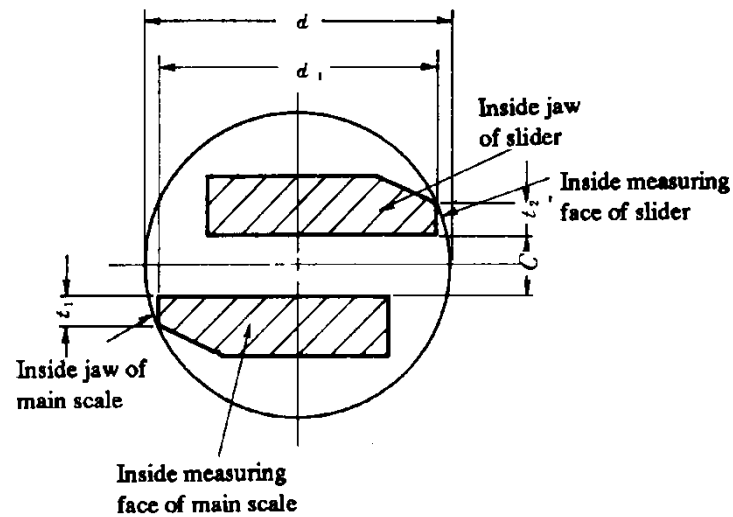
Sources of measurement uncertainties and error

There are a number of factors affecting the measuring accuracy of callipers. The user should be aware of both the cause and effect of these errors. The errors can be broken down into three categories:

1. errors inherent to the construction of the calliper;
2. parallax error; and
3. environmental conditions and measuring force.

Calliper construction errors

1. In 1890, Ernst Abbe formalised what is now known as Abbe's principle that states "maximum accuracy may be obtained only when the standard is in line with the axis of the object being measured." The construction of the calliper does not conform to Abbe's principle. Therefore, to minimise Abbe offset errors, care should be taken by the user to ensure that the workpiece is measured as close to the main scale beam as possible and that the fitting clearance between the main scale and the slider is minimised to ensure that the calliper jaw faces are parallel to one another. NPL measurement good practice guide No. 80 also describes the Abbe error.
2. The main scale of the vernier calliper may bend in two directions both of which affect the accuracy of the instrument.
3. The faces of the calliper may not be perfectly flat, parallel or square to the beam.
4. Because the tips of the jaws of M-type callipers are thin (for measuring narrow grooves), they are prone to wear. With M type callipers, the bottom portion of the jaws has a bevelled edge to facilitate the measurement of narrow grooves. With use, this portion can wear. Therefore, wherever possible, use the portion of the jaws closer to the main scale.
5. Inside diameter measurements made with M-type vernier calliper involve measurement errors that are inherent to the design of the jaws. These errors are more significant when measuring small holes and result from the measuring face of the jaws being offset from the centre line of the hole. It is therefore necessary to take these errors into consideration and make necessary compensations or use another type of instrument if greater accuracy is required. In figure 27 below, dimension d_1 is obtained instead of the actual dimension d . In this case, thickness t_1 and t_2 of the inside measuring faces and the clearance C between the main scale jaw and the slider jaw greatly affect the measuring accuracy.



ID measurement using inside jaws of M-type caliper

Figure 26 Internal diameter measurement using internal measurement faces of M-type calliper

Table 4 shows the errors (ε) calculated for different hole diameters and a range of values of B between 0.3 mm and 0.7 mm in 0.1 mm increments, where $B = t_1 + t_2 + C$

Table 4 Small hole diameter measurement errors (relative to offset of measured points from hole centre line)

Unit: mm

Hole diameter	Offset from hole centre line B				
	0.3	0.4	0.5	0.6	0.7
1.5	0.030	0.050	0.090	0.12	0.17
2.0	0.023	0.041	0.060	0.09	0.13
2.5	0.018	0.032	0.050	0.07	0.10
3.0	0.015	0.027	0.042	0.06	0.08
3.5	0.013	0.023	0.036	0.05	0.07
4.0	0.011	0.020	0.031	0.045	0.06
4.5	0.010	0.017	0.028	0.038	0.05
5.0	0.009	0.014	0.026	0.033	0.047
6.0	0.008	0.013	0.021	0.029	0.041
7.0	0.007	0.011	0.018	0.026	0.036
8.0	0.007	0.010	0.016	0.023	0.033
9.0	0.006	0.009	0.013	0.020	0.028
10.0	0.005	0.008	0.012	0.017	0.023

Figure 28 shows an error curve when B is constant (0.7 mm). The offset of the measuring jaws from the centre line of the hole ($\frac{B}{2}$) is therefore 0.35 mm ($t_1 = 0.3$ mm, $t_2 = 0.3$ mm, $C = 0.1$ mm). The error ε in the measured hole diameter is calculated as follows:

$$\varepsilon = 2 \left(r - \sqrt{r^2 - \left(\frac{B}{2}\right)^2} \right)$$

$$\varepsilon = 2 \left(r - \sqrt{r^2 - 0.35^2} \right)$$

where r is the radius of the hole.

Hole Diameter vs. measurement error

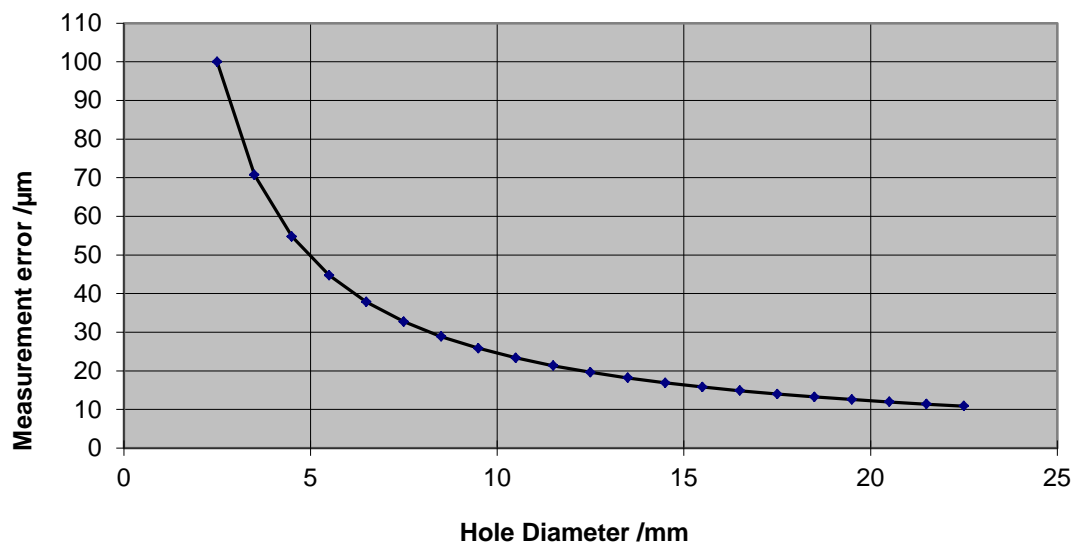


Figure 27 Hole diameter vs. measurement error

Figure 29 shows error curves with reference to different jaw clearances and thickness when a hole diameter of 10 mm is measured.

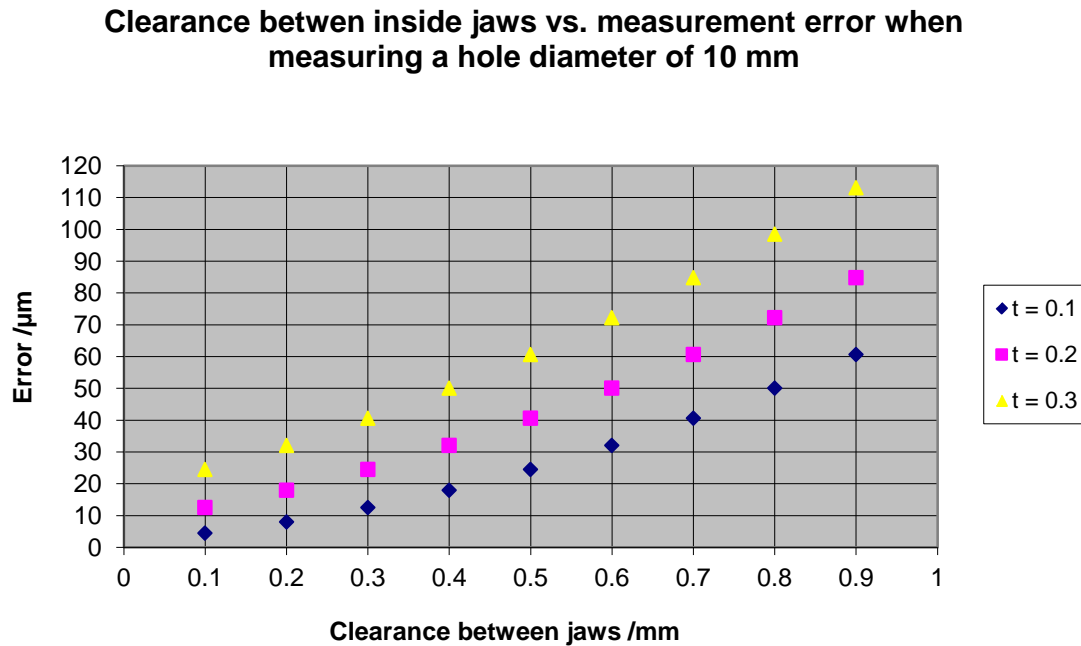


Figure 28 Clearance between inside jaws vs. measurement error when measuring a hole dia. of 10 mm

Parallax error

As illustrated in section on reading vernier callipers, the reading on a vernier calliper is obtained by finding the vernier graduation that is aligned with a main scale graduation. However, because the graduated faces of the main scale and vernier scale of a calliper are usually not in the same plane, the apparent alignment position will vary slightly depending on the viewing angle (parallax error). The user should therefore view the calliper directly above the matching graduations to avoid such errors.

Environmental conditions and measuring force.

1. Objects will generally expand or contract with temperature changes. Lengths of objects are determined at the internationally adopted temperature of 20 °C. Any dimensions shown on a drawing will refer to this temperature. If the thermal expansion coefficients and temperatures of the workpiece and the measuring instrument are exactly the same, a temperature related measurement error will not result even if the measurement is taken at a temperature other than 20 °C. The operator should therefore ensure that the temperature difference between the calliper and the workpiece is minimised. On no account measure workpieces that are still hot from the machining process. It is of particular importance to ensure that at the conclusion of a machining operation the workpiece is allowed to cool before a measurement is taken. Always avoid extremely high and low workpiece temperatures.
2. Unlike micrometers, most vernier callipers are not provided with a device that allows a constant measuring force. Therefore, the measuring force will vary each time a measurement is made, especially with different users. The degree of smoothness of the

vernier motion along the main scale greatly affects the measuring force of the calliper. There is a clearance fit between the sliding faces of the main scale and the vernier, where a leaf spring (typically made of phosphor bronze) is installed. If an excessive force is applied to the workpiece by the jaws, the leaf spring will bend, causing the jaw slider to tilt and thus resulting in a measurement error.

To minimise errors observe the following precautions:

- a) the slider must move smoothly;
- b) do not apply excessive measuring force; and
- c) measure the workpiece using the portions of the jaws that are closest to the main scale.

Overall errors of callipers

The overall error considers all individual errors. This overall error will normally be defined in an international or manufacturer's specification. The error is defined as the estimated error in the calliper, at 20 °C, when measuring a steel artefact. The JIS standard requires that the overall errors of callipers are no greater than the values in table 5 below.

Table 5 Overall errors, Unit: mm (JIS)

Discrimination Measuring Range	0.1 mm	0.05 mm	0.02 mm
150 mm	± 0.1	± 0.08	± 0.05
200 mm	± 0.1	± 0.08	± 0.05
300 mm	± 0.1	± 0.10	± 0.06
600 mm	± 0.15	± 0.13	± 0.08
1000 mm	± 0.20	± 0.18	± 0.15

Uncertainties when making measurements with callipers

This section deals with the measurement uncertainty associated with measurements made using callipers. However, before addressing callipers a general introduction to uncertainties will be given. A Good Practice Guide entitled *A Beginner's Guide to Uncertainty in Measurement* is available from NPL. This guide is a gentle and short introduction to uncertainty of measurement for beginners, including laboratories preparing for UKAS accreditation. The guide explains the concept and importance of measurement uncertainty, using examples from everyday life. It illustrates how to estimate uncertainties in real measurement situations, showing step by step a detailed uncertainty calculation and is recommended reading.

Terminology

Before discussing uncertainty with relation to callipers, the reader should be aware of the correct terminology. The following is a list of terms that are often confused with the term uncertainty. The terms are repeated here for anyone who has not read the chapter on callipers.

Accuracy	<i>A general term describing the degree of closeness with which the indications of an instrument approach the values of the quantities measured.</i>
Error	<i>The discrepancy between the result of the measurement and the true value of the quantity measured</i>
Precision	<i>The closeness of agreement between the results obtained by applying the experimental procedure several times under the prescribed conditions.</i>

The accuracy of an instrument indicates how well it agrees with the (conventional) true value.

The precision of an instrument refers to the dispersion of measurements.

Other terms you will come across in manufacturers' brochures and calibration certificates are resolution, uncertainty of measurement and error.

The resolution of an instrument is a quantitative expression of the ability of an indicating device to distinguish meaningfully between closely adjacent values of the quantity indicated.

The uncertainty of measurement is a calculation made to describe the bounds within which you have every reason to believe the true value lies.

For more details see NPL Good Practice guide number 80 *Fundamental Good Practice in Dimensional Metrology*

The terms accuracy, error and precision should not be confused with the term uncertainty. The expression of a measurement result is incomplete unless it includes a statement of the associated uncertainty. The uncertainty of a measurement result is a parameter that characterises the spread of values that could reasonably be attributed to the measureand.

Uncertainty - A worked example for callipers

In this section, it is assumed that the reader is familiar with uncertainty of measurement and the methods of calculating uncertainty values.

Sources of uncertainty in using a pair of callipers will arise from:

- (a) not applying the corrections for calibrated errors of the callipers or relying on the calliper errors being within specification *;
- (b) errors due to face flatness;
- (c) errors due to face parallelism;
- (d) errors due to face squareness;
- (e) errors due to resolution; and

(f) errors of a random nature ascertained from repeated measurements.

* Note - if corrections for the calibration errors are applied there still will be uncertainties in the determination of the errors and in interpolation between calibration points.

The following is an example of how to estimate the uncertainty associated with measurements made with callipers.

In this example, the user makes measurements on a component using a pair of callipers with a resolution of 0.02 mm. The specified maximum deviation of reading is ± 0.02 mm. The faces are flat to 0.005 mm, parallel to within 0.008 mm and are square to the guiding edge of the beam to within 0.008 mm per 25 mm. The user measures a component five times and obtains the following readings

20.08 mm, 20.08 mm, 20.06 mm, 20.10 mm, 20.12 mm.

This variation is due to both operator and component related influences. The operator has a certificate that tells him that the callipers meet specification but does not show the individual errors.

The first contribution to the uncertainty is called the Type A contribution. It is calculated from the standard deviation of the measurements (in this case, 0.022 8 mm) divided by the square root of the number of measurements ($n = 5$).

$$\frac{\sigma_{n-1}}{\sqrt{n}} = \frac{0.0228}{\sqrt{5}} = 0.010\ 2\ \text{mm}$$

The next contribution is from the resolution of the instrument. The resolution of the callipers is 0.02 mm. There is, therefore, a possible rounding error of 0.01 mm. The contribution is found by dividing the resolution by the square root of 12.

$$\frac{0.02}{2\sqrt{3}} = \frac{0.02}{\sqrt{12}} = 0.006\ \text{mm}$$

The next contribution is due to the flatness of each face. Each face is flat to 0.005 mm and assuming a systematic, rectangular *a priori* probability distribution the contribution is,

$$\frac{0.005}{\sqrt{3}} = 0.003\ \text{mm}.$$

The next contribution is due to the parallelism of the faces. The faces are parallel to within 0.008 mm and assuming a systematic, rectangular *a priori* probability distribution the contribution is,

$$\frac{0.008}{\sqrt{3}} = 0.005\ \text{mm}.$$

The squareness error will either result in the faces being parallel but out of square to the beam which will result in a cosine error that can be ignored or will contribute to the parallelism error.

The calibration certificate stated that the callipers were within specification (0.02 mm). Assuming the error at any position falls within these bounds the contribution is,

$$\frac{0.02}{\sqrt{3}} = 0.012 \text{ mm.}$$

The combined standard uncertainty is calculated from the square root of the sum of the squares of each contribution

$$u_c = \sqrt{0.010^2 + 0.006^2 + 0.003^2 + 0.005^2 + 0.012^2} = 0.018 \text{ mm,}$$

the expanded uncertainty at $k = 2$ is therefore 0.035 mm (2×0.018).

Note that this calculation has made some assumptions for simplicity and is not totally rigorous but will suffice for most purposes. Certain factors such as the number of degrees of freedom have been ignored. The number of degrees of freedom will need to be taken into account if fewer than 10 measurements are recorded (9 degrees of freedom). In the above example, a better approximation for the uncertainty could be obtained by substituting $k = 2.87$ for $k = 2$.

Calibration uncertainty

The uncertainty budget for the calibration of callipers is similar to that shown for a micrometer in a later section.

A note regarding the purchasing of callipers

When purchasing a calliper, the type, size, accuracy and service life of the calliper should all be considered with respect to the user's specific application. For example, if an application requires a discrimination of 0.05 mm the purchase of a calliper with a discrimination of 0.02 mm would be uneconomical and could possibly increase the inspection time.

When specifying, for instance, that callipers should comply with the now withdrawn British Standard you knew exactly what to expect from its performance. However, with the new ISO standards you will have to carefully examine each manufacturers specification to see which callipers are suitable for you application. This may seem like more work. However, it will also mean that you do not buy an instrument that is over specified for the task. BS EN ISO 14978:2006 gives further guidance.

Chapter summary

- Be aware of the operating principles and limitations of callipers.
- Be aware of the different types of callipers and their applications.
- Be aware of the factors affecting calliper performance.
- Be aware of the sources of measurement error.
- Be aware of the factors involved in the handling and storage of callipers.
- Be careful when purchasing callipers.
- Be aware of the differences between the old and new standards.

Micrometers

3

IN THIS CHAPTER

- Operating principles
- Reading a micrometer – worked examples
- Factors affecting performance
- Set-Up and preparation
- Micrometer calibration
- Awareness of uncertainties
- Handling and storage of micrometers
- Micrometers for specialist tasks
- Chapter summary

The purpose of chapter 3 is to give the reader an introduction to some of the considerations necessary when using micrometers for measurement. The operating principles of micrometers will be discussed along with factors affecting performance and sources of measurement uncertainty and error. Finally, handling and storage of micrometers will be discussed.

The following national and international standards apply to micrometers

BS 1734:1951 *Specification for micrometer heads.*

BS EN ISO 3611:2010 *Geometrical product specifications (GPS). Dimensional measuring equipment. Micrometers for external measurements. Design and metrological characteristics.*

BS 959:2008 *Specification for internal micrometers (including stick micrometers).*

BS 6468:2008 *Specification for depth micrometers.*

BS 870:2008 *Specification for external micrometers**

* withdrawn

Operating principles

A micrometer is a device that uses a graduated screw mechanism to produce precise linear displacement of a spindle along its axis. Distance measurement is achieved referencing the linear displacement of the spindle to a fixed measuring face on the axis of the spindle (the anvil). Figure 30 shows the main components of a micrometer.

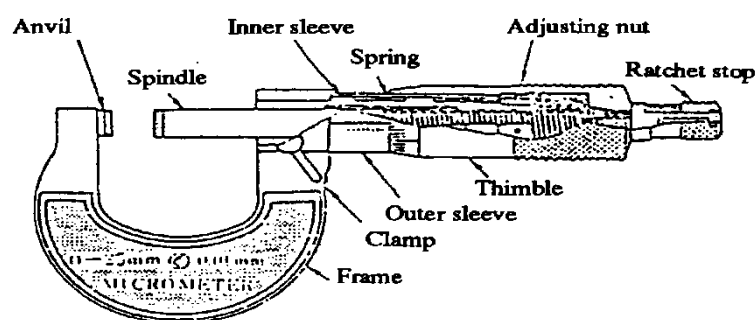


Figure 29 Sectioned view of a micrometer

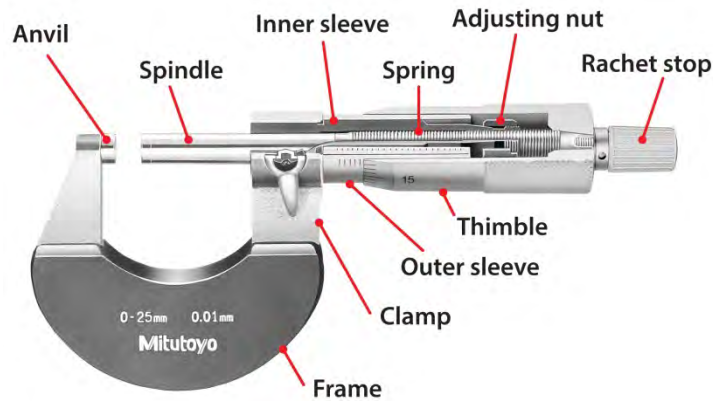


Figure 30 Photograph of a sectioned micrometer (courtesy Mitutoyo)

The main components are described below.

The *inner sleeve*, which has the guide threads of the feed mechanism, is fixed to one end of the frame. The *anvil*, which serves as a fixed measuring face, is attached to the opposite end of the frame.

The *spindle* has a measuring face at one end and an external thread at the other. It is fitted to the inner sleeve, which ensures the linearity of the spindle motion in the axial direction. The spindle's external thread engages with the internal thread of the inner sleeve.

The *measuring face* of the spindle serves as a contact point for measuring the workpiece. Measurement is performed by feeding the spindle so that both the anvil measuring face and the spindle measuring face touch the workpiece.

The *outer sleeve* has graduations that correspond to the spindle's thread pitch and an index line to aid reading of the graduations on the thimble.

The *thimble* is fixed to the spindle so that both components turn together and is knurled for ease of turning.

The *ratchet stop* applies constant pressure to the workpiece being measured and consists of a leaf spring and a ratchet mechanism.

The *clamp*, fixed to the spindle guide section of the frame, locks the spindle against the inner sleeve.

A standard micrometer has a screw thread of 0.5 mm pitch with a thimble graduated in fifty equal divisions around its circumference. Micrometers are manufactured in size ranges of 0 mm to 25 mm, 25 mm to 50 mm, ..., 575 mm to 600 mm *etc.* As an example, you would measure a dimension of 19.45 mm with a 0 mm to 25 mm micrometer and a dimension of 580.25 mm with a 575 mm to 600 mm micrometer.

Constant force device

In order to minimise the variation in measurements due to deformation of the workpiece, measurements should be performed under the same force as is used for setting the zero reading (when the two measuring faces contact each other).

To facilitate this setting, a constant force device called the ratchet stop (figure 32) is used on many micrometers. Figure 32 shows three types of ratchet stops. The mechanism shown in figure 32(b) is the most commonly used. The mechanism comprises two ratchets that are opposed to each other and whose toothed faces are pressed together by the force of a spring. When the barrel of the ratchet stop is rotated clockwise, both ratchets turn together until the measuring force reaches a certain limit. As the force exceeds this limit, the ratchet in the barrel spins idly and clicks. When the barrel is rotated counter-clockwise there is no idling between the ratchets because the ratchet teeth remain engaged and the thimble is allowed to rotate.

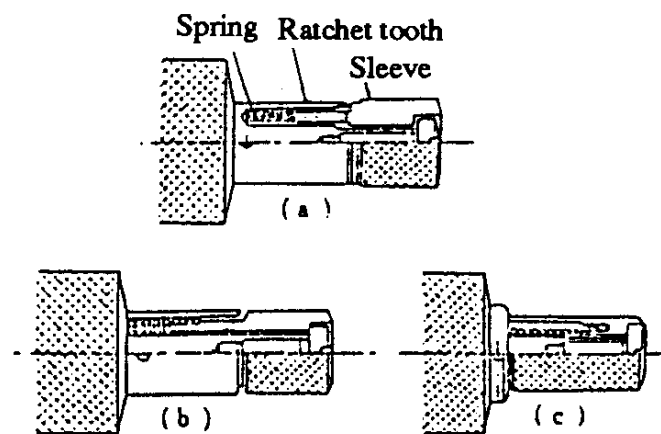


Figure 31 Types of ratchet device

Types of micrometer

The following paragraphs give an indication of the different types of micrometer available for specific tasks. They all work on the same basic principle.

Standard external micrometer

Figure 33 shows an external micrometer of the type described in the section on operating principles and shown sectioned in figure 30. It is probably the most common type of micrometer that the reader will encounter.



Figure 32 A micrometer for external measurement

Spherical anvil and spindle type

A spherical anvil type micrometer is shown in figure 34. The anvil and spindle measuring faces of this type of micrometer are either both spherical or spherical and flat.



Figure 33 Spherical anvil and spindle type micrometer (courtesy Mitutoyo)

This type of micrometer is useful for measuring the wall thickness of special shaped tubes with a non-circular outside diameter or of tubes in general (figure 35).



Figure 34 Using this type of micrometer (courtesy Tesa Group)

Spline micrometer

The anvil and the spindle of this type of micrometer (figure 36) are of small diameter in order to measure splined shafts, slots and keyways for which standard outside micrometers are not suitable.



Figure 35 Spline type micrometer (courtesy Mitutoyo)

Point micrometer

This instrument (figure 37) has a pointed spindle and anvil and is typically used for measuring the web thickness of drills, root circle diameters of external threads and small grooves where access is restricted. The point anvils are usually 0.3 mm radius with 15° or 30° anvils.



Figure 36 Point micrometer (courtesy Mitutoyo)

Disc type paper thickness micrometer

The disc type of micrometer (figure 38 and figure 39) is designed to measure the root tangent length of spur and helical gears and any soft material where a greater anvil surface area is desirable. This type of micrometer uses a non-rotating spindle in order to eliminate torsion on work surfaces, thus making it suitable for measuring paper and thin workpieces. The use of discs provides large measuring faces in order to avoid concentrating the measuring force.



Figure 37 Disc type paper thickness micrometer (courtesy Mitutoyo)

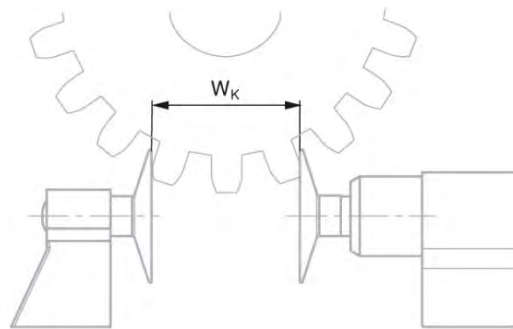


Figure 38 Measuring a gear (courtesy Tesa Group)

Blade micrometer

The anvil and non-rotating spindle of this type of micrometer (figure 40) both have blades to allow narrow grooves, keyways and other restricted areas to be measured. They require careful checking as the small contact area is subject to wear as is the non-rotating spindle against the rotating screw.



Figure 39 Blade micrometer (courtesy Mitutoyo)

Indicating micrometers

An indicating micrometer (figure 41) incorporates a dial indicator in its construction. The anvil can move a small distance in the axial direction and its displacement is shown on the indicator. This mechanism allows a uniform measuring force to be applied to workpieces, minimising the variations in measurements that could be caused by variations in the measuring force.



Figure 40 Indicating micrometer (courtesy Mitutoyo)

Digital micrometers

All of the micrometers described in the previous section can be purchased with digital readouts.

Micrometers with digital readouts normally incorporate a photoelectric or capacitance type rotary encoder, which detects the spindle rotation and electronically converts this to a digital readout of spindle displacement. Typical resolution of such micrometers is 0.001 mm.

The obvious advantage of these instruments is their ease of reading. On a conventional micrometer, there is the possibility to misread the sleeve divisions by 0.05 mm. A digital readout eliminates this problem. However, exercise care with a digital micrometer since it is possible to select the wrong measurement units or inadvertently introduce a zero offset. Always recheck the zero after a measurement.

The advanced features of the digital micrometer have nevertheless eliminated most human errors in reading and as a result have enabled the integration of micrometers into automatic measurement and data processing systems.



Figure 41 A digital micrometer (courtesy Mitutoyo)

Types of Digital Micrometers

Figure 43 to figure 46 show some examples of the various types of digital micrometer.

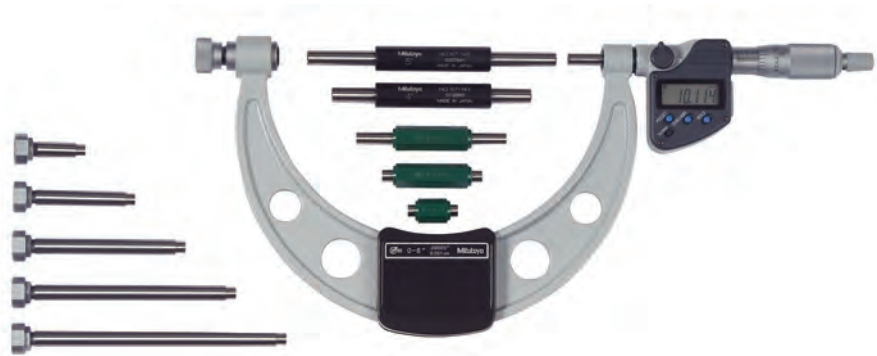


Figure 42 Interchangeable anvil type outside micrometer (courtesy Mitutoyo)



Figure 43 Gear-tooth micrometer (courtesy Mitutoyo)



Figure 44 Depth micrometer (courtesy Mitutoyo)



Figure 45 Micrometer head (courtesy Mitutoyo)

Reading a micrometer – worked examples

The examples below explain how a reading is taken using various micrometers.

Standard micrometer (0.01 mm discrimination)

With 0.01 mm discrimination micrometers the gap between the measuring faces changes by 0.5 mm for one full turn of the thimble. Therefore, for a spindle movement of 1 mm, the thimble will have turned through two revolutions. Figure 47 shows the sleeve of a standard metric micrometer with the 1mm divisions above the datum line and the 0.5 mm divisions below the datum line. Example readings are given in figure 48 and figure 49.

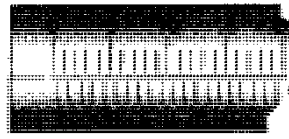


Figure 46 1 mm and 0.5 mm divisions on the sleeve.

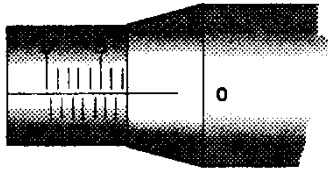


Figure 47 This reading is 7.5 mm

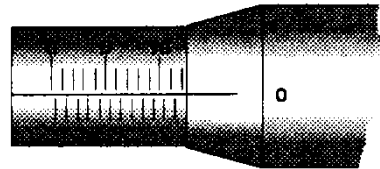


Figure 48 This reading is 12.5 mm

The thimble has fifty divisions; therefore a rotation of one division of the thimble scale produces a change in gap between the measuring faces of a fiftieth of 0.5 mm; equal to 0.01 mm. Each thimble graduation therefore equals one hundredth of a millimetre.

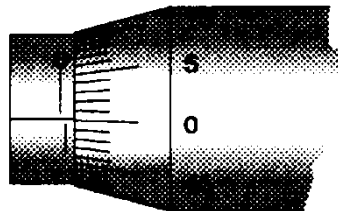


Figure 49 Graduations equal to one hundredth of a millimetre

To perform a measurement with a micrometer the general procedure is that the value of the nearest visible graduation on the sleeve to the thimble is determined and added to the value of the graduation on the thimble which lines up with the datum line on the sleeve.

Figure 51 shows how to read a metric micrometer. In the top half of the figure, the sleeve reading is 7 mm. The thimble reading is just over 37 divisions. The excess has been estimated to be 0.3 of a division (see figure 52) hence the total reading is 7.373 mm. In the bottom half of the figure the sleeve reading is 7.5 mm. The thimble reading is just over 37 divisions. The excess has been estimated to be 0.3 of a division hence the total reading is 7.873 mm.

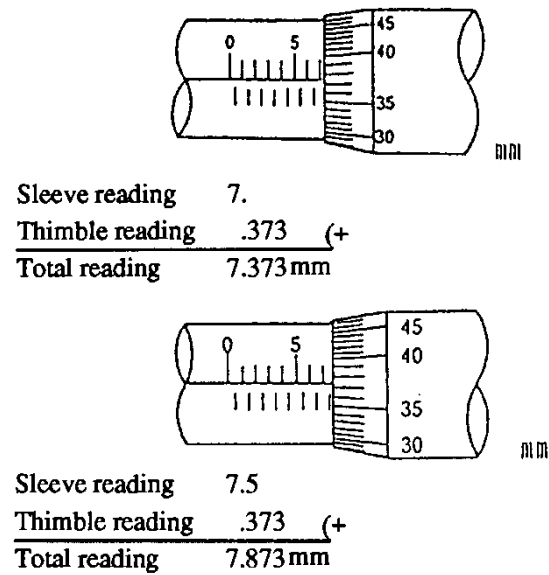


Figure 50 Reading a metric micrometer

Take care not to misread the smallest graduation on the sleeve (potentially resulting in an error of 0.5 mm on a standard metric micrometer), figure 52 shows a method of reading a micrometer to discriminate 0.001 mm. This method relies on the fact that the width of a thimble graduation line equals one fifth of a thimble division.

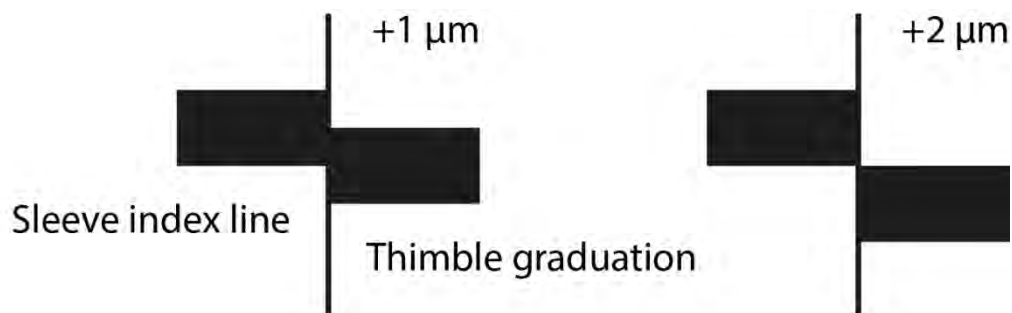
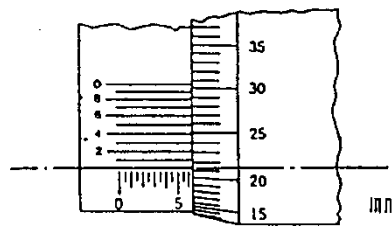


Figure 51 Method of reading to resolve 0.001 mm

Micrometers with a 0.001 mm discrimination

Some micrometers have a special device (an auxiliary scale or a vernier on the sleeve) to provide a discrimination of 0.001 mm (figure 53). This type of instrument has the same construction as a standard micrometer but has a vernier above the index line in order to provide the discrimination required. Take readings on the vernier scale by recording the vernier graduation that is aligned with the graduation on the thimble in a similar manner to that described for callipers.



Sleeve reading	6.
Thimble reading	.21
Vernier reading	.003 (+)
Total reading	6.213mm

Figure 52 A micrometer with a vernier scale on the sleeve

Reading an imperial (inch) micrometer

The procedure for reading an inch micrometer is similar to that previously described for the metric version in that the final reading is arrived at by totalling the main scale and thimble readings (plus a vernier scale reading if appropriate). Figure 54 shows how the main scale is divided into tenths of an inch (0.100 in) and each main division is subdivided into four equal parts. Each of these divisions represents twenty-five thousandths (0.025 in, that is to say, 0.1 divided by 4).

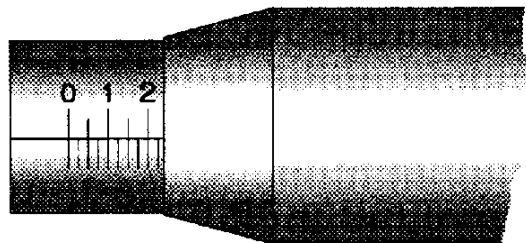


Figure 53 main division 0.100 in Sub-division 0.025 in

One complete turn of the thimble moves the spindle twenty-five thousandths of an inch. (0.025 in), therefore each of the twenty-five thimble graduations equals one-thousandth of an inch (0.001 in). The reading shown in figure 55 is 0.239 in which comprises

2 main 0.100 divisions;
1 0.025 in sub-division; and
14 thimble divisions.

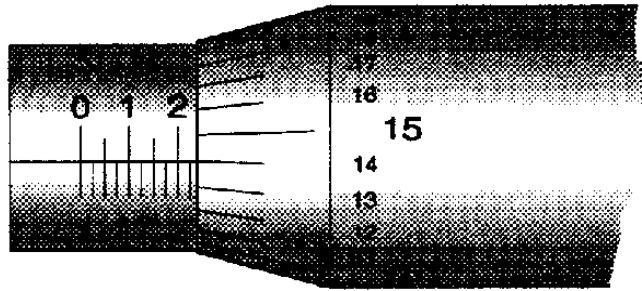


Figure 54 Reading a micrometer (0.239 in)

Figure 56 illustrates another example. The reading is 0.361 in which comprises

3 main 0.100 divisions;
2 0.025 in sub-division; and
11 thimble divisions.

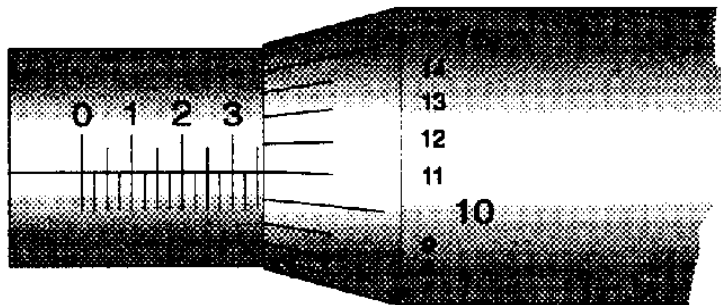


Figure 55 Reading a micrometer (0.361 in)

Factors affecting performance

Table 6 below lists factors affecting micrometer performance and appropriate corrective actions.

Table 6 Factors affecting performance and corrective actions

Item	Degree of defect	Repair Possible?	Countermeasure
Fit	Spindle rotation is tight or sticky	✓	Disassembly and cleaning
Ratchet	Ratchet rotation is tight or sticky	✓	Disassembly and cleaning. If the problem persists replace the ratchet.
Clamp	Spindle clamping is not sufficient	✓	Send the micrometer to the manufacturer for repair
Burr on measuring face	Burr was created on the measuring face by a bump drop <i>etc.</i>	✓	Remove the burr carefully with an Arkansas stone or CERASTON
Flatness	Lustre of the measuring faces reduced or the flatness error exceeds 0.6 μm	✓	Send the micrometer to the manufacturer for repair
Parallelism	Parallelism error between the anvil and the spindle exceeds the specified value	✓	Send the micrometer to the manufacturer for repair
Instrument error	Instrument error exceeds the specified value	✓	Send the micrometer to the manufacturer for repair
Locked screw threads	Locked because the spindle was rotated with dust or contaminants between the screw threads	✗	Discard the micrometer (depending on the severity)
Frame Bent	Frame was bent by mishandling (<i>e.g.</i> , micrometer caught in running lathe, used as a vice)	✗	Discard the micrometer
Excessive clearance in spindle guide	The clearance between the spindle and the spindle guide at the end of the inner sleeve should not exceed 10 μm	✗	Discard the micrometer
Play in screw threads caused by local wear	Even when the taper nut is tightened, sections of the threads are loose and other sections are tight	✗	Discard the micrometer
Graduations	Hard to read because of scratched sleeve or damaged graduations	✓	Send the micrometer to the manufacturer for repair

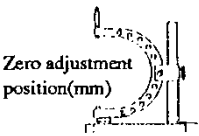
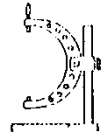
Set-Up and preparation

In order to minimise measurement errors when using a standard micrometer, users should adhere to the following good practice:

- Select the micrometer that best fits the application, making sure the type, measuring range, graduation and other specifications are appropriate for the application.
- Clamp the anvils lightly over a sheet of paper and gently pull the paper through the anvils. Check for scratches and burrs on measuring faces. Burrs are frequently found near the outer edge of the measuring face. Use a fine-grained oilstone to remove any burrs found.
- **Fit.** Check that the thimble turns evenly and does not stick to the sleeve. If the thimble rotation is tight or sticky, disassemble the instrument, clean and reassemble. Check the rotation once again. If the problem persists then the user should suspect run out of the spindle as the likely cause. The instrument may have to be repaired or discarded.
- **Ratchet.** Ensure ratchet turns evenly. If it does not turn evenly, dismantle and clean. If this does not improve things, the ratchet may need replacing.
- **Clamp.** If fitted, check that the clamp is effective. A micrometer with ineffective clamp may have to be returned to the manufacturer for repair.
- Adjust the collet slightly, if the movement is stiff. Do not be tempted to immerse the micrometer in solvent. If the micrometer requires cleaning, dismantle, wash in clean solvent and relubricate before assembly.
- Never use compressed air to clean a micrometer. The high air velocity could force abrasive particles into the mechanism and more importantly into the operator's skin (see ROSPA leaflet '*Compressed Air Care*') and chapter 6.
- Wipe off any dust from the micrometer before use; thoroughly wipe the spindle and the measuring faces. Use only clean lint free paper or cloth.
- Check the micrometer zero as follows. Clamp the anvils lightly over a sheet of paper and gently pull the paper through the anvils. Hold the ratchet between the thumb and the middle finger and gently turn the ratchet to bring the measuring faces of the spindle and the anvil into contact. Next, rotate the ratchet by one click, that is to say, as soon as the ratchet or friction drive has slipped. Rapid rotation of the ratchet or friction drive will give false readings. Confirm that the zero line on the thimble is aligned with the index line on the sleeve. Repeat this process two or three times to confirm the alignment. When measuring a workpiece, manipulate the ratchet in the same way as described for zero setting.
- Adjust the zero point if necessary.
 - With the anvil and spindle apart, unlock cap with spanner wrench and then tighten cap lightly with fingers to bring slight tension between thimble and spindle.
 - Bring anvil and spindle together by turning spindle and set zero line on thimble to coincide with line on barrel
 - Move spindle away from anvil by turning spindle, not by turning thimble
 - Holding thimble only, tighten cap with fingers. Take care not to touch frame
 - Lock cap with wrench still holding thimble only.

- When making measurements, periodically check the zero point to confirm that there is no discrepancy. Always take measurements under the same conditions (orientation, measuring force *etc.*) that existed when setting the zero point for the measurement.
- When making measurements ensure that the micrometer is not subject to sudden temperature changes, direct sunlight, radiant heat or air currents that may cause a significant variation in temperature.
- Never measure a component that is still warm from the machining process.
- Leave the micrometer and the workpiece in the room long enough to adjust to room temperature (at least one hour). A 100 mm (4 in.) long iron rod will change length by 0.012 mm (0.000 47 in.) with a temperature change of 10 °C.
- When measuring a heavy/large workpieces mounted on a machine tool, the micrometer should be carefully orientated. This is especially important when the measuring length exceeds 300 mm.
- When measuring a spherical or cylindrical workpiece, where the workpiece surface contacts the micrometer measuring faces at a point or line, take special care to prevent “spindle play”, due to excessive clearance between the spindle and spindle guide at the end of the inner sleeve. Apply a constant and appropriate measuring force. It is also important that measuring faces are flat and parallel.
- Minimise parallax errors by viewing from the correct angle, that is to say, view the index line on the sleeve from directly above.
- Never measure a workpiece that is rotating. When measuring a workpiece on a machining stage, stop the machine tool and allow the workpiece to come to rest. After cleaning the workpiece of dust and other contaminants, take measurements with the micrometer.
- Feed the spindle by turning the thimble only. Never spin the micrometer by holding the thimble as such mishandling will damage the instrument.
- Do not attempt to turn the thimble when it is clamped.
- If the micrometer is dropped, or is subject to a blow, carry out the daily inspection checks listed in the section daily inspection.
- When mounting the micrometer on a stand, ensure that the instrument is clamped at the centre of the frame using a tool stand. Do not over tighten the clamp.
- Use clamp if incorporated in to the micrometer.
- Always take the reading on the first click of the ratchet.
- Do not over tighten when using a micrometer
- To avoid operator bias it is always a good idea to make the measurement and then check the drawing specified size rather than the other way round.

Figure 57 gives an indication of the variation in reading that can be obtained by using different support positions.

Support position		Supported at bottom and center	Supported at center
Maximum measuring length (mm)	Orientation		
	Zero adjustment position(mm)	0	-5.5
325		0	-5.5
425		0	-2.5
525		0	-5.5
625		0	-11.0
725		0	-9.5
825		0	-18.0
925		0	-22.5
1025		0	-26.0



Support position		Supported at center (horizontal)	Held by hand
Maximum measuring length (mm)	Orientation		
	Zero adjustment position(mm)	+1.5	-4.5
325		+1.5	-4.5
425		+2.0	-10.5
525		-4.5	-10.0
625		0	-5.5
725		-9.5	-19.0
825		-5.0	-35.0
925		-14.0	-27.0
1025		-5.0	-40.0

Figure 56 Variation in measurement at different support positions

Many micrometers are fitted with thermally insulating handles (Figure 58) to avoid the operator heating the frame of the micrometer. If these are fitted, they should be used. Otherwise, consider the use of a suitable holding fixture (Figure 59).



Figure 57 Some micrometers are fitted with thermal insulation to prevent the operators hands heating the micrometer frame (courtesy Tesa Group)



Figure 58 the use of a micrometer stand is good practice as it minimises operator influence on the measurements (courtesy Tesa Group)

It is good practice to check the anvil flatness and parallelism from time to time using a set of optical parallels (figure 60). These parallels come in a range of sizes so that the parallelism can be checked at various positions along the travel (figure 61).



Figure 59 A set of optical parallels (courtesy Tesa Group)

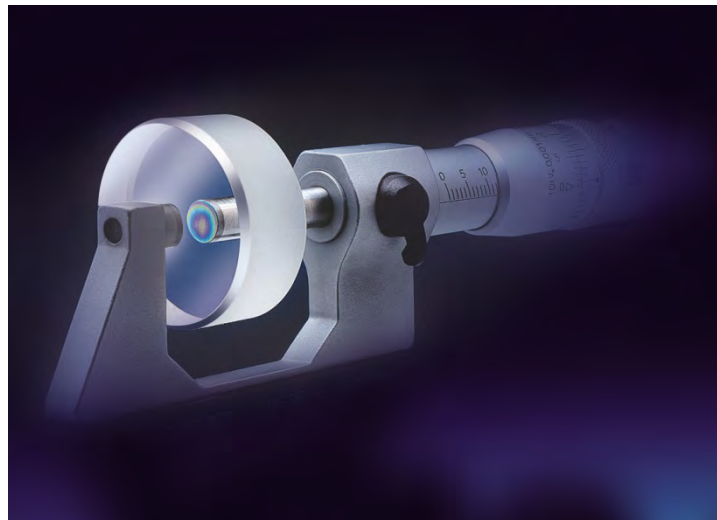


Figure 60 An optical parallel being used to examine the faces of a micrometer. The coloured interference fringes that can be seen on the face are an indication of anvil geometry. Image courtesy Tesa Group.

Micrometer calibration

Micrometers can be calibrated using a special set of gauge blocks and a set of optical parallels. The sizes of the gauge blocks (figure 62) are chosen to test both the periodic and progressive error of the micrometer. Two sets are needed; one for imperial micrometers (figure 63) and one for metric micrometers.



Figure 61 Metric gauge blocks used for micrometer calibration (courtesy Tesa Group)

The process involves inserting each gauge block, in turn, between the anvils of the micrometer and noting the micrometer reading. Figure 64 shows the process of calibrating a micrometer. The operator in this photograph is not following good practice. Ideally, the gauge blocks should not be held using uncovered hands. A better method would involve the use of gloves or tongs. The operator will be heating the gauge blocks and potentially could leave corrosion marks on the gauge. Good practice that is evident in the image includes the use of a micrometer stand and leaving the gauge blocks to soak (reach thermal equilibrium with the environment).

In practice, most organisations would send their micrometers to an accredited laboratory and would not undertake this calibration themselves.



Figure 62 Imperial gauge blocks used for micrometer calibration (courtesy Tesa Group)



Figure 63 Calibrating a micrometer (courtesy Tesa Group)

Awareness of uncertainties

The general information on uncertainties/terminology in the sections introduction and terminology have been discussed earlier in connection with callipers however it is repeated again for those readers who have not read the guidelines on callipers.

Introduction

A Good Practice Guide entitled *A beginner's Guide to Uncertainty in Measurement* is available from NPL. This guide is a gentle and short introduction to uncertainty of measurement for beginners, including laboratories preparing for UKAS accreditation. The guide explains the concept and importance of measurement uncertainty, using examples from everyday life. It illustrates how to estimate uncertainties in real measurement situations, showing the steps in a detailed uncertainty calculation.

Terminology

Before discussing uncertainty with relation to micrometers, the reader should be aware of the correct terminology. The following is a list of terms that are often confused with uncertainty.

Accuracy	<i>A general term describing the degree of closeness with which the indications of an instrument approach the values of the quantities measured.</i>
Error	<i>The discrepancy between the result of the measurement and the true value of the quantity measured</i>
Precision	<i>The closeness of agreement between the results obtained by applying the experimental procedure several times under the prescribed conditions.</i>

The terms accuracy, error and precision should not be confused with the term uncertainty. The expression of a measurement result is incomplete unless it includes a statement of the associated uncertainty. The uncertainty of a measurement result is a parameter that characterises the spread of values that could reasonably be attributed to the measureand.

To make these terms clear look at the results of a micrometer calibration given in table 7.

Table 7 Calibration of a micrometer

Position /mm	Error /mm
2.5	0.000
10.3	+ 0.001
12.9	– 0.001
15	– 0.002
20.2	–0.002
25	– 0.003

The following statement accompanies the results in table 7.

'The uncertainty of the above measured values has been calculated in accordance with the ISO document 'Guide to the expression of uncertainty in measurement'. The expanded uncertainty has been calculated to be ± 0.002 mm and is based on a standard uncertainty multiplied by a coverage factor $k = 2$ providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements'

The error at the 12.9 mm position is -0.001 mm. The overall accuracy of the micrometer is 0.003 mm. The uncertainty of measurement is 0.002 mm.

Micrometers

It is important for the user to be aware of the many things that can undermine a measurement made with a micrometer. Because measurements are never made under perfect conditions, errors and uncertainties can come from a number of sources: -

- **The measuring instrument** – these errors include bias, changes due to ageing, wear drift, poor readability etc.
- **The item being measured** – the workpiece may not be dimensionally stable. A component after machining can be hot due to heat generated in the machining process. Form and surface finish errors can also contribute to the overall measurement uncertainty.
- **The measurement process** – the measurement may be difficult to make. Remember maximum accuracy may be obtained only when the scale (in this case the axis of the spindle thread) is in line with the axis of the object being measured.
- **Ignoring the errors given on the calibration certificate.**
- **Imported uncertainties** – When the micrometer is calibrated the measured errors have an uncertainty which is then built into the uncertainty of the measurements you make.
- **Temperature effects** for example, measuring a brass artefact with a steel micrometer at a temperature other than 20.0°C .

Example uncertainty budget for the calibration of a 0 - 25 mm micrometer

Accuracy of micrometer traverse calibrated against steel grade 1 gauge blocks

The uncertainty budget is based on a calibration of the micrometer screw in accordance with the requirements of BS 870:2008, Appendix A. The result of the calibration is the maximum range of error, as indicated from measurements over a series of ten individual gauge blocks along the micrometer screw.

Table 8 Accuracy of micrometer traverse calibrated against steel Grade 1 Gauge Blocks

Source of uncertainty	Value	Probability distribution	Divisor	Standard uncertainty / μm
Uncorrected errors in length of gauge block (a) at point of minimum error	0.25 μm	Rectangular	$\sqrt{3}$	0.144
Uncorrected errors in length of gauge block (b) at point of maximum error	0.3 μm	Rectangular	$\sqrt{3}$	0.173
Uncertainty in calibration of gauge block (a)	0.1 μm	Normal	2	0.050
Uncertainty in calibration of gauge block (b)	0.1 μm	Normal	2	0.050
Repeatability at point (a) ⁺	0.5 μm	Normal	1	0.500
Repeatability at point (b) ⁺	0.5 μm	Normal	1	0.500
Resolution of micrometer (2.0 μm)	1.0 μm	Rectangular	$\sqrt{3}$	0.577
Effect of temperature differences between micrometer and gauge blocks *	0.14 μm	Rectangular	$\sqrt{3}$	0.081
Combined standard uncertainty	-	Normal	-	0.943
Expanded uncertainty	-	Normal ($k = 2$)	-	1.885

⁺Repeatability determined as the standard deviation of ten repeated readings for a typical, previously calibrated instrument.

* Basing temperature effects on an expansion coefficient of $11 \times 10^{-6} / ^\circ\text{C}$, with temperature difference of $0.5 ^\circ\text{C}$ over 25 mm.

Calculate the combined standard uncertainty as follows,

$$u_c = \sqrt{0.144^2 + 0.173^2 + 0.050^2 + 0.050^2 + 0.500^2 + 0.500^2 + 0.577^2 + 0.081^2} .$$

Report the uncertainty as follows

The uncertainty of the above measured values has been calculated in accordance with the ISO document 'Guide to the expression of uncertainty in measurement'. The expanded uncertainty has been calculated to be $\pm 0.002 \text{ mm}$ and is based on a standard uncertainty

multiplied by a coverage factor $k = 2$ providing a confidence probability of approximately 95%.

Handling and storage of micrometers

This section covers the handling and storage of micrometers.

Routine checks of micrometers

On a regular basis, make the following routine checks.

- Check the condition of the plating and paint. There should be no discoloration, peeling or rust.
- Check that the measuring faces should be free from scratches and burrs.
- Check the fit of the threads. The screw should turn freely over the entire operation and be free from backlash.
- The threads of the spindle and inner sleeve should permit easy adjustment of the fit when they become worn
- Any misalignment that may exist between the spindle and the anvil should be small enough so as not affect measurement (0.002 inch for a 0 inch to 1 inch micrometer).
- The spindle should be easy to clamp. The micrometer reading should not change by more than 2 μm when the spindle is clamped.
- The ratchet stop should rotate smoothly.
- The clearance between the thimble and the sleeve should be even around the circumferences. The runout of the thimble should be minimal (should not be seen by the naked eye).
- When the zero line on the thimble is aligned with the index line on the sleeve, the end of the thimble should be aligned with a graduation line on the sleeve but should not overlap the graduation line so as to hide it.

Maintenance of micrometers

The following actions are required to maintain micrometer accuracy:

- daily inspection;
- cleaning and rust prevention; and
- storage of micrometers.

Each action is described in more detail below

Daily inspection

The following points should be addressed on a daily basis

- *Checking the zero point*

Even if the zero point of a micrometer has been adjusted accurately, it may need to be adjusted again after a few hours use since changes in temperature and other environmental conditions can cause the zero point to change.

- *Checking the measuring force*

A variation in the measuring force significantly affects the accuracy. For micrometers with a ratchet stop, check that the ratchet barrel turns smoothly and otherwise functions correctly.

- *Checking the fit*

Check the fit of the spindle and spindle guide, and the threads of the spindle and inner sleeve. Make sure that the spindle and other threaded parts move smoothly and evenly over their entire traverse. Eliminate excessive play or backlash with the adjusting device (taper nut).

- *Checking the micrometer after it has been dropped or subjected to a blow*

If the micrometer has been dropped or subjected to a blow, check the zero point, measuring force, fit conditions, runout of the thimble, parallelism between the measuring faces and the instrumental error.

Cleaning and rust prevention

- After using the micrometer, wipe off oil, cutting or grinding fluid, fingerprints and contaminants (fingerprints may cause rust). Wipe carbide tipped measuring faces thoroughly with a dry cloth. If the measuring faces are not carbide tipped, wipe clean and apply rust-preventing oil. Separate the two measuring faces slightly before storing the instrument.
- Wipe cutting or grinding swarf from the spindle before using the micrometer as these particles may become trapped between the spindle and the spindle guide.
- If a micrometer is not going to be used for an extended period, wipe it thoroughly and apply high-grade rust-preventing oil. Protect the micrometer from dampness by tightly wrapping the instrument with an oil soaked paper or cloth before putting it in the case. Select a storage place where humidity is low and temperature changes are small. If the micrometer has been stored for a long period, inspect it thoroughly before use.

Storage of micrometers

Note the following points when storing a micrometer.

- When storing the micrometer do not expose it to direct sunlight.
- Store the micrometer in a low humidity, well ventilated and dust free environment.
- Leave the measuring faces separated by 0.1 mm to 1 mm.
- Do not clamp the spindle
- Store the micrometer in a case.



Figure 64 Store micrometers in their container when not in use (courtesy Tesa Group).

Maintenance and periodic inspection of micrometers

To enable effective quality control it is essential to preserve the measuring accuracy and performance of measuring instruments. Poor maintenance leads to poor quality control, which may result in considerable losses due to out of tolerance parts. For example, an inaccurate micrometer could result in an entire batch of products failing to meet specifications. Even worse, the shipped products might be sent back to the company because of their poor quality, resulting in the company's reputation and image becoming tarnished.

Neglecting periodic inspection of measuring instruments may result in variations of measurements, which may result in problems arising between the design department, shop floor and inspection room. Proper maintenance cannot be maintained unless all employees concerned understand the importance of maintaining precision measuring equipment.

As with any instrument, deterioration of micrometers is unavoidable after a long period of service. The degree of deterioration depends on the frequency of use, environmental conditions and handling. To implement a periodic inspection schedule the following must be established:

- inspection criteria (for example, manufacturers specification, National or International Standard or company internal specification);
- periodic inspection interval (dependent on usage and calibration history);
- items and procedures of inspection (defined equipment and procedure documents); and
- criteria for inspection result judgements (conformance/non-conformance rules).

Special care in using and storing electronic micrometers

Because electronic micrometers can be easily damaged they require greater care than conventional micrometers. Observe the following additional precautions listed below.

- Do not subject the micrometer to direct sunlight or ultraviolet (UV) radiation. UV radiation accelerates the deterioration of Liquid Crystal Displays (LCD).
- Do not subject the micrometer to sudden changes of temperature, as this may cause internal condensation that could detrimentally affect the adhesive used in the assembly of the instrument.
- Do not apply voltage to the micrometer as this may damage the internal integrated circuits. For example, do not use an electric marker pen on the instrument.
- Electrical interference may cause failure or malfunction of electronic components. Micrometers that use the mains power via an alternating current (AC) adapter can be affected by electrical interference from other equipment that shares the same power outlet. Electromagnetic fields, current leaks and static electricity can also interfere with electronic micrometers.
- Do not use an organic solvent to clean the surface of the micrometer, it may cause deterioration of the plastic parts, instead use a neutral detergent for cleaning.
- Make sure the battery is orientated correctly, otherwise the micrometer will not operate and its electronic components may be damaged. If the micrometer is not going to be used for an extended period of time, remove the battery to prevent damage that may be caused by battery leakage.
- If a fault occurs, do not disassemble the micrometer but return it to the manufacturer for repair.

Micrometers for specialist tasks

Tubular inside micrometer

A number of tubular type micrometers are available; single rod type, extension type, interchangeable rod and the interchangeable tip type. They are covered by British Standard BS959 *Internal Micrometers (including stick micrometers)*.

The single rod type is the most widely used inside micrometer. It is available in many sizes with maximum measuring lengths ranging from 50 mm to 1000 mm in 25 mm increments. The spindle traverse is typically 25 mm.

The interchangeable rod type has a micrometer head and comes with a number of interchangeable rods of different length. One of the rods is attached to the micrometer head to obtain the desired measuring range.

The interchangeable tip type is the same construction as the single rod type, but the measuring heads have a hole for attaching various types of tips, for measuring threads and grooves.

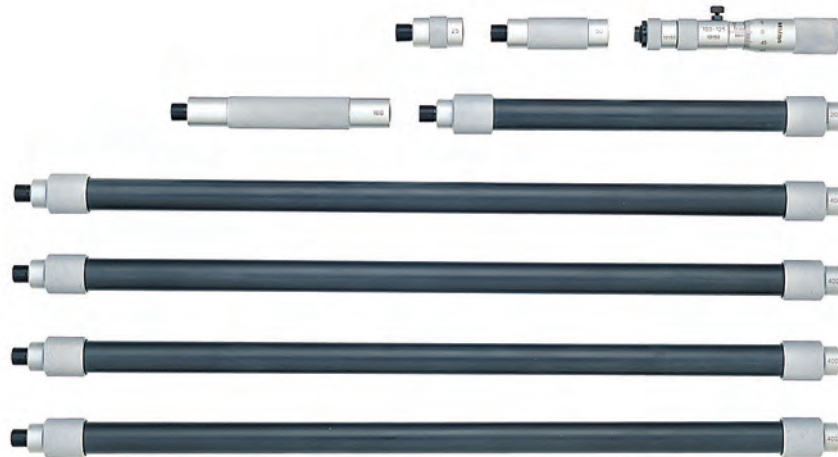


Figure 65 Tubular inside micrometer

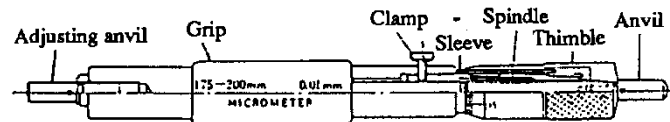


Figure 66 A schematic of a Tubular inside micrometer

A degree of expertise is required to accurately measure the inside diameters of tubes because of the difficulty in accurately positioning the micrometer inside the tube. If the micrometer is tilted in either the axial or diametral direction, a measurement error will result. In addition, many tubular micrometers are not provided with a constant-force device such as a ratchet stop, making accurate measurement even more difficult.

The correct way to use this micrometer is by rocking it left and right and in and out of the hole. Adjust the micrometer to a slightly larger reading after each series of rocking motions until the rod will no longer rock from left to right (figure 68). At this point there should be a slight drag on the in and out motion.

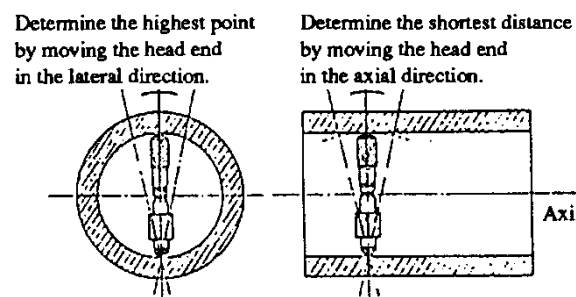


Figure 67 Use of inside micrometers

This procedure is required even if the micrometer has a constant-force device provided. Another measurement technique is to set the micrometer length to the dimension of the lower limit on the drawing and while measuring, make fine adjustments a little at a time until an accurate diameter is obtained.

To measure at a position deep inside a hole, a holder may be used. In this case, first set the micrometer length to the approximate dimension, and then make fine adjustments until the micrometer accurately indicates the diameter. Bore gauges are more effective for this type of measurement.

It can take a relatively long time to make a reliable measurement with a tubular micrometer and the longer handling time increases the effect of heat from the hands on the micrometer. This heat can substantially increase the micrometer length, resulting in a negative measurement error. To minimise thermal effects, the user should always wear gloves and should try to minimise the measuring time.

Calliper type inside micrometer

The calliper type micrometer (figure 69) has the same structure of thimble and sleeve as seen on the outside micrometer.



Figure 68 Calliper type inside micrometer (courtesy Mitutoyo)

To measure hole diameters with a calliper type micrometer insert the ribs of the jaws in the hole and turn the thimble until the ratchet stop turns idly for two or three clicks. Slightly move one of the jaws back and forth along the circumference of the hole whilst turning the ratchet stop slowly. This adjustment is required to obtaining the maximum reading of the diameter of the hole.

To set the zero point, uses a gauge block with jaws attached to both measuring faces of the block, or use an accurately calibrated plain setting ring gauge.

A simpler way is to use an outside micrometer and measure the distance between the measuring faces of the calliper type micrometer

Because the structure of a calliper type inside micrometer does not satisfy Abbe's principle, large errors of measurement will result when an excessive measuring force is applied. Apply the same force as is used when setting the zero point when performing measurements.

Three point type inside micrometer

Inside diameters measured with calliper and tubular type instruments use only two measurement contact points on the workpiece. The method requires considerable expertise and can result in significant measurement errors if great care is not taken.

The three-point type inside micrometer (figure 70) is simpler to use because it aligns itself with the hole axis by means of three evenly spaced contact points (figure 71). This allows

accurate measurements to be made easily and without special skill. The micrometer uses a tapered cone (or tapered threads) for converting the spindle's axial displacement to the radial displacements of the contact points. To measure a diameter at a position deep inside a hole, an extension rod may be attached between the measuring head and the micrometer head.



Figure 69 A three-point type inside micrometer (courtesy Mitutoyo)



Figure 70 A three point inside micrometer in use (courtesy Tesa Group)

The depth micrometer

Depth micrometers (figure 72) are used to measure the depths of holes, slots and steps. British standard BS6468:1984 *Specification for depth micrometers* covers depth micrometers.

The classifications for depth micrometers are

1. single rod type;
2. interchangeable rod type; and
3. sectioned rod type.

Of the above three types, the interchangeable rod type is the most widely used.



Figure 71 Using a depth micrometer (courtesy Tesa Group)

Single rod type depth micrometer

The single rod type depth micrometer (figure 73) consists of a micrometer head, spindle and base. The construction of the sleeve and the thimble is the same as that of a standard outside micrometer, but the graduations are given in the reverse direction. The typical measuring range is 25 mm. The end face of the spindle serves as the measuring face. The base is of hardened steel. Since the bottom face of the base is used as a reference face, it is precision lapped to high degree of flatness.



Figure 72 A single rod type depth micrometer (Spindle type S)

Interchangeable rod type depth micrometers

This type of micrometer (figure 74) uses a hollow spindle without a measuring face. An interchangeable rod passes through the spindle and the base. The rod has a precision lapped measuring face on one end. The other end of the rod is fixed to the spindle. The method of clamping the rod to the spindle depends on the manufacturer, for example, using a rod collar and setscrew or pressing the ratchet stop screw against the rod end.

Interchangeable rods of various lengths are available in 25 mm increments and these can be easily fitted to achieve the desired measuring length. The standard measuring range is 0 mm to 150 mm although rods are available to measure to a depth of up to 300 mm.



Figure 73 Interchangeable rod type depth micrometer (Spindle type R)

Sectioned rod type depth micrometer

The sectioned rod type depth micrometer is designed to overcome the measuring range limitations of the single rod type micrometer and the disadvantage of the interchangeable rod type micrometer that various lengths of rods are required for different measuring situations.

The sectioned rod type micrometer allows the user to select the effective rod length. It contains one long rod that has vee grooves around its circumference at 25 mm intervals along the axis. The spindle is hollow (similar to that of the interchangeable rod type) and it has a groove at one end for clamping the rod at one of the groove positions.

The standard measuring range of this type of instrument is 0 mm to 300 mm.

Error sources when using depth micrometers

The following sources of error can arise when using depth micrometers. The following gives guidance on error sources and how to avoid them.

1. The reference surface of the base tends to collect dust and cutting chips. Always keep the surface clean to ensure accuracy of results.
2. If the force is insufficient, the base may lift off the component face due to the measuring force applied to the spindle, resulting in measurement errors. Apply sufficient force to the base when taking measurements.
3. When using a long rod, an excessive measuring force can cause the rod to bend.
4. Be careful of ambient temperature changes. Thermal expansion is significant on long rods and it is good practice to wear gloves to minimise heat transfer during handling.
5. Each time a rod is replaced check the zero point.

Chapter summary

- Be aware of the operating principles of micrometers.
- Know how to use the constant force device.
- Be aware of the various types of micrometer and their application.
- Be aware of the factors affecting micrometer performance.
- Be aware of the sources of uncertainty.
- Know the correct way to store micrometers.

Summary

4

IN THIS CHAPTER

- Summary

This measurement good practice guide has provided an overview of the various considerations when using micrometers and callipers. The contents of this guide can be summarised as follows

The main factors when using micrometers and callipers can be summarised below

- Be aware of the factors affecting performance.
- Use the most appropriate instrument and make sure you know how to use it.
- Make sure that this instrument is calibrated and in good working order.
- Take care with the set up and preparation for measurement.
- Keep everything clean.
- Beware of temperature effects.
- Be aware of sources of uncertainty.
- Store instruments appropriately after use.

Glossary of terms

5

IN THIS CHAPTER

- Glossary Of Terms
- Terms Relating To Callipers
- Terms Relating To Micrometers

Glossary of terms

Terms defined below are based on the VIM, 3rd edition, JCGM 200:2008 (*International Vocabulary of Metrology - Basic and General Concepts and Associated Terms*) and ISO 10360 Parts 1 and 2.

General metrological terms

Abbe principle	The Abbe principle can be paraphrased as ‘maximum accuracy may be obtained only when the standard is in line with the axis of the part being measured.’
Accuracy of measurement	The closeness of the agreement between the result of a measurement and the (conventional) true value of the measurand. The use of the term precision for accuracy should be avoided. The statistical definition of ‘Accuracy’ is given in BS 5532. (BS 5233:1986).
Calibration	The set of operations which establish, under specified conditions, the relationship between values indicated by a measuring instrument or measuring system, or values represented by a material measure, and the corresponding known values of a measurand. (BS 5233:1986).
Coverage factor	A numerical factor, symbol k , used as a multiplier of the combined standard uncertainty in order to obtain an expanded uncertainty. (GUM 2.3.6).
Combined standard uncertainty	Combined standard uncertainty - standard uncertainty of the result of a measurement when that result is obtained from the values of a number of other quantities, equal to the positive square root of a sum of terms, the terms being the variances or covariances of these other quantities weighted according to how the measurement result varies with changes in these quantities. (GUM 2.3.4).
Cosine error	An error caused by the angular misalignment of the measuring system with the item being measured.
Fringe	A light or dark band observed when using an interferometer. Caused by constructive or destructive interference.
Gauge block	... material measure of rectangular section, made of wear-resistant material, with one pair of planar, mutually parallel

	measuring faces, which can be wrung to the measuring faces of other gauge blocks to make composite assemblies, or to similarly finished surfaces of auxiliary plates for length measurements. (ISO 3650:1999)
GUM	A document entitled <i>Guide to the expression of uncertainty in measurement</i> (GUM). BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML, 1st edition, 1995. This document explains one accepted method of calculating an uncertainty budget.
ISO	International Organization for Standardization
Mean	The mean is one way of obtaining a best estimate of a quantity. It is sometimes referred to as average. Summing all the measurements of a quantity and then dividing by the number of measurements will give you the mean of those measurements.
Measurand	The particular quantity subject to measurement.
NIST	National Institute of Standards and Technology
NPL	National Physical Laboratory
Precision	The reproducibility of a measurement.
PTB	Physikalisch-Technische Bundesanstalt
Resolution	A quantitative expression of the ability of an indicating device to distinguish meaningfully between closely adjacent values of the quantity indicated. (BS 5233:1986).
Result of measurement	...value attributed to a measurand, obtained by measurement.
Size	A number expressing, in a particular unit, the numerical value of a linear dimension.
SI	Système International d'Unités (International System of Units, international abbreviation SI)
Standard deviation	A statistical term that refers to the root mean square deviation of the measurements used to obtain a mean value. It is a useful way to characterise the dispersion of the measurements.
SEOM	Standard error of the mean. This is calculated by dividing the standard deviation by the square root of the number of readings.

Standard uncertainty	Uncertainty of a result of measurement expressed as a standard deviation.
Thermal expansion	How much a material changes length for a given temperature change is known as the coefficient of linear thermal expansion.
Tolerance	... difference between the upper and lower tolerance limits.
Traceability	... property of the results of a measurement whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties.
Type A contribution	Method of evaluation of uncertainty by the statistical analysis of a series of observations. (GUM 2.3.2).
Type B contribution	Method of evaluation of uncertainty by means other than the statistical analysis of a series of observations. (GUM 2.3.3).
Uncertainty	An estimate characterizing the range of values within which the true value of a measurand lies. (BS 5233:1986).
Value	...magnitude of a particular quantity generally expressed as a unit of measurement multiplied by a number.
Variance	A number that is the square of the standard deviation.

Terms relating to callipers

Deviation of reading. The difference between the vernier scale reading and the length separating the external measuring faces

Measuring range. The range of lengths that the external jaws may be used to measure without the vernier scale extending beyond the main scale.

Error of measurement. The algebraic difference between the measured size and the true size.

Calliper measuring instrument which gives the evaluation of a dimensional quantity of an internal or external feature on the basis of the movement of a slider with a measuring jaw, moving relative to a measuring scale on a rigid beam and a fixed jaw

1. Callipers with an additional measuring face at the end of the beam and a depth measuring rod are used for depth measurements.
2. The indication may be either analogue (vernier), circular scale or digital.

Measuring face line contact contact between a line, perpendicular to the length of the jaws, on the measuring face and a feature of a workpiece.

Deviation of reading difference between the vernier scale reading and the length separating the external measurement faces.

Measuring range range of lengths that can be measured using the external measurement jaws without the vernier scale extending beyond the main scale.

Terms relating to micrometers

Deviation of traverse of the micrometer screw. The maximum difference between the ordinates of the curve for the deviation of the readings obtained along the complete traverse of the screw.

Micrometer for external measurements measuring instrument which gives the evaluation of a dimensional quantity of an external feature of a workpiece on the basis of movement of a spindle with a measuring face, moving relatively to a material measure and an anvil, with the movement generated by a screw thread.

1. The guiding elements of the spindle and of the anvil are connected by a frame.
2. Usually, micrometers for external measurements have a thread as a material measure with the anvil, spindle and material measure arranged in a line.

Terms relating to callipers and micrometers

Measuring face contact contact between the measuring face and a feature of a workpiece.

Full measuring face contact contact between the full area of the measuring face and a feature of a workpiece.

Partial measuring face contact contact between a partial area of the measuring face and a feature of a workpiece.

Health and safety

6

IN THIS CHAPTER

- Mechanical hazards
- Chemical hazards
- Compressed air safety

Micrometers and callipers themselves are intrinsically safe. Hazards are therefore likely to arise mainly from their mis-use. Some specific things to look for when carrying out a risk assessment are listed below.

Mechanical hazards

Many of the items to be measured may be heavy. The appropriate lifting techniques and equipment should always be used and safety shoes worn. Operators should wear laboratory coats or overalls for safety reasons and to prevent fibres shed from clothing from falling on items being measured.

Machines under direct computer control may move without warning. The operator should stand back from the machine during an automatic run.

- Never attempt to measure a rotating work piece.
- Never measure workpieces that are hot from the machining process.

Chemical hazards

Chemicals may need to be used for cleaning purposes. Make sure the manufacturer's safety guidance is followed and the relevant personal protective equipment worn. Substances may be covered by the COSHH regulations.

- Take care when using cleaning solvents and oils and always wear the appropriate protective equipment.

Compressed air safety

Compressed air is often not seen as a safety hazard as the tendency is to think of air as harmless. It is advisable to check national regulations and to note the following.

- Air forced into body tissues through the skin can cause embolism which can be fatal.
- Eye and ear injuries can occur from a blast of air or flying particles. Flying particles can cause cuts and bruises to any part of the body.
- Never play with a compressed air line. As little as 5 PSI blown in to the mouth can rupture oesophagus or the lungs. A pressure of 40 PSI can blow out an eardrum and cause brain injury. Remember, never direct compressed air at yourself or another person.
- It is advisable to wear suitable personal protective equipment.
- Regularly check hoses and connectors for signs of damage.

Appendices

7

IN THIS CHAPTER

- Appendix A Links to other useful sources of information
- Appendix B Further reading
- Appendix C Manufacturers

Appendix A Links to other useful sources of information

A.1 National and International Organisations

A.1.1 National Physical Laboratory

"When you can measure what you are speaking about and express it in numbers you know something about it; but when you can not express it in numbers your knowledge is of a meagre and unsatisfactory kind."

Lord Kelvin, British Scientist (1824 – 1907)



The National Physical Laboratory (NPL) is the UK's national measurement institute and is a world-leading centre of excellence in developing and applying the most accurate measurement standards, science and technology available. For more than a century NPL has developed and maintained the nation's primary measurement standards. These standards underpin an infrastructure of traceability throughout the UK and the world that ensures accuracy and consistency of measurement.

NPL ensures that cutting edge measurement science and technology have a positive impact in the real world. NPL delivers world-leading measurement solutions that are critical to commercial research and development, and support business success across the UK and the globe.

Good measurement improves productivity and quality; it underpins consumer confidence and trade and is vital to innovation. NPL undertake research and shares its expertise with government, business and society to help enhance economic performance and the quality of life.

NPL's measurements help to save lives, protect the environment, enable citizens to feel safe and secure, as well as supporting international trade and companies to innovation. Support in areas such as the development of advanced medical treatments and environmental monitoring helps secure a better quality of life for all.

NPL employs over 500 scientists, based in south west London, in a laboratory, which is amongst the world's most extensive and sophisticated measurement science buildings.

The National Physical Laboratory is operated on behalf of the National Measurement Office by NPL Management Limited, a wholly owned subsidiary of Serco Group plc. For further information: Switchboard 020 8977 3222 | www.npl.co.uk/contact

A.1.2 National Institute of Standards and Technology (NIST)

NIST is the equivalent of NPL in the United States of America. Founded in 1901, NIST is a non-regulatory federal agency within the U.S. Department of Commerce. NIST's mission is to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve quality of life.

The NIST web site at www.nist.gov often contains documents relevant to this guide in Adobe PDF.

A.1.3 EURAMET

The European Association of National Metrology Institutes (EURAMET) is a Regional Metrology Organisation (RMO) of Europe. It coordinates the cooperation of National Metrology Institutes (NMI) of Europe in fields such as research in metrology, traceability of measurements to the SI units, international recognition of national measurement standards and related Calibration and Measurement Capabilities (CMC) of its members. Through knowledge transfer and cooperation among its members EURAMET facilitates the development of the national metrology infrastructures.

EURAMET serves the promotion of science and research and European co-operation in the field of metrology.

This is realized by the following measures in particular:

- development and support of European-wide research co-operation in the field of metrology and measurement standards;
- development, regular updating and implementation of a European Metrology Research Programme (EMRP);
- support of members and associates when applying for research funds for the purpose of European cooperative projects;
- co-ordination of joint use of special facilities;
- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards;
- technical co-operation with metrology institutes beyond EURAMET and with other regional and international metrology organisations;
- performing the tasks of a Regional Metrology Organisation (RMO) with the objective of worldwide mutual recognition of national measurement standards and of calibration and measurement certificates;

- promotion and co-ordination of scientific knowledge transfer and experience in the field of metrology;
- representing metrology at the European level and promoting best practice to policy and political decision makers with regard to the metrological infrastructure and European co-operation;
- co-operation with European and international organisations responsible for quality infrastructure, in particular by participation in the preparation of harmonized technical documents.

For more information visit the EURAMET web site at: www.euramet.org

A.1.4 Institute for Geometrical Product Specification

More information about GPS can be found at the Institute for Geometrical Product Specification website www.ifgps.com. Click on resources for more information on GPS.

A.2 Networks

A.2.1 Mathematics and Modelling for Metrology (MMM)

MMM is an programme that underpins the NMS, focussing on the use of mathematics and computing in metrology. It aims to achieve a balance between research and development, whilst also extending the range of techniques and applications available to meet the continually changing needs of metrology. The overall aim of the Programme is to tackle a wide range of generic issues, some of which are problems in metrology that require the application of established software engineering practices, whilst others require advances in mathematics, software engineering or theoretical physics. The programme, thus, includes work in metrology, mathematics, software and theoretical physics, with strong links between the various disciplines.

Further details can be found at website: <http://www.npl.co.uk/category/384>

A.3 National and International Standards

A.3.1 British Standards Institution (BSI)

BSI started in 1901 as a committee of engineers determined to standardise the number and type of steel sections in order to make British manufacturers more efficient and competitive. The BSI Group is now the oldest and arguably the most prestigious national standards body in the world and is among the world's leading commodity and product testing organisations. Website www.bsi-group.com.

A.3.2 International Organisation for Standardization (ISO)

The International Organization for Standardization (ISO) is a worldwide federation of national standards bodies from some 140 countries.

The mission of ISO is to promote the development of standardisation and related activities in the world with a view to facilitating the international exchange of goods and services, and to developing cooperation in the spheres of intellectual, scientific, technological and economic activity.

ISO's work results in international agreements that are published as International Standards.

Further information on ISO can be found at: www.iso.ch

The following BS and ISO specifications are relevant to this guide.

ISO 3599:1976 Vernier callipers reading to 0,1 and 0,05 mm*

ISO 6906:1984 Vernier callipers reading to 0,02 mm*

BS EN ISO 13385-1:2011 Geometrical product specifications (GPS) -- Dimensional measuring equipment -- Part 1: Callipers; Design and metrological characteristics

BS EN ISO 13385-2:2011 Geometrical product specifications (GPS) -- Dimensional measuring equipment -- Part 2: Calliper depth gauges; Design and metrological characteristics

BS 887:2008 Precision vernier callipers. Requirements and test methods.*

JIS B 7502 Micrometer callipers

JIS B 7507:1993 Vernier, dial and digital callipers

ISO 14253

* withdrawn

BS 1734:1951 Specification for micrometer heads.

BS EN ISO 3611:2010 Geometrical product specifications (GPS). Dimensional measuring equipment. Micrometers for external measurements. Design and metrological characteristics.

BS 959:2008 Specification for internal micrometers (including stick micrometers).

BS 6468:2008 Specification for depth micrometers.

BS 870:2008 Specification for external micrometers.

96/704404DC (Geometrical product Specification (GPS). *Dimensional Measuring Instruments. Internal Micrometers with two-point contact*. Design and metrological requirements (ISO/DIS 9121) is a draft available for public comment.

A.4 Traceability

Traceability in measurement is the concept of establishing a valid calibration of a measuring instrument or measurement standard, by a step-by-step comparison with better standards up to an accepted or specified standard. In general, the concept of traceability implies eventual reference to an appropriate national or international standard.

The National Physical Laboratory is the United Kingdom's national standards laboratory. It operates at the heart of the National Measurement System (NMS) which is the infrastructure designed to ensure accuracy and consistency in every physical measurement made in the UK. Chains of traceability link UK companies' measurements directly to national standards held at NPL.

For the majority of industrial applications, companies can establish a link to national measurement standards through the calibration and testing services offered by United Kingdom Accreditation Service (UKAS) accredited laboratories, which are in turn traceable to NPL. However, for challenging or novel measurements to the highest standards of accuracy, which are not catered for by UKAS-accredited laboratories, NPL can often provide a traceable measurement solution directly to industry.

The United Kingdom Accreditation Service is the sole national accreditation body recognised by government to assess, against internationally agreed standards, organisations that provide certification, testing, inspection and calibration services.

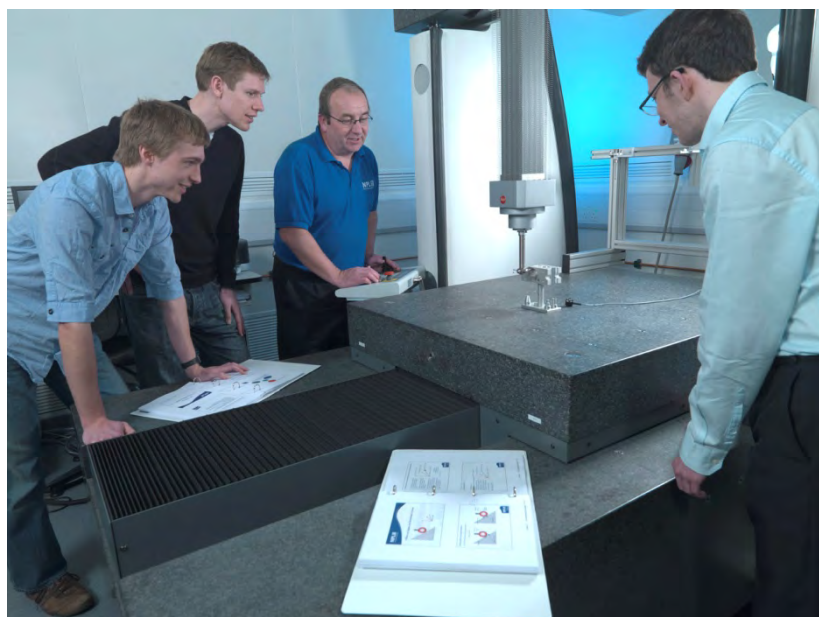
Accreditation by UKAS demonstrates the competence, impartiality and performance capability of these evaluators.

UKAS is a non-profit-distributing private company, limited by guarantee. UKAS is independent of Government but is appointed as the national accreditation body by the Accreditation Regulations 2009 (SI No 3155/2009) and operates under a Memorandum of Understanding with the Government through the Secretary of State for Business, Innovation and Skills.

UKAS accreditation demonstrates the integrity and competence of organisations providing calibration, testing, inspection and certification services.

Further information on UKAS can be found at: www.ukas.com.

A.5 Training courses



A.5.1 Dimensional measurement Training: Level 1 – Measurement User

A three day training course introducing measurement knowledge focusing upon dimensional techniques.

Aims & Objectives

To provide:

- the underpinning knowledge and expertise for anyone who uses measurement tools or requires an appreciation of the importance of measurement,
- the principle knowledge and practical training for people who are required to use dimensional measurement techniques to complete their daily tasks; and
- the tools to instil and encourage questioning culture.

Enabling:

- An understanding of the fundamentals of standards, traceability, calibration, uncertainty, repeatability, drawing symbols and geometrical tolerances, the importance of the relationship between tolerances and measuring equipment and be able to question the measurement.

Level 1 is applicable to all industrial sectors as a stand-alone qualification or as a building block for further NPL Dimensional Measurement Training levels – 2 & 3.

Course Content

Day 1 - Geometric Product Specification (GPS) A

Including what is GPS, drawing practice and geometrical tolerances.

Day 2 - Measurement Principles and Methods A

Including successful measurements, standards, traceability, calibration, uncertainty, units, relationship between tolerances and measuring equipment using micrometers and callipers, repeatability and reproducibility of measurements.

Day 3 - Measurement Principles and Methods B

Including the relationship between tolerances and measuring equipment by the use of height gauges, dial test indicators, dial gauges, plug gauges, gap gauges and temperature effects.

NB: Fundamental Measurement Calculation is incorporated into all 3 days including powers, scientific notation and triangles. This is achieved by understanding the relationship of these calculations when applied to tolerance zones and practical measuring tasks.

A workbook of evidence must be completed successfully during the training course and, where required, post assessment tasks can be set for each individual to be completed in the workplace.

A.5.2 Dimensional Measurement Training: Level 2 - Measurement Applier

A four day training course for those who have a good basic understanding of measurement principles gained through the Level 1 training course.

Aims & Objectives

To provide:

- the underpinning knowledge and expertise for anyone who uses measurement tools or requires an appreciation of the importance of measurement,
- the principle knowledge and practical training for people who are required to use co-ordinate measurement techniques to complete their daily tasks; and
- the tools to instil and encourage questioning and planning culture

Enabling:

- a visible return on investment for a manufacturing organisation in the form of various production cost savings and an upskilled workforce,
- a reduction in re-work time and waste on the production line - faults and problems will be detected earlier in the production process; and
- An in-depth appreciation of *why* measurement is carried out and not simply *how*

Level 2 is applicable to all industrial sectors as a stand-alone qualification or as a building block for further NPL Dimensional Measurement Training levels – 3 & 4.

A workbook of evidence must be completed successfully during the training course and, where required, post assessment tasks can be set for each individual to be completed in the workplace.

Course Content

Geometric Product Specification (GPS) B

Content covered:

GPS standards; Envelope tolerance; Size Principles; ISO Limits and Fits
Projected tolerance; Free state condition; Virtual condition; Maximum
Material Condition principles; Geometrical tolerancing measurements using
first principle measuring equipment; Surface texture principles.

Measurement Principles and Methods C

Content covered:

Calibration; Uncertainties; Traceability; Procedures; First Principle
Measurement; Angle plate; Gauge blocks; Surface plate; Height micrometer;
Sine bar or sine table.

Process Control A

Content covered:

Statistical Process Control theory; Variation – common, special causes;
Prevention versus detection; Collecting and calculating data when using

measuring tools; Callipers; micrometers; Basic charts – Tally chart/Frequency Table, Histogram, Control Chart; Reacting to variation; Benefits of process control; Standard deviation; Capability indices; Fundamentals of Gauge R&R.

Measurement Principles and Methods D

Content covered:

Taper calculations; Angles; Diameters; Searching for triangles; Chords; Radians; Manipulation of formula.

Co-ordinate Principles A

Content covered:

Application of equipment: First principles; Co-ordinate Measuring Machine; Optical and vision machines; Articulating arm; Laser tracker; Projector; Microscopes; Height gauge with processor; Contour measurement equipment.

Machine performance: Calibration standards; Self-verification/artefacts; Measurement volume.

Alignment Techniques: 321/point system alignment; Flat face alignment; Axes alignment; Car line/engine centre line.

Machine appreciation: Ownership; Care; Respect; Cost; Contribution to the business.

Work Holding: Fixturing; Rotary table; Clamping; How to hold the part; Influence of component weight, size, shape; Free state; Restrained state.

Co-ordinate geometry: Points; Plane; Line; Circle; Cylinder; Cone; Sphere; Ellipse.

Sensor Types: Probing Strategies; Relevant standards; Environment.

Measurement Strategies: Number of points; Partial arc; Contact/non contact.

Co-ordinate methods A (OEM Training - equipment specific)

Content covered:

First principles; Co-ordinate Measuring Machine; Optical and vision machines; Articulating arm; Laser tracker; Projector; Microscopes; Height gauge with processor; Contour measurement equipment.

A.5.3 Mitutoyo training courses

The Mitutoyo Institute of Metrology offers qualifications and training in over thirty metrology related subjects. Mitutoyo training programmes are vocation based and are accredited with the Open College Network (<http://www.nocn.ac.uk>) for a qualification in Dimensional Metrology. These credits in turn, contribute towards the evidence route of the Technical Services Engineering NVQ recently accredited by EMTA (Engineering and Maritime Training Authority). These courses are recognised nationally and are available in various areas of metrology.

See the Mitutoyo training pages <http://www.mitutoyo.co.uk/service-and-support/training/> for more information.

A.5.4 NPL E-Learning

Access over a century of **measurement knowledge** and **state-of-the-art techniques**, quality assured from the UK's National Measurement Institute. NPL's new e-Learning programme delivers measurement training, globally accessible across PCs and mobile devices, helping to provide confidence, value and performance from your measurement systems.

Engage with cost-effective on-demand content, globally accessible through an easy-to-use professional solution, compatible across devices.

NPL e-Learning offers:

- metrology training courses;
- free online open units; and
- free *Glossary of Metrology Terms*.

Ready for:

- apprenticeship programmes;
- national curricula; and
- workplace learning schemes.

Measurement just got simpler, and is now available to you **whenever you want and wherever you like – sign up now for free.**

<http://www.npl.co.uk/e-learning>



- Save time - Reduce time away from the job and fit training into busy work schedules
- Save money - Save travel costs and adjust training to your own schedule
- Take the classroom with you - Have your lessons anytime, anywhere
- Control your learning - Sequence your own learning and access only the materials you require
- Own your progression - Assess your progress and receive immediate feedback

Appendix B Further reading

Fundamentals of Dimensional Metrology, Sixth Edition Connie L Dotson

Mitutoyo Metrology Handbook, Nobuo Suga, 2007

Good Practice Guide Number No. 11 A Beginners Guide to Uncertainty in Measurement, NPL 1999

<http://www.wikihow.com/Use-and-Read-an-Outside-Micrometer>

<http://en.wikipedia.org/wiki/Micrometer>

Some micrometer simulators can be found here <http://www.stefanelli.eng.br/en/aka-micrometer-caliper-outside-inch-thousandths.html>

<http://labs.physics.dur.ac.uk/skills/skills/micrometer.php>

<http://www.mitutoyo.co.uk/metrology-handbook/>

There are also a number of YouTube videos that can be found on reading micrometers and callipers for instance <http://www.youtube.com/watch?v=jNwiRLM3STA>.

Other information is published regularly in QMT, Measurement Science and Technology, Metrologia, Measurement and Precision Engineering

Appendix C Manufacturers

The following is a list of manufacturers providing products or services relevant to this guide. The appearance of a manufacturer in this list is not an endorsement of its products or services. The list contains those companies known to the author and may not be complete.

Hexagon Metrology Limited (also Tesa Group and Cary products)

Metrology House
Halesfield 13
Telford,
Shropshire
TF7 4PL

Mahr U.K. Plc

19 Drakes Mews
Crown Hill
Milton Keynes
MK8 0ER

Mitutoyo (UK) Ltd

Coventry showroom
6 Banner Park
Wickmans Drive
Coventry, Warwickshire
CV4 9XA

Moore & Wright - Europe and North Africa

Bowers Metrology Ltd
32 Leeds Old Road
Bradford
West Yorkshire BD3 8HU

Preisner UK Limited

37 Dickerage Road
Kingston-Upon-Thames
Surrey
KT1 3SR

The L. S. Starrett Company Ltd.

Oxnam Road
Jedburgh
Scotland TD8 6LR

M J Allen Group of Companies**Verdict Gauge Limited**

Hilton Road
Cobbs Wood Industrial Estate
Ashford
Kent TN23 1EW