

Measurement Good Practice Guide

Callipers and Micrometers

Calibradores y micrómetros

David Flack



National Physical Laboratory

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MATERIAL REFERENCIAL



Measurement Good Practice Guide No. 40

Callipers and Micrometers

Guía de Buenas Prácticas de Medición N°40
Calibradores y micrómetros

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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.

Resumen: Esta guía cubre el uso de calibradores y micrómetros para mediciones internas, externas y de profundidad. Los temas cubiertos incluyen el efecto de la fuerza de medición, tanto cuando un trinquete está presente (por ejemplo micrómetros) y cuándo no, sobre todo cuando se miden materiales blandos es; uso y cuidados generales, apoyo y manejo de micrómetros y calibres; orientación sobre cómo elegir el tipo de equipo más adecuado para la medición; asesoramiento sobre métodos de calibración y verificación y cómo generar un presupuesto incertidumbre para una medición; uso de instrumentos electrónicos, conciencia culpa, efectos de la temperatura; la conciencia de los errores introducidos en las mandíbulas de borde cuchillo internos como externos / internos usan las mandíbulas; y métodos de calibración estándar y notificación de los resultados.

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Callipers and Micrometers

Contents

1	INTRODUCTION	1
1.1	CALLIPERS AND MICROMETERS.....	1
1.2	UNITS OF MEASUREMENT.....	1
2	CALLIPERS.....	2
2.1	OPERATING PRINCIPLES.....	2
2.1.1	Introduction.....	2
2.1.2	Types of Vernier Callipers	3
2.1.3	Standard Vernier Calliper	5
2.1.4	Dial Calliper	6
2.1.5	Electronic Calliper	7
2.1.6	Special purpose callipers	8
2.2	FACTORS AFFECTING PERFORMANCE	10
2.2.1	Instrumental error of outside measurement	11
2.2.2	Instrumental error of inside measurement.....	13
2.2.3	Straightness of inside and outside measuring faces.....	13
2.3	SET-UP, PREPARATION AND MEASUREMENTS.....	14
2.3.1	Set-up and preparation.....	14
2.3.2	Measurements.....	14
2.4	WORKED EXAMPLES	15
2.5	SOURCES OF MEASUREMENT UNCERTAINTIES AND ERROR	16
2.5.1	Calliper construction errors	16
2.5.2	Parallax error.....	20
2.5.3	Environmental conditions and measuring force.....	20
2.5.4	Overall errors of callipers.....	21
2.5.5	Uncertainties	21
2.6	HANDLING AND STORAGE OF CALLIPERS	24
2.6.1	Purchasing callipers	24
2.6.2	Storage of callipers	24
2.6.3	Periodic inspection and calibration	25
3	MICROMETERS.....	27
3.1	OPERATING PRINCIPLES.....	27
3.1.1	Constant force device.....	28

3.1.2	Types of Micrometer	29
3.1.3	Digital Micrometers	33
3.2	FACTORS AFFECTING PERFORMANCE	36
3.3	SET-UP AND PREPARATION	37
3.4	WORKED EXAMPLES	40
3.4.1	Standard micrometer (0.01 mm discrimination).....	40
3.4.2	Micrometers with a 0.001 mm discrimination.....	42
3.4.3	Reading an imperial (inch) micrometer	43
3.5	AWARENESS OF UNCERTAINTIES	45
3.5.1	Introduction.....	45
3.5.2	Terminology	45
3.5.3	Micrometers.....	46
3.5.4	Example Uncertainty Budget for the calibration of a 0 - 25 mm Micrometer	47
3.6	HANDLING AND STORAGE OF MICROMETERS	49
3.6.1	Routine checks of micrometers.....	49
3.6.2	Maintenance of Micrometers	50
3.6.3	Daily inspection	50
3.6.4	Cleaning and rust prevention.....	50
3.6.5	Storage of micrometers	51
3.6.6	Maintenance and Periodic Inspection of Micrometers	51
3.6.7	Special care in using and storing electronic micrometers	52
3.7	OTHER MICROMETERS	53
3.7.1	Tubular Inside Micrometer	53
3.7.2	Calliper type inside micrometer.....	55
3.7.3	Three point type inside micrometer	55
3.7.4	The Depth Micrometer	56
4	SUMMARY	60
5	GLOSSARY OF TERMS	61
5.1	CALLIPERS	61
5.2	MICROMETER	61
6	HEALTH AND SAFETY	62
APPENDIX A LINKS TO OTHER USEFUL SOURCES OF INFORMATION ...		63
A.1	NATIONAL / INTERNATIONAL ORGANISATIONS.....	63
A.1.1	National Physical Laboratory	63
A.1.2	National Institute of Science and Technology (NIST).....	63
A.1.3	EUROMET	63

A.1.4	European Co-operation for Accreditation (EA).....	64
A.2	METROLOGY CLUBS	65
A.2.1	Dimensional Metrology Awareness Club (DMAC).....	65
A.2.2	Software Support for Metrology Programme (SSfM)	65
A.3	NATIONAL AND INTERNATIONAL STANDARDS.....	66
A.3.1	British Standards Institution (BSI)	66
A.3.2	International Organisation for Standardisation (ISO).....	66
A.4	TRACEABILITY.....	67
A.5	NATIONAL MEASUREMENT PARTNERSHIP.....	68
A.6	TRAINING COURSES.....	69
A.7	AWARDING BODIES.....	69
A.8	MANUFACTURERS.....	70
A.9	FURTHER READING	71

List of Figures

Figure 1	M type vernier callipers.....	2
Figure 2	M type vernier calliper.....	3
Figure 3	CM Type Precision Vernier Calliper.....	4
Figure 4	Dial Calliper	4
Figure 5	Electronic (Digital) Calliper	4
Figure 6	Dial calliper.....	6
Figure 7	Electronic calliper	7
Figure 8	Offset calliper	8
Figure 9	Swivel jaw callipers	9
Figure 10	Long Jaw Callipers	9
Figure 11	Constant Force Dial Callipers	10
Figure 12	Offset Callipers	10
Figure 13	Outside measurement.....	11
Figure 14	Inside Measurement.....	13
Figure 15	Straightness of inside faces.....	13
Figure 16	An integer reading.....	15
Figure 17	A non integer reading on the main scale	16
Figure 18	ID measurement using internal measurement faces of M-type calliper	17
Figure 19	Hole diameter vs. measurement error.....	19
Figure 20	Clearance between inside jaws vs. measurement error when measuring a hole dia. of 10 mm	19
Figure 21	Sectioned view of a micrometer	27
Figure 22	Types of ratchet device	29
Figure 23	A micrometer	29

Figure 24 Spherical anvil and spindle type micrometer.....	30
Figure 25 Spline type Micrometer	30
Figure 26 Point Micrometer	31
Figure 27 Disc type paper thickness micrometer	31
Figure 28 Blade Micrometer	32
Figure 29 Indicating Micrometer	33
Figure 30 A digital micrometer	34
Figure 31 Interchangeable anvil type outside micrometer	34
Figure 32 Gear-tooth micrometer	34
Figure 33 Depth micrometer.....	35
Figure 34 Micrometer head.....	35
Figure 35 Variation in measurement at different support positions	39
Figure 36 1 mm and 0.5 mm divisions on the sleeve.	40
Figure 37 This reading will be 7.5 mm.....	40
Figure 38 This reading will be 12.5 mm.....	40
Figure 39 Graduations equal to one hundredth of a millimetre	41
Figure 40 Reading a micrometer.....	41
Figure 41 Method of reading down to 0.001 mm	42
Figure 42 Micrometer with a vernier scale on the sleeve.....	42
Figure 43 main division 0.100 in Sub-division 0.025 in	43
Figure 44 Reading a micrometer (0.239 in).....	43
Figure 45 Reading a micrometer (0.361 in).....	44
Figure 46 Tubular inside micrometer.....	53
Figure 47 Tubular inside micrometer.....	53
Figure 48 Inside micrometers	54
Figure 49 Calliper type inside micrometer.....	55
Figure 50 Three point type inside micrometer	56
Figure 51 Single rod type depth micrometer	57
Figure 52 Interchangeable rod type depth micrometer.....	58
Figure 53 Rod type depth micrometers	59

List of tables

Table 1 Graduations of main and vernier scales	5
Table 2 Graduations of main and vernier scales	5
Table 3 Dial calliper graduations	7
Table 4 Small hole diameter measurement errors.....	18
Table 5 Overall errors Unit: mm (JIS).....	21
Table 6 Factors affecting performance and corrective actions	36
Table 7 Calibration of a micrometer	46
Table 8 Accuracy of Micrometer Traverse Calibrated Against Steel Grade 1 Gauge Blocks	48

MEASUREMENT GOOD 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.*

Demonstratable 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*

1 INTRODUCTION

1.1 CALLIPERS AND MICROMETERS

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

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, 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 section 2 of this guide and micrometers in section 3.

1.2 UNITS OF MEASUREMENT

Parts of this guide cover the use of instruments calibrated in imperial units. Units of measurement are covered by European Directives. 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 the Consumer Affairs Division of the DTI.

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

2 CALLIPERS

2.1 OPERATING PRINCIPLES

2.1.1 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. A typical calliper can be used to make three types of measurement, i.e., outside, inside and depth.

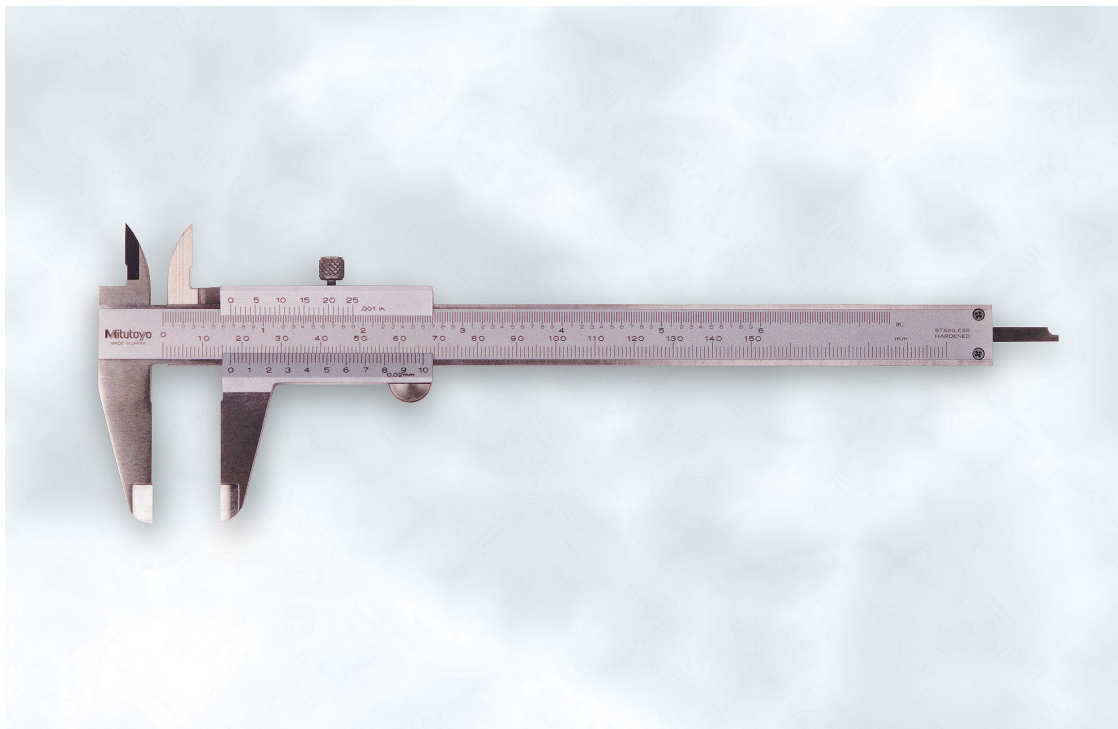


Figure 1 M type vernier callipers

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 following standard specifications are relevant to callipers:

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

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

BS 887:1982 Specification for precision callipers

JIS B 7502 Micrometer callipers

JIS B 7507:1993 Vernier, dial and digital callipers

* Note: The UK has expressed disapproval of these two standards on technical grounds.

2.1.2 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.

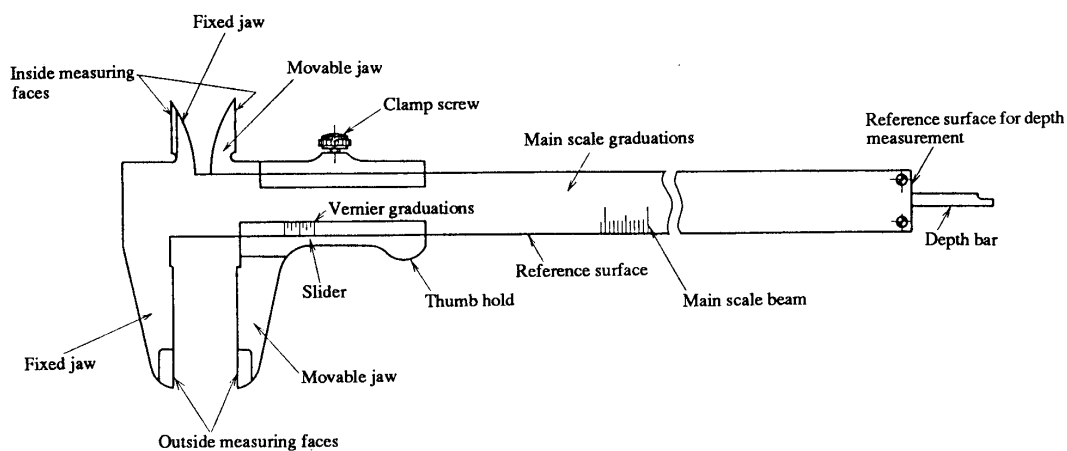


Figure 2 M type vernier calliper

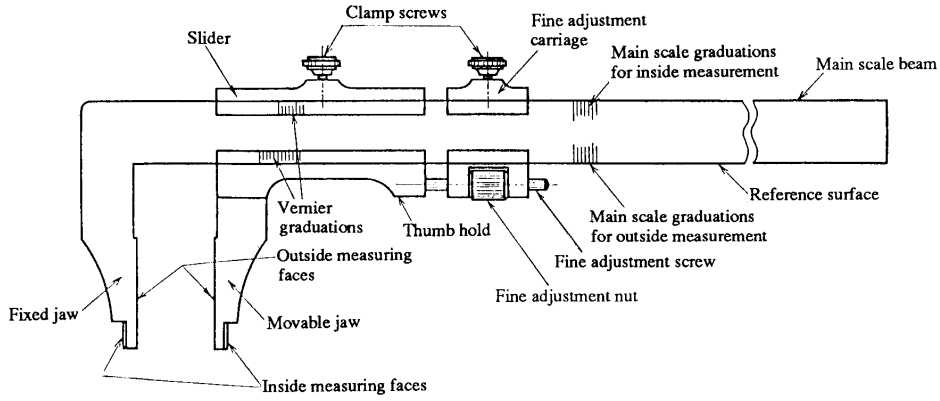


Figure 3 CM Type Precision Vernier Calliper

The CM type is the type of calliper covered by ISO 6906 and ISO 3599. The M type is covered by ISO 3599. Other types of calliper include the dial calliper (Figure 4) and the electronic calliper (Figure 5).

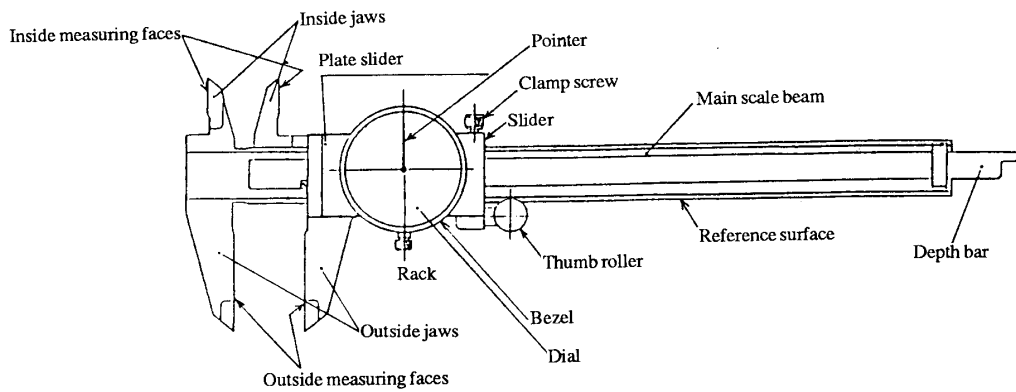


Figure 4 Dial Calliper

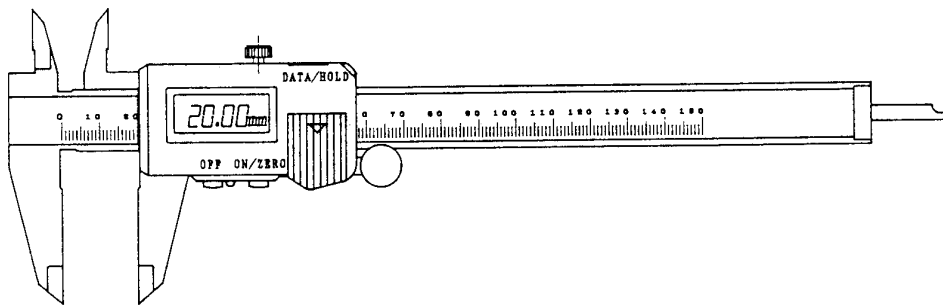


Figure 5 Electronic (Digital) Calliper

2.1.3 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. 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 e.g. 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 section 2.4).

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		
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

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

2.1.4 Dial Calliper

Dial callipers are used extensively 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. Measurements are taken by adding the position of the pointer on the dial to the reading on the main scale. Before using dial callipers the jaws should be cleaned. The jaws should then be closed and the zero adjusted by rotating the scale bezel.

With dial callipers it is essential that the toothed rack is kept clean. Contamination can cause the pinion gear to jump and lead to the pointer not returning to zero.

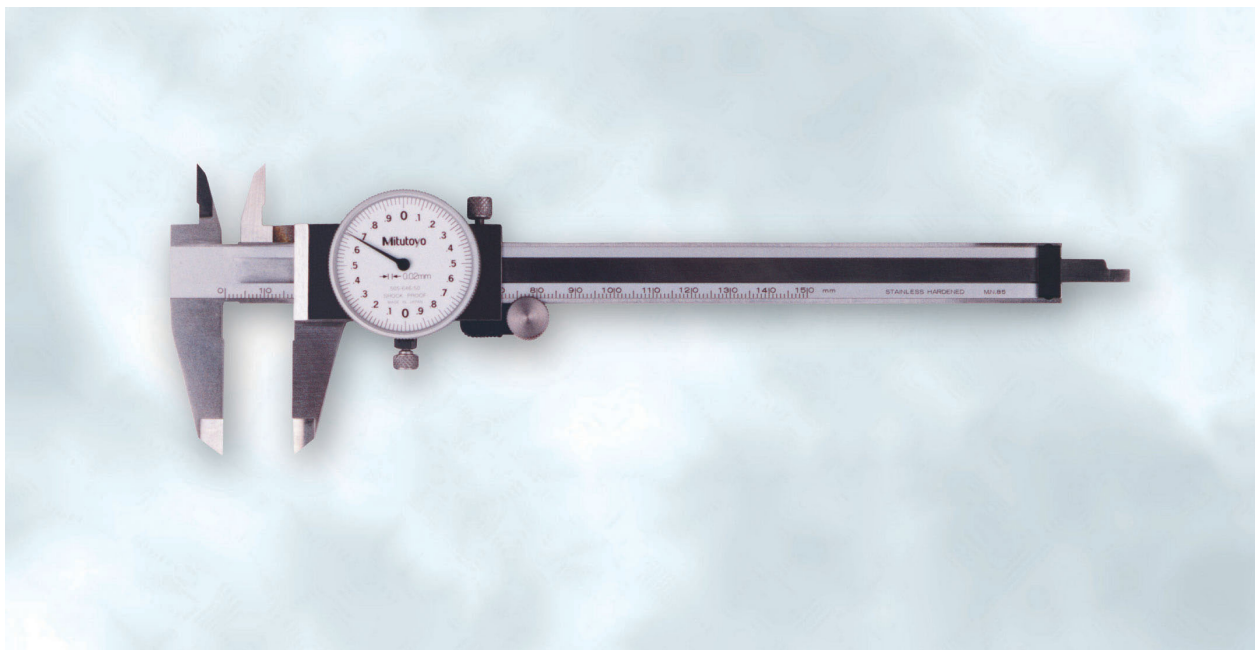


Figure 6 Dial calliper

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			

2.1.5 Electronic Calliper

The electronic calliper (Figure 7) generally uses a capacitance type detector as its displacement detection system. The advantages of this type of instrument are ease of reading and operation and enhanced functionality. Before electronic callipers are used the jaws should be cleaned. The jaws should then be closed and the zero set.



Figure 7 Electronic calliper

2.1.6 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. Many special purpose callipers have therefore been developed to cope with these and other difficult measurement situations. The following sections contain examples of special purpose callipers.

2.1.6.1 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, e.g. castings and grinding stones.

2.1.6.2 Offset Calliper

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

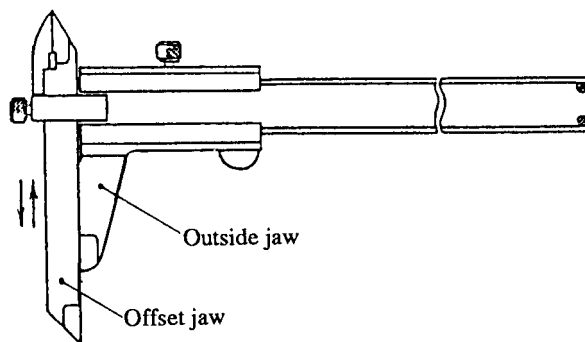


Figure 8 Offset calliper

2.1.6.3 Swivel jaw callipers

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

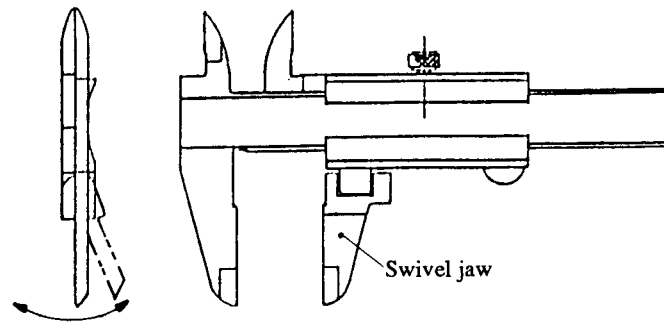


Figure 9 Swivel jaw callipers

2.1.6.4 Long jaw callipers

This type of calliper 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 cannot be measured with standard type callipers. 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.

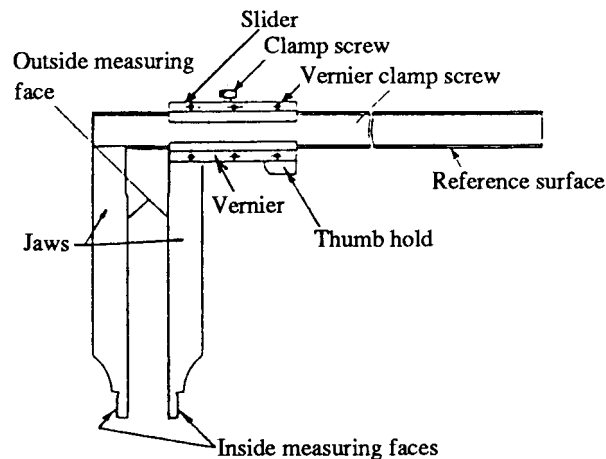


Figure 10 Long Jaw Callipers

2.1.6.5 Constant force dial callipers

Polymer materials are now extensively used for machine parts and require accurate dimensional measurement. Because these materials are often soft, they can be deformed by the measuring force applied by ordinary callipers and micrometers, resulting in

inaccurate measurements. Constant force dial callipers have consequently been developed to allow the measurement of materials that are easily deformed.

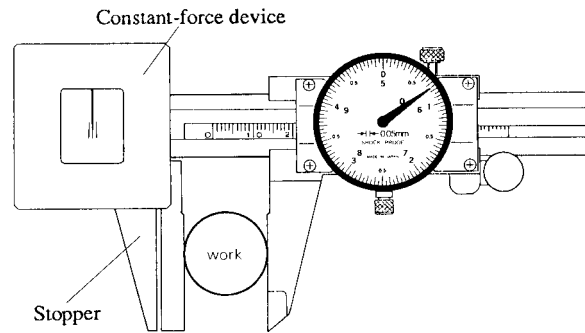


Figure 11 Constant Force Dial Callipers

2.1.6.6 Offset callipers for hole distance measurement

This type of calliper 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.

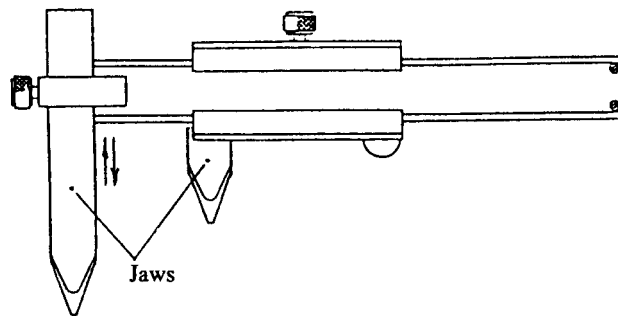


Figure 12 Offset Callipers

2.2 FACTORS AFFECTING 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, measuring instruments should be selected according to the accuracy requirement of the intended application. It should be noted that even if a very accurate instrument is used,

measurement errors still may 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 a measurement is taken under the standard conditions specified for that instrument. It is important to know the instrument error because by compensating for the error more accurate measurements can be obtained.

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.

The performance of a calliper is checked according to the following procedures:

2.2.1 Instrumental error of outside measurement

Insert a gauge block between the two faces used for external measurement. 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.

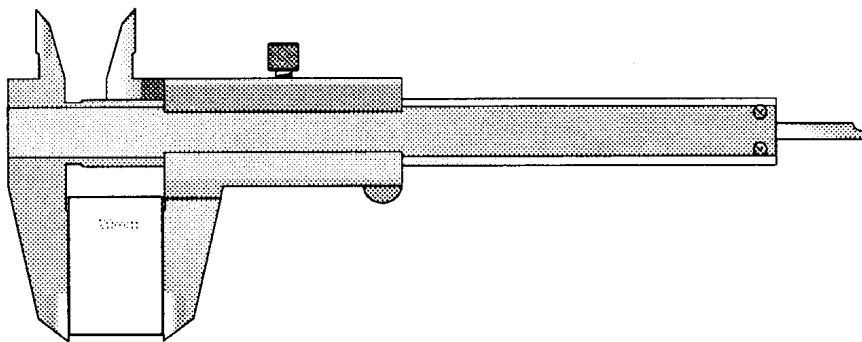


Figure 13 Outside measurement

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. The squareness of the fixed face to the guiding edge should be checked with a knife-edge square. The flatness of the faces should be checked with an optical flat (See *Fundamentals of Dimensional Metrology* Chapter 13 – full details at the end of this guide).

2.2.2 Instrumental error of inside measurement

Produce a known internal dimension using a gauge block and holding device and jaws from an accessory set. 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.

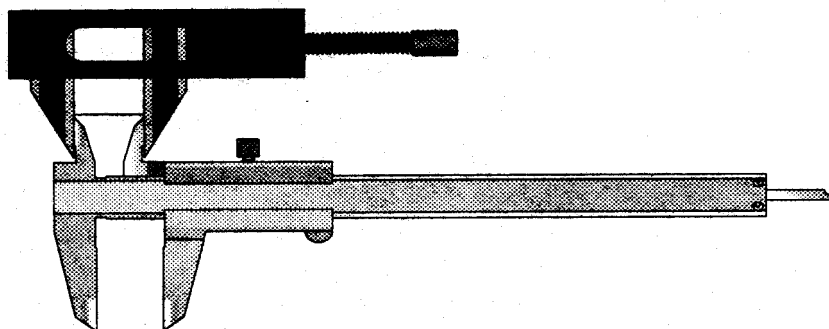


Figure 14 Inside Measurement

The parallelism of the faces for internal measurement should be checked with a micrometer with small diameter anvils.

2.2.3 Straightness of inside and outside measuring 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 15) and noting the change in reading.

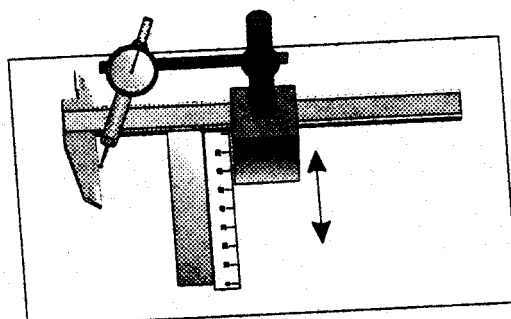


Figure 15 Straightness of inside faces

Appendix B of BS887:1982 gives further information of methods of testing Precision Vernier callipers.

2.3 SET-UP, PREPARATION AND MEASUREMENTS

The following is a list of steps and precautions to be observed when making external measurements with callipers. British standard BS 887:1982 *Specification for Precision vernier callipers* Appendix C contains notes on the use of precision callipers.

2.3.1 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. Damaged callipers should not be used.
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. Correct any problems found 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.

2.3.2 Measurements

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, which should be as close as possible to the main scale.
4. Align beam of 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. The clamping screw should not be regarded 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 workpiece 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.

2.4 WORKED EXAMPLES

The example below explains how a reading is taken using a metric vernier calliper. Figure 16 illustrates the case where the zero graduation on the vernier scale aligns perfectly with a graduation on the main scale.

MAIN AND VERNIER SCALE

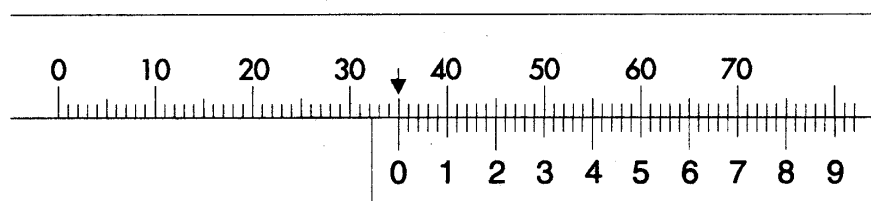


Figure 16 An integer reading

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.

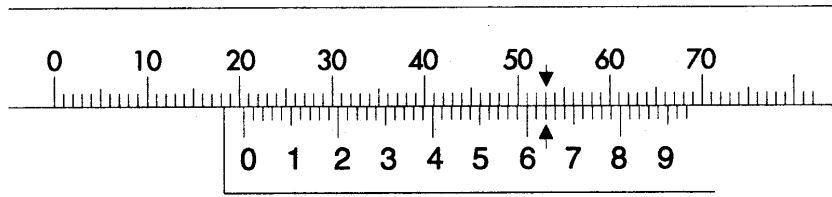


Figure 17 A non integer reading on the main scale

Figure 17 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 17) 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 17 this is 64 on the vernier scale.
3. The correct reading in the above example is therefore $20 \text{ mm} + 0.64 \text{ mm} = 20.64 \text{ mm}$

2.5 SOURCES OF MEASUREMENT UNCERTAINTIES AND ERROR

There are a number of factors that affect 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.
3. Environmental conditions and measuring force.

2.5.1 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.

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, the portion of the jaws closer to the main scale should be used.
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 the figure 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.

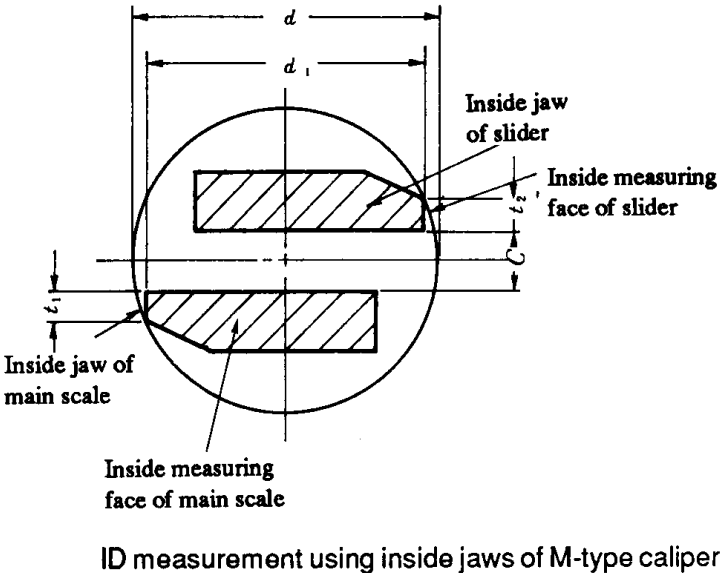


Figure 18 ID measurement using internal measurement faces of M-type calliper

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

Unit: mm

Hole Diameter	B				
	0.3	0.4	0.5	0.6	0.7
1.5	0.030	0.050	0.090	0.12	0.17
2	0.023	0.041	0.060	0.09	0.13
2.5	0.018	0.032	0.050	0.07	0.10
3	0.015	0.027	0.042	0.06	0.08
3.5	0.013	0.023	0.036	0.05	0.07
4	0.011	0.020	0.031	0.045	0.06
4.5	0.010	0.017	0.028	0.038	0.05
5	0.009	0.014	0.026	0.033	0.047
6	0.008	0.013	0.021	0.029	0.041
7	0.007	0.011	0.018	0.026	0.036
8	0.007	0.010	0.016	0.023	0.033
9	0.006	0.009	0.013	0.020	0.028
10	0.005	0.008	0.012	0.017	0.023

Figure 19 shows an error curve when B is constant (0.7 mm). The offset of the measuring jaws from the centre line of the hole $\left(\frac{B}{2}\right)$ 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:

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

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

where r is the radius of the hole

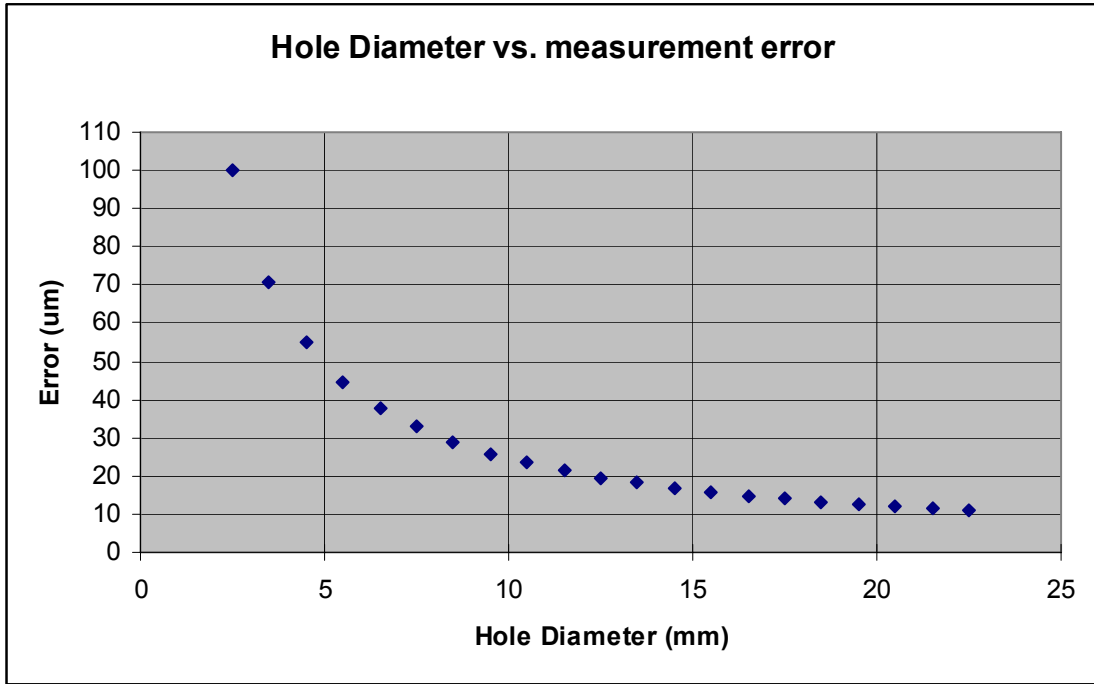


Figure 19 Hole diameter vs. measurement error

Figure 20 shows error curves with reference to different jaw clearances and thickness when a hole diameter of 10 mm is measured.

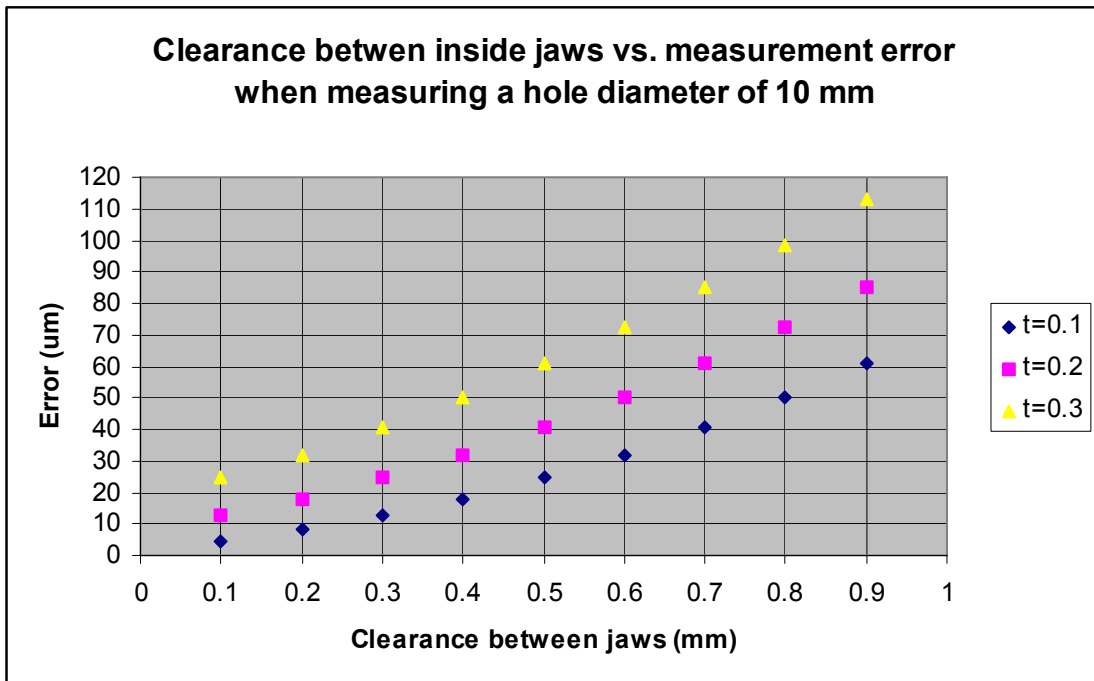


Figure 20 Clearance between inside jaws vs. measurement error when measuring a hole dia. of 10 mm

2.5.2 Parallax error

As illustrated in section 2.4, 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.

2.5.3 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 the following precautions must be observed: -

- a) The slider must move smoothly.
- b) Do not apply excessive measuring force.
- c) Measure the workpiece using the portions of the jaws that are closest to the main scale.

2.5.4 Overall errors of callipers

The overall error takes all individual errors into account. This will normally be defined in an international or manufacturer's specification. It 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 the table 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

2.5.5 Uncertainties

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 a detailed uncertainty calculation step by step and is recommended reading.

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.

Accuracy *A general term describing the degree of closeness with which the indications of an instrument approach the values of the quantities measured.*

Error *The discrepancy between the result of the measurement and the true value of the quantity measured*

Precision *The closeness of agreement between the results obtained by applying the experimental procedure several times under the prescribed conditions.*

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.

Specific details relating to callipers are given in the following sections.

2.5.5.1 Uncertainty when making a measurement with 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
- (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.

A pair of callipers with a resolution of 0.02 mm is used to measure a component. 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, 20.08, 20.06, 20.10, 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 (0.022 8 mm) divided by the square root of the number of measurements (5).

$$\frac{\sigma_{n-1}}{\sqrt{n}} = \frac{0.0228}{\sqrt{5}} = 0.0102 \text{ mm}$$

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. Assuming an *a priori* rectangular 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. Assuming an *a priori* rectangular 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

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

the expanded uncertainty at $k = 2$ is therefore 0.035 mm.

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 $k = 2$.

2.5.5.2 Calibration uncertainty

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

2.6 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.

2.6.1 Purchasing callipers

An effective method of maintenance control for measuring tools, such as callipers, which are frequently used on the shopfloor is to limit the number of tools in the toolroom and on the shopfloor. Although callipers are relatively cheap, they are not consumables and should not be treated as such. 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.

2.6.2 Storage of callipers

The following precautions should be observed 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 so that the main scale beam will not bend and to protect the vernier from damage.
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. At least once a month, check the storage condition and movement of callipers that are seldom used and kept in storage 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. Ensure that detailed information is maintained 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 after the measurements have been carried out.

Callipers should never be left 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 a measurement is complete, the callipers should be cleaned and stored properly.

2.6.3 Periodic inspection and calibration

Periodic inspections of callipers should be carried at least once a year, the exact interval depending on the frequency of use. Inventory control methods should also be implemented to prevent inadvertent use of callipers that are 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. All personnel who use callipers in the workplace should be informed 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 further checks on the jaw faces using optical flats should be made.

Frequency of calibration will depend on frequency of use and on the previous history of the calibration errors. Calibration should be carried out using traceable standards. Alternatively use should be made of a UKAS accredited laboratory to perform the calibration. British Standard BS 887 *Precision vernier callipers* gives methods for calibrating callipers in its Appendix B.

3 MICROMETERS

3.1 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). The main components of a micrometer are shown in Figure 21.

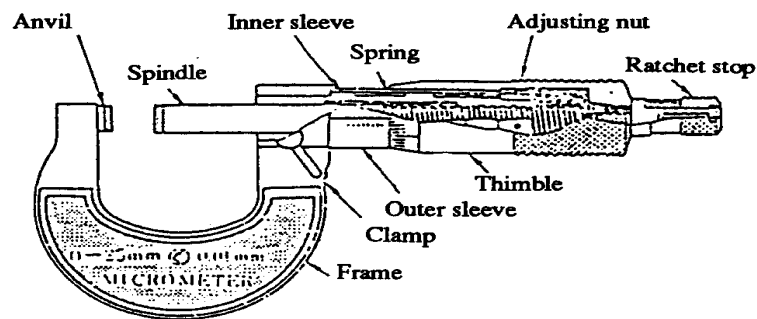


Figure 21 Sectioned view of a micrometer

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 to 25 mm, 25 to 50 mm, ..., 575 –600 mm etc. As an example a dimension of 19.45 mm would be measured with a 0 to 25 mm micrometer and a dimension of 580.25 mm with a 575-600 mm micrometer.

3.1.1 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, a constant force device called the ratchet stop (Figure 22) is used on many micrometers. Figure 22 shows three types of ratchet stops. The mechanism shown in Figure 22(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.

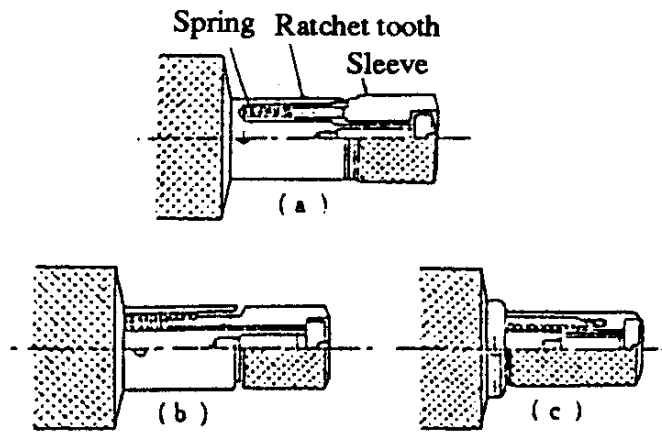


Figure 22 Types of ratchet device

3.1.2 Types of Micrometer

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

3.1.2.1 Standard micrometer

Figure 23 shows a micrometer of the type described in section 3.1 and shown sectioned in Figure 21. It is probably the most common type of micrometer that the reader will encounter.



Figure 23 A micrometer

3.1.2.2 Spherical anvil and spindle type

A spherical anvil type micrometer is shown in Figure 24. The anvil and spindle measuring faces of this type of micrometer are either both spherical or spherical and flat. This type of micrometer is useful for measuring the wall thickness of special shaped tubes with a non-circular outside diameter.



Figure 24 Spherical anvil and spindle type micrometer

3.1.2.3 Spline micrometer

The anvil and the spindle of this type of micrometer (Figure 25) are of small diameter in order to measure splined shafts, slots and keyways for which standard outside micrometers are not suitable.



Figure 25 Spline type Micrometer

3.1.2.4 Point micrometer

This instrument (Figure 26) 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 degrees anvils.



Figure 26 Point Micrometer

3.1.2.5 Disc type paper thickness micrometer

This type of micrometer (Figure 27) 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 disks are used to provide large measuring faces in order to avoid concentrating the measuring force.



Figure 27 Disc type paper thickness micrometer

3.1.2.6 Blade micrometer

The anvil and non-rotating spindle of this type of micrometer (Figure 28) 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 28 Blade Micrometer

3.1.2.7 Indicating micrometers

An indicating micrometer (Figure 29) 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 29 Indicating Micrometer

3.1.3 Digital Micrometers

All of the micrometers described in section 3.1.2 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. This problem is completely eliminated by digital readout. However, care should still be exercised with a digital micrometer since it is possible to select the wrong measurement units or inadvertently introduce a zero offset. The zero should always be rechecked after a measurement.

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



Figure 30 A digital micrometer

3.1.3.1 Types of Digital Micrometers

Some examples of the various types of digital micrometer are shown below.



Figure 31 Interchangeable anvil type outside micrometer



Figure 32 Gear-tooth micrometer

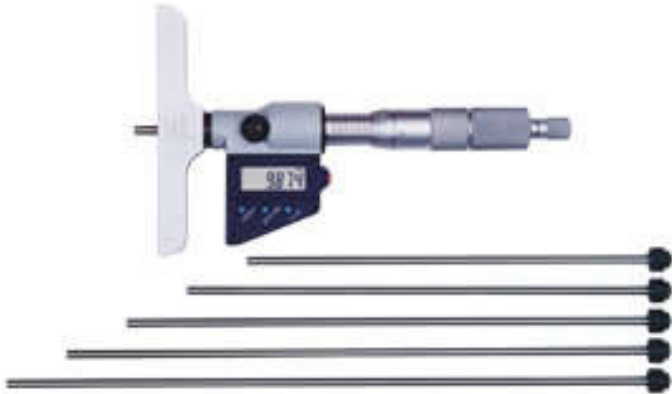


Figure 33 Depth micrometer



Figure 34 Micrometer head

3.2 FACTORS AFFECTING PERFORMANCE

Table 6 below lists factors affecting micrometer performance and 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 etc.	✓	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 (e.g. 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 µ,	✗	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

3.3 SET-UP AND PREPARATION

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

- 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. If burrs are found use a fine-grained oilstone to remove.
- **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 is not even, 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.
- If the movement is stiff adjust the collet slightly. 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 operators skin (see ROSPA leaflet '*Compressed Air Care*').
- 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 i.e. 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, check the zero point periodically to confirm that there is no discrepancy. Measurements should always be taken 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") long iron rod will change length by 0.012 mm (0.00047") with a temperature change of 10 °C.
- When measuring a heavy workpiece 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, special care must be taken to prevent "spindle play", due to excessive clearance between the spindle and spindle guide at the end of the inner sleeve. A constant and appropriate measuring force should be applied. It is also important that measuring faces are flat and parallel.
- Minimise parallax errors by viewing from the correct angle, i.e., 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 section 3.6.3.
- 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 overtighten 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 35 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
Orientation		
Maximum measuring length (mm)		
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
Orientation		
Maximum measuring length (mm)		
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 35 Variation in measurement at different support positions

3.4 WORKED EXAMPLES

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

3.4.1 Standard micrometer (0.01 mm discrimination)

With these 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 36 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.

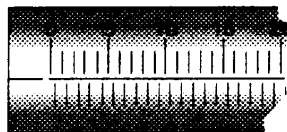


Figure 36 1 mm and 0.5 mm divisions on the sleeve.

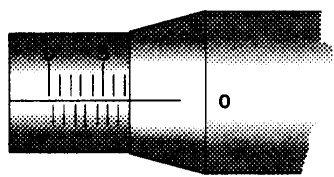


Figure 37 This reading will be 7.5 mm

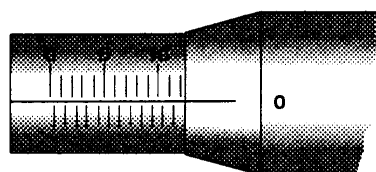


Figure 38 This reading will be 12.5 mm

The thimble has 50 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.

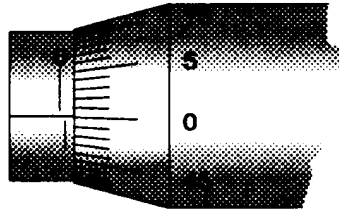


Figure 39 Graduations equal to one hundredth of a millimetre

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 40 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 41) 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.

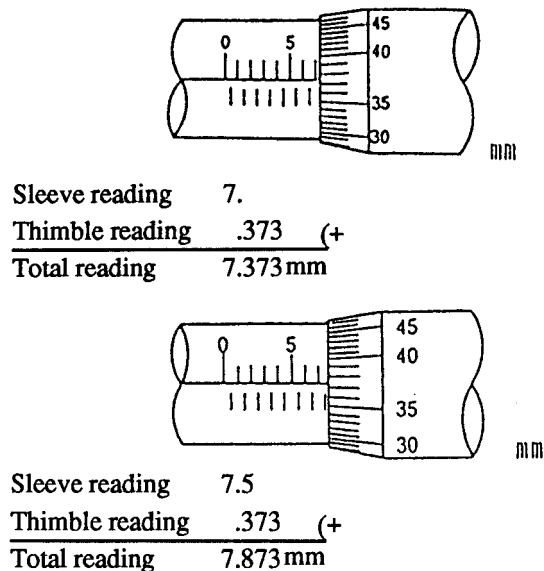


Figure 40 Reading a micrometer

Care must be taken not to misread the smallest graduation on the sleeve (this will result in an error of 0.5 mm on a standard metric micrometer), Figure 41 shows a method of reading a micrometer so as 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.

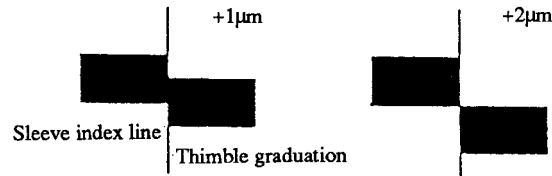
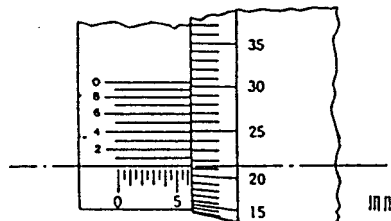


Figure 41 Method of reading down to 0.001 mm

3.4.2 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. 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. Readings on the vernier scale are taken 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 (+)
<hr/>	
Total reading	6.213mm

Figure 42 Micrometer with a vernier scale on the sleeve

3.4.3 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 43 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, i.e., 0.1 divided by 4).

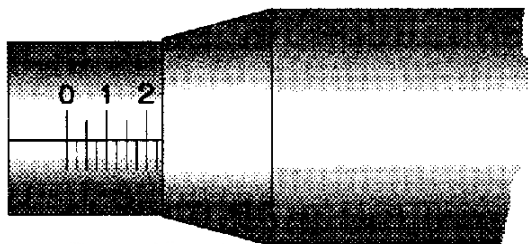


Figure 43 main division 0.100 in Sub-division 0.025 in

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 44 is 0.239 in which is made up from:

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

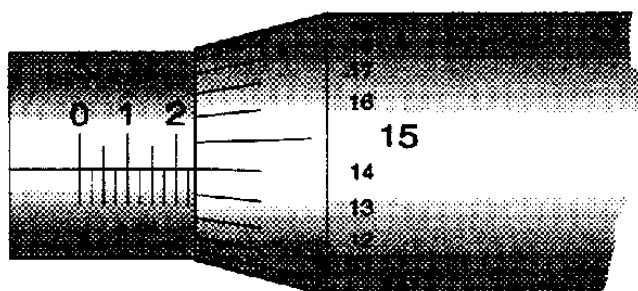


Figure 44 Reading a micrometer (0.239 in)

Figure 45 is another example. The reading is 0.361 in which is made up from:

3 main 0.100 divisions

2 0.025 in sub-division

11 thimble divisions

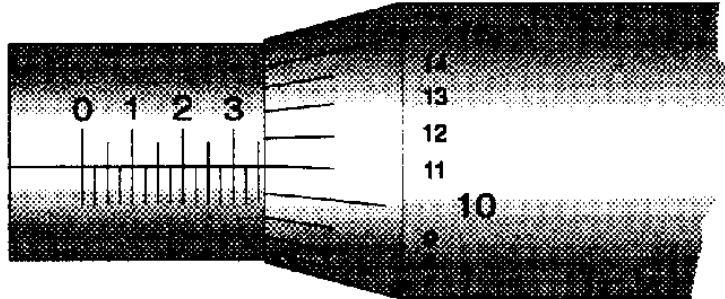


Figure 45 Reading a micrometer (0.361 in)

3.5 AWARENESS OF UNCERTAINTIES

The general information on uncertainties/terminology in section 3.5.1 and 3.5.2 has been discussed earlier in connection with callipers however it is repeated again for those readers who have not read the guidelines on callipers. It is recommended reading.

3.5.1 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 a detailed uncertainty calculation step by step.

3.5.2 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 *A general term describing the degree of closeness with which the indications of an instrument approach the values of the quantities measured.*

Error *The discrepancy between the result of the measurement and the true value of the quantity measured*

Precision *The closeness of agreement between the results obtained by applying the experimental procedure several times under the prescribed conditions.*

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. Although the error at the 25 mm position is on top limit the instrument is very repeatable so can be said to be precise.

3.5.3 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** e.g. measuring a brass artefact with a steel micrometer at a temperature other than 20.0 °C.

3.5.4 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 870:1950, 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	√3	0.144
Uncorrected errors in length of gauge block (b) at point of maximum error	0.3 µm	Rectangular	√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	√3	0.577
Effect of temperature differences between micrometer and gauge blocks *	0.14 µm	Rectangular	√3	0.081
Combined standard uncertainty	-	Normal	-	0.943
Expanded uncertainty	-	Normal (<i>k</i> =2)	-	1.885

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

* Temperature effects based on expansion coefficient of 11 µm/metre/°C, with temperature difference of 0.5 °C over 25 mm.

The combined standard uncertainty is calculated from

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

The uncertainty is reported 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 ± 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%.

3.6 HANDLING AND STORAGE OF MICROMETERS

This section covers the handling and storage of micrometers.

3.6.1 Routine checks of micrometers

The following routine checks should be made on a regular basis.

- Check the condition of the plating and paint. There should be no discoloration, peeling or rust.
- 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 0-1 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 hide it.

3.6.2 Maintenance of Micrometers

The following actions are required to maintain micrometer accuracy:

- Daily inspection (3.6.3)
- Cleaning and rust prevention (3.6.4)
- Storage of micrometers (3.6.5)

3.6.3 Daily inspection

- Checking the zero point

Even if the zero point of a micrometer has been accurately adjusted, 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.

3.6.4 Cleaning and rust prevention

- After using the micrometer, wipe off oil, cutting or grinding fluid, fingerprints and contaminants (fingerprints may cause rust). Carbide tipped measuring faces should be wiped thoroughly with a dry cloth. If the measuring faces are not carbide tipped, wipe clean and apply a 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 of time, 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 of time, inspect it thoroughly before use.

3.6.5 Storage of micrometers

The following points should be noted 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.

3.6.6 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, shopfloor 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 (e.g. 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)
- Criteria for inspection result judgements (Pass/Fail rules)

3.6.7 Special care in using and storing electronic micrometers

Because electronic micrometers can be easily damaged they require greater care than conventional micrometers. The following additional precautions must be observed:

- 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 which 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.

3.7 OTHER MICROMETERS

3.7.1 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 46 Tubular inside micrometer

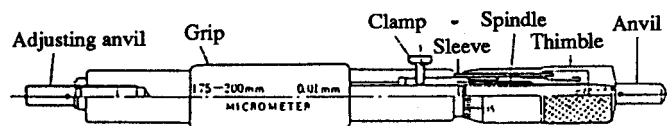


Figure 47 Tubular inside micrometer

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 48). At this point there should be a slight drag on the in and out motion.

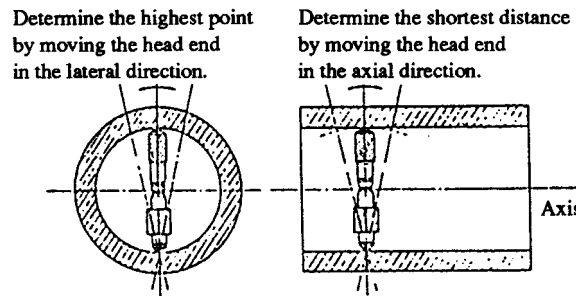


Figure 48 Inside micrometers

This procedure is required even if the micrometer is provided with a constant-force device. 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, 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.

3.7.2 Calliper type inside micrometer

The calliper type micrometer (Figure 49) has the same structure of thimble and sleeve as seen on the outside micrometer.

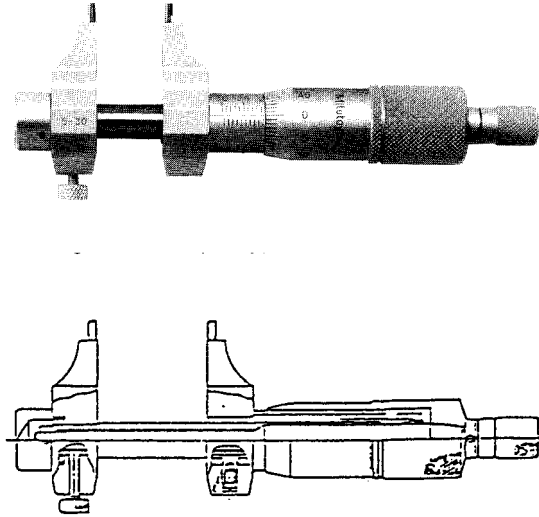


Figure 49 Calliper type inside micrometer

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, use 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. The same force as is used when setting the zero point should be applied when performing measurements.

3.7.3 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 is simpler to use because it aligns itself with the hole axis by means of three evenly spaced contact points. 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.

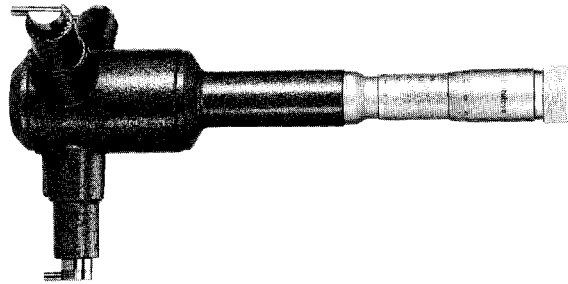


Figure 50 Three point type inside micrometer

3.7.4 The Depth Micrometer

Depth micrometers are used to measure the depths of holes, slots and steps. They are covered by British standard BS6468:1984 Specification for depth micrometers.

They are classified as follows:

1. Single rod type
2. Interchangeable rod type
3. Sectioned rod type

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

3.7.4.1 Single Rod Type Depth Micrometer

The single rod type depth micrometer 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.

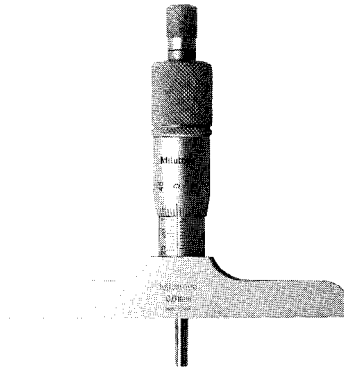
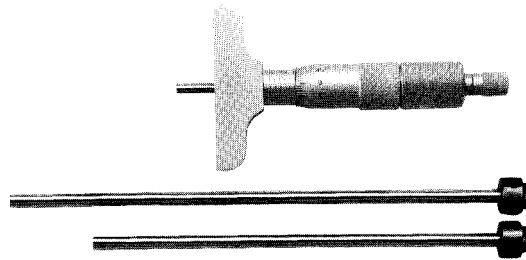


Figure 51 Single rod type depth micrometer

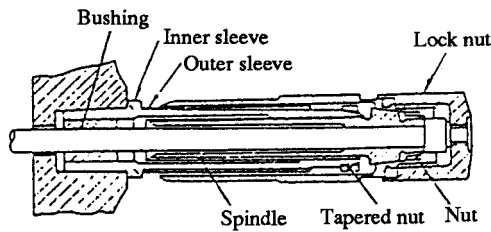
3.7.4.2 Interchangeable Rod Type Depth Micrometers

This type of micrometer uses a hollow spindle without a measuring face. An interchangeable rod passes through the spindle and the base. This 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 e.g. 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 to 150 mm although rods are available to measure to a depth of up to 300 mm.



Interchangeable rod type depth micrometer



Structure of an interchangeable rod type depth micrometer

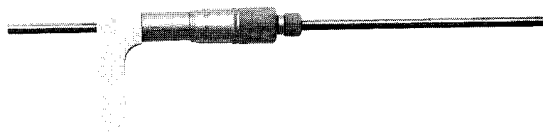
Figure 52 Interchangeable rod type depth micrometer

3.7.4.3 Sectioned Rod Type Depth Micrometer

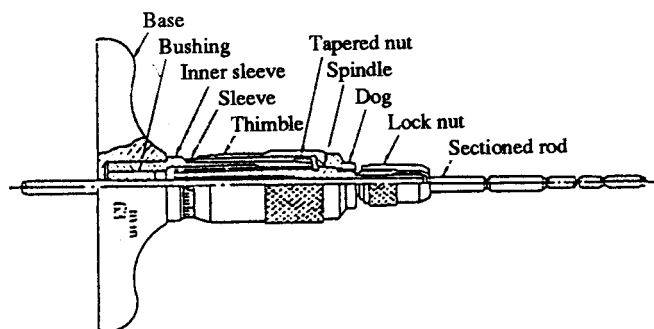
The sectioned rod type depth micrometer is designed to overcome the measuring range limitations of the single rod type micrometer and the disadvantage of the interchangeable rod type micrometer that various lengths of rods are required for different measuring situations.

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 to 300 mm.



Sectioned rod type depth micrometer



Structure of a sectioned rod type depth micrometer

Figure 53 Rod type depth micrometers

3.7.4.4 Error Sources when using Depth Micrometers

The following sources of error can arise when using depth micrometers.

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. Check the zero point each time a rod is replaced.

4 SUMMARY

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

5 GLOSSARY OF TERMS

5.1 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.

5.2 MICROMETER

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.

6 HEALTH AND SAFETY

Micrometers and callipers themselves are intrinsically safe. Hazards are therefore likely to arise mainly from their mis-use. Users should therefore take note of the following:

- Never attempt to measure a rotating work piece.
- Never measure workpieces that are hot from the machining process.
- Take care when using cleaning solvents and oils and always wear the appropriate protective equipment.
- Make sure that the manufacturers' guidelines are followed for all solvents.

APPENDIX A LINKS TO OTHER USEFUL SOURCES OF INFORMATION

A.1 NATIONAL/INTERNATIONAL ORGANISATIONS

A.1.1 National Physical Laboratory

The National Physical Laboratory (NPL) is a world-leading centre in the development and application of highly accurate measurement techniques. As the UK's national standards laboratory, NPL underpins the national measurement system (NMS), ensuring consistency and traceability of measurements throughout the UK. NPL offers a unique range of measurement services, contract research, consultancy and training services. Other areas of expertise include the design and characterisation of engineering materials, and mathematical software, especially its application to measurement and instrumentation.

For more information on the wide range of metrology services, facilities and research work carried out at NPL either visit the NPL web site at <http://www.npl.co.uk>

Or contact the NPL Helpline at

Tel: 020 8943 6880, Fax: 020 8943 6458, E-mail: enquiry@npl.co.uk

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

NIST is the equivalent of NPL in the United States of America. The NIST web site at <http://www.nist.gov/> often contains relevant documents in pdf format.

A.1.3 EUROMET

EUROMET is a cooperative organisation between the national metrology institutes in the EU including the European Commission, EFTA and EU Accession States. The participating metrology institutes collaborate in EUROMET with the objective of promoting the co-ordination of metrological activities and services with the purpose of achieving higher efficiency.

The main aims of EUROMET are:

- to encourage cooperation in the development of national standards and measuring methods

- to optimise the use of resources and services
- to improve measurement facilities and make them accessible to all members

For more information visit the EUROMET web site at:

<http://www.euromet.ch>

A.1.4 European Co-operation for Accreditation (EA)

Until recently, the branches of European national accreditation bodies have been handled separately by EAC (European Accreditation of Certification) and EAL (European co-operation for Accreditation of Laboratories) dealing with certification bodies and laboratories respectively.

These organisations have joined to form European Co-operation for Accreditation (EA) that now covers all European conformity assessment activities including:

- testing and calibration
- inspection
- certification of management systems
- certification of products
- certification of personnel
- Environmental verification under the European Eco-Management and Audit Scheme (EMAS) regulation

The members of EA are the nationally recognised accreditation bodies of the member countries or the candidate countries, of the European Union and EFTA. Associate membership is open to nationally recognised accreditation bodies in countries in the European geographical area who can demonstrate that they operate an accreditation system compatible with EN45003 or ISO/IEC Guide 58.

The web site <http://www.european-accreditation.org/> contains some useful information and documentation on measuring techniques.

A.2 METROLOGY CLUBS

A.2.1 Dimensional Metrology Awareness Club (DMAC)

DMAC is an industry-focused club that has been set up as part of the 1999-2002 NMS Length Programme. This club is managed by NPL on behalf of the DTI and has the following objectives:

- to provide a focused platform for interaction across all the technical areas covered by the Length Programme
- to enable members to learn about the latest developments in their own as well as related areas of dimensional metrology
- to provide a mechanism to encourage and facilitate interaction and exchange of ideas with other member organisations
- to give members the opportunity to provide input to, and influence the development of future NMS programmes.

For further information visit the DMAC web site at: <http://www.npl.co.uk/npl/clubs/dmac/>

A.2.2 Software Support for Metrology Programme (SSfM)

SSfM is an NMS metrology-focused programme comprising projects designed to meet the requirements of other NMS scientific programmes. The overall aim of the SSfM 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.

The SSfM Club is aimed at users and suppliers of metrology software, giving them a say in the direction of the Programme. It is the focal point for the distribution of general information arising from the Programme.

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

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.

Further information on BSI can be found at:

<http://www.bsi-global.com/group.xhtml>

A.3.2 International Organisation for Standardisation (ISO)

The International Organisation for Standardisation (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:

<http://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*

Note: The ISO member body for the United Kingdom has expressed disapproval of the above two documents on technical grounds.

ISO 3611:1978 *Micrometer callipers for external measurement*

BS 887:1982 *Specification for precision callipers*

BS870:1950 *Specification for external micrometers*

BS1734 *Micrometer heads*

BS959:1950 *Specification for internal micrometers (including stick micrometers)*

BS6468:1984 *Specification for depth 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 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 (UKAS) is the sole national body recognised by government for the accreditation of testing and calibration laboratories, certification and inspection bodies. A not-for-profit company, limited by guarantee, UKAS operates under a Memorandum of Understanding with the government through the Department of Trade and Industry.

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

Further information on UKAS can be found at <http://www.ukas.com>

Most UKAS laboratories in the dimensional field are able to calibrate callipers and micrometers. For a list see <http://www.ukas.org>

A.5 NATIONAL MEASUREMENT PARTNERSHIP

The National Measurement Partnership programme is an initiative of the Department of Trade and Industry with the aim of developing the organisational infrastructure of the UK's National Measurement System.

The objectives of this programme are to:

- increase the uptake of accredited calibration in the UK
- increase the qualified skill base in measurement
- increase user access to measurement expertise

To achieve these objectives, the programme will:

- establish a network of accredited UKAS Calibration Laboratories
- expand the Competing Precisely initiative to provide increased measurement advice
- establish a National Measurement Helpline
- manage the roll-out of measurement training in the form of a National Vocational Qualification
- establish a National Measurement Forum to steer and support the programme

The National Measurement Partnership has produced a number of products to help promote good measurement practice, including case histories, good practice guides and self-assessment checklists.

For further details see <http://www.nmpuk.co.uk>

A.6 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> for more information.

- The National Measurement Partnership (<http://www.nmptraining.co.uk>), through a DTI funded initiative, has developed supporting technical literature and provides good measurement practice through National Vocational Qualifications (NVQ) in Technical Services (measurement related evidence routes) for those who have a technical support role (operators or semi-skilled employers). The programme is most suitable for people who work to clearly defined procedures.

Development and promotion of the NVQ with measurement routes was undertaken by a consortium led by Brunel University, Coventry Technical College and Mitutoyo (UK) Ltd. The activity was part of the National Measurement Partnership programme managed by NPL and funded by the DTI as a project to support the National Measurement System.

See <http://www.brunel.ac.uk/research/bcmm/measnvq.htm> for more information.

A.7 AWARDING BODIES

A wide variety of engineering courses offered by educational institutions include some aspects of metrology studies, however the prospective student should enquire as to the amount and content of dimensional metrology that is included in specific courses.

The following awarding bodies offer qualifications that can include aspects of metrology. The amount of metrology content is dependent on the college or centre offering the

qualification on behalf of the awarding body. Information can be obtained from the awarding body by telephone or e-mail at the following:

Edexcel <http://www.edexcel.org.uk>
Customer information centre: 0870 2409000
enquires@edexcel.org.uk

City & Guilds

Customer services: 020 7294 2800
Publication sales: 020 7294 2787
enquiry@city-and-guilds.co.uk

Oxford Cambridge and RSA Examinations

Customer services: 02476 470033
cib@ocr.org.uk

A.8 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.

Brown & Sharpe Limited (also Tesa 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

Heathcote Way
Heathcote Industrial Estate
Warwick
Warwickshire
CV34 6TE

Moore and Wright

Atlas Way
Sheffield
S4 7QQ

Preisser UK Limited

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

The L. S. Starrett Company Ltd.

Jedburgh
Scotland TD8 6LR

Verdict Gauge Limited

Hilton Road
Cobbs Wood Industrial Estate
Ashford
Kent TN23 1EW

A.9 FURTHER READING

Fundamentals of Dimensional Metrology, Third Edition Ted Busch, Roger Harlow, Richard L. Thompson

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

The Mitutoyo web site www.mitutoyo.co.jp/keisoku/attn/atten.html contains Tips and Precautions for using Measuring Tools (On callipers and micrometers)

Toolrooms and tools Chapter 1 - part of a series available on the web. This document contains lots of information on hand measuring tools.

http://www.advancement.cnet.navy.mil/products/web-pdf/tramans/bookchunks/12204a_ch1.pdf

Reference is made in the above document to 'Use and care of hand tools and measuring tools, Navedtra 12085'.

www.njautocare.com/garage/subsys/batest03.html contains information on the use of micrometers

Quality Magazine June 1997, 'Versatile Micrometer is a Measuring Standby'.

Using the vernier callipers and micrometer screw gauge:

<http://www.phy.uct.ac.za/courses/c1lab/vernier.html>

Gage use and abuse

<http://www.quality.digest.com/feb99/html/body-gages.html>

How to read an inch based micrometer

<http://deepcnet.usi.edu/enginech/machasst/meastool/readmic.htm>

Measurement <http://io.newi.ac.uk/tatlerj/mit/intro2.html>

<http://mmuic.polyu.edu.hk/handout/0101/0101.htm> may also be of interest

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

