Mitutoyo

# QUICK GUIDE TO MEASUREMENT

## Precision instruments in dimensional metrology

ENGLISH EDITION


QUICK GUIDE TO MEASUREMENT

Mitutoyo

# Contents



| | |
|---|---|
| Meaning of symbols | 02 |
| Conformance to CE marking | 03 |
| Quality control | 04 |
| Micrometers | 06 |
| Micrometer heads | 12 |
| Bore micrometers | 16 |
| Calipers | 18 |
| Height gauges | 22 |
| Gauge blocks | 26 |
| Dial gauges and digital indicators | 28 |
| Linear gauges | 32 |
| Laser scan micrometers | 34 |
| Linear scales | 36 |
| Profile projectors | 38 |
| Microscopes | 40 |
| Vision measuring machines | 42 |
| Surface measurement | 46 |
| Contour measurement | 52 |
| Roundform measurement | 54 |
| Hardness testing | 58 |
| Coordinate measuring machines | 60 |

# Meaning of symbols

## The ABSOLUTE linear encoder

This is an electronic measuring scale that provides a direct readout of absolute linear position when switched on, without needing to be zeroed or reset. Mitutoyo measuring instruments incorporating these scales provide the significant benefit of being always ready for measurement without the need of preliminary setting after switching on. Electrostatic, electromagnetic and a combination of electrostatic and optical methods are used in implementing this capability but the key enabling feature is Mitutoyo's patented technology of building absolute positional information into the scale so it can be read at start up. These linear encoders are widely used in Mitutoyo's measuring instruments as the in-built length standard and their use greatly contributes to the generation of highly reliable measurement data in industry, especially in harsh environments where contamination by cutting fluids, coolants and dust must not affect performance.

ABSOLUTE

Advantages

1. No count error occurs even if you move the slider or spindle extremely rapidly.
2. You do not have to reset the system to zero when turning on the system after turning it off*1.
3. As this type of encoder can drive with less power than the incremental encoder, the battery life is prolonged to about 3.5 years (continuous operation of 20,000 hours)*2 under normal use.

*1: Unless the battery is removed. *2: In the case of the ABSOLUTE Digimatic caliper (electrostatic capacitance model).

## IP codes

These are codes that indicate the degree of protection provided (by an enclosure) for the electrical function of a product against the ingress of foreign bodies, dust and water as defined in IEC 60529: 2001 and JIS C 0920: 2003.

IP65 IP67

IP X X

| 1st characteristic numeral | Degree of protection against solid foreign objects | |
|---|---|---|
| | Brief description | Definition |
| 0 | Unprotected | — |
| 1 | Protected against solid foreign objects of Sø50 mm and greater | A Sø50 mm object probe shall not fully penetrate enclosure*. |
| 2 | Protected against solid foreign objects of Sø12.5 mm and greater | A Sø12.5 mm object probe shall not fully penetrate enclosure*. |
| 3 | Protected against solid foreign objects of Sø2.5 mm and greater | A Sø2.5 mm object probe shall not fully penetrate enclosure*. |
| 4 | Protected against solid foreign objects of Sø1.0 mm and greater | A Sø1.0 mm object probe shall not fully penetrate enclosure*. |
| 5 | Protected against dust | Ingress of dust is not totally prevented, but dust that does penetrate must not interfere with satisfactory operation of the apparatus or impair safety. |
| 6 | Dustproof | No ingress of dust allowed |

* For details of the test conditions used in evaluating each degree of protection, please refer to the original standard.

| 2nd characteristic numeral | Degree of protection against water | |
|---|---|---|
| | Brief description | Definition |
| 0 | Unprotected | — |
| 1 | Protected against vertical water drops | Vertically falling water drops shall have no harmful effects. |
| 2 | Protected against vertical water drops within a tilt angle of 15° | Vertically falling water drops shall have no harmful effects when the enclosure is tilted at any angle up to 15° on either side of the vertical. |
| 3 | Protected against spraying water | Water splashed against the enclosure from any direction shall have no harmful effects. |
| 4 | Protected against splashing water | Water splashed against the enclosure from any direction shall have no harmful effects. |
| 5 | Protected against water jets | Water projected in jets against the enclosure from any direction shall have no harmful effects. |
| 6 | Protected against powerful water jets | Water projected in powerful jets against the enclosure from any direction shall have no harmful effects. |
| 7 | Protection against water penetration | Ingress of water in quantities causing harmful effects shall not be possible when the enclosure is temporarily immersed in water under standardized conditions of pressure and time. |
| 8 | Protected against the effects of continuous immersion in water | Ingress of water in quantities causing harmful effects shall not be possible when the enclosure is continuously immersed in water under conditions which shall be agreed between manufacturer and user but which are more severe than for IPX7. |

## Independent confirmation of compliance

IP65, IP66 and IP67 protection level ratings for applicable Mitutoyo products have been independently confirmed by the German accreditation organization, TÜV Rheinland.

www.tuv.com TÜVRheinland® ID:4011207400
Dust tight and water jet protected **IP65**

www.tuv.com TÜVRheinland® ID:0000007161
Dust tight and water protected **IP66**

www.tuv.com TÜVRheinland® ID:0000006683
Dust tight and watertight **IP67**

# Conformance to CE marking


Mitutoyo's manufacturing plants throughout the world have programs to comply with the Machinery Directives, the EMC Directives, and the Low Voltage Directives. CE marking on a product indicates compliance with the essential requirements of the relevant European health, safety and environmental protection legislation.

> Testing for EMC compatibilty.

# Quality control

## Quality control (QC)
A system for economically producing products or services of a quality that meets customer requirements.

## Process quality control
Activities to reduce variation in product output by a process and keep this variation low. Process improvement and standardization as well as technology accumulation are promoted through these activities.

## Statistical process control (SPC)
Process quality control through statistical methods.

## Population
A group of all items that have measurable characteristics to be considered for improving and controlling processes and quality of product.

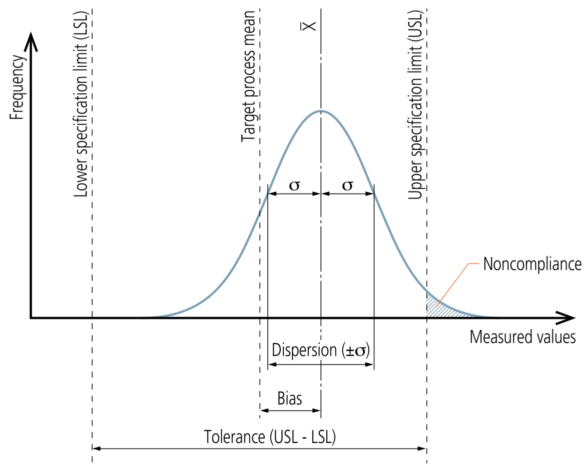
## Lot
Collection of product produced under the same conditions.

## Sample
An item of product (or items) taken out of the population to investigate its characteristics.

## Sample size
Number of product items in the sample.

## Bias
Value calculated by subtracting the target process mean value from the mean of the measured values.

## Dispersion
Variation in the values of a target characteristic in relation to the mean value. Standard deviation ($\sigma$) is usually used as the measure of dispersion around the mean.




## Histogram
A diagram that divides the range between the maximum and the minimum measured values into several divisions and shows the number of values (appearance frequency) in each division in the form of a bar graph. This makes it easier to understand the rough average or the approximate extent of dispersion. A bell-shaped symmetrical distribution is called the normal distribution and is much used in theoretical examples on account of its easily calculable parameters. However, caution should be observed because many real processes do not conform to the normal distribution, and error will result if it is assumed that they do.

## Process capability
Process-specific performance demonstrated when the process is sufficiently standardized, any causes of malfunctions are eliminated, and the process is in a state of statistical control. The process capability is represented by $\pm 3\sigma$ about the mean (or $6\sigma$ total width) when the target characteristic output from the process shows a normal distribution.

## Process capability index (PCI or Cp)
A measure of how well the process can operate within the tolerance limits set for the target characteristic. It should always be significantly greater than one. The index value is calculated by dividing the tolerance of the target characteristic by the process capability ($6\sigma$). The value calculated by dividing the difference between the mean ($\bar{X}$) and the standard value by $3\sigma$ may be used to represent this index in cases of a unilateral tolerance. The process capability index assumes that a characteristic follows the normal distribution.

**Note:** If a characteristic follows the normal distribution, 99.74% of the measured values will fall within the range $\pm 3\sigma$ about the mean.

Bilateral tolerance

$$Cp = \frac{USL\text{-}LSL}{6\sigma}$$

USL: Upper specification limit
LSL: Lower specification limit

Unilateral tolerance ... if only the upper limit is stipulated

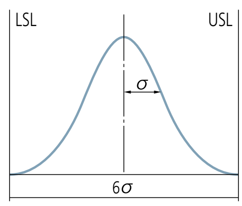
$$Cp = \frac{USL\text{-}\bar{X}}{3\sigma}$$

Unilateral tolerance ... if only the lower limit is stipulated

$$Cp = \frac{\bar{X}\text{-}LSL}{3\sigma}$$

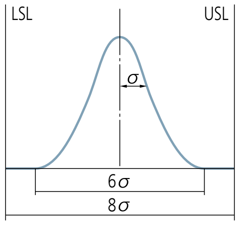
**Specific examples of Cp values for bilateral tolerancing:**

Cp = 1



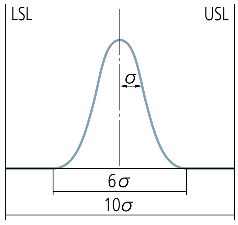

In this case the process capability is barely achieved as the 6-sigma process limits are coincident with the tolerance limits.

Cp = 1.33




Here the process capability is the minimum value that can be generally accepted as it is no closer than 1 sigma to the tolerance limits.

Cp = 1.67



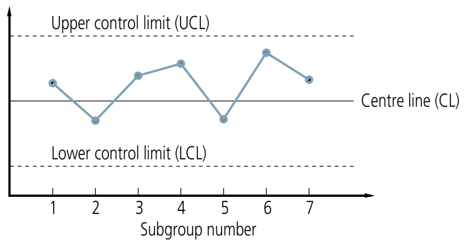

This shows the case where the process capability is sufficient as it is no closer than 2 sigma to the tolerance limits.

Note that Cp only represents the relationship between the tolerance limits and the process dispersion and does not consider the position of the process mean.

A process capability index that takes the difference between the *actual process mean* and the *target process mean* into consideration is generally called Cpk, which is defined as the upper tolerance (USL minus the mean) divided by 3σ (half of process capability) or the lower tolerance (the mean minus LSL) divided by 3σ, whichever is smaller.

## Control chart

Used to control the process by separating the process variation into that due to chance causes and that due to a malfunction. The control chart consists of one centre line (CL) and the control limit lines rationally determined above and below it (UCL and LCL). It can be said that the process is in a state of statistical control if all points are within the upper and lower control limit lines without notable trends when the characteristic values that represent the process output are plotted. The control chart is a useful tool for controlling process output, and therefore quality.




## $\bar{X}$-R control chart

A control chart used for process control that provides the most information on the process. The $\bar{X}$-R control chart consists of the $\bar{X}$ control chart that uses the mean of each subgroup for control to monitor abnormal bias of the process mean and the R control chart that uses the range for control to monitor abnormal variation. Usually, both charts are used together.

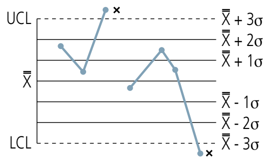
## Chance causes and special causes

All variation in a process has a cause, and in principle these individual causes can be tracked down and eliminated, but there is a point beyond which this is technologically or economically impractical. Causes of variation that must inevitably remain are known as *chance causes* and their sum effect defines the limiting capability of a process. In contrast, those causes that can readily be eliminated are known as *special causes*.

## Rules and the control chart

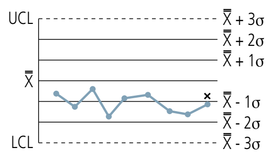
Examples of typical undesirable trends in measurement seen on control charts are shown below, and are taken to mean that a special cause is probably affecting the process output. The process operator is required to identify such trends by applying appropriate *decision rules* and to remedy the situation by eliminating the special cause. These trends only provide a guideline and the process-specific variation should be taken into consideration when formulating the rules to apply. Assuming typical upper and lower control limits of 3σ, divide the control chart into six zones at intervals of 1σ and apply the rules given, which apply to the X control chart and the $\bar{X}$ control chart. Note that these rules were formulated assuming a normal distribution, but can be formulated to suit any other distribution.

Rule 1



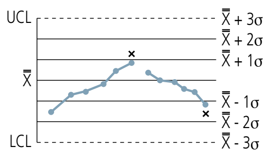

There is a point beyond either of the control limits.

Rule 2



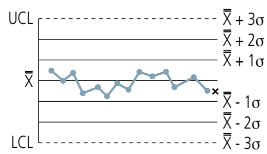

Nine consecutive points are to one side of the centreline.

Rule 3



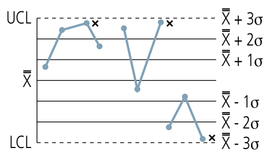

Six points consecutively increase or decrease.

Rule 4



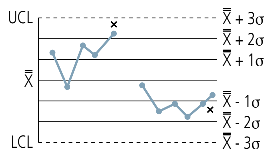

14 points alternately increase and decrease.

Rule 5



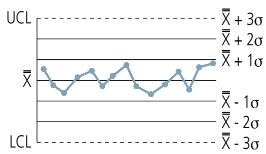

Two of three consecutive points are further than 2σ from the centreline on either side.

Rule 6



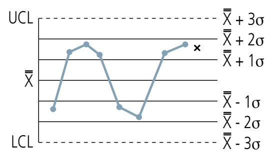

Four of five consecutive points are further than 1σ from the centreline on either side.

Rule 7




There are 15 consecutive points within 1σ of the centreline.

Rule 8




There are eight consecutive points further than 1σ from the centreline.

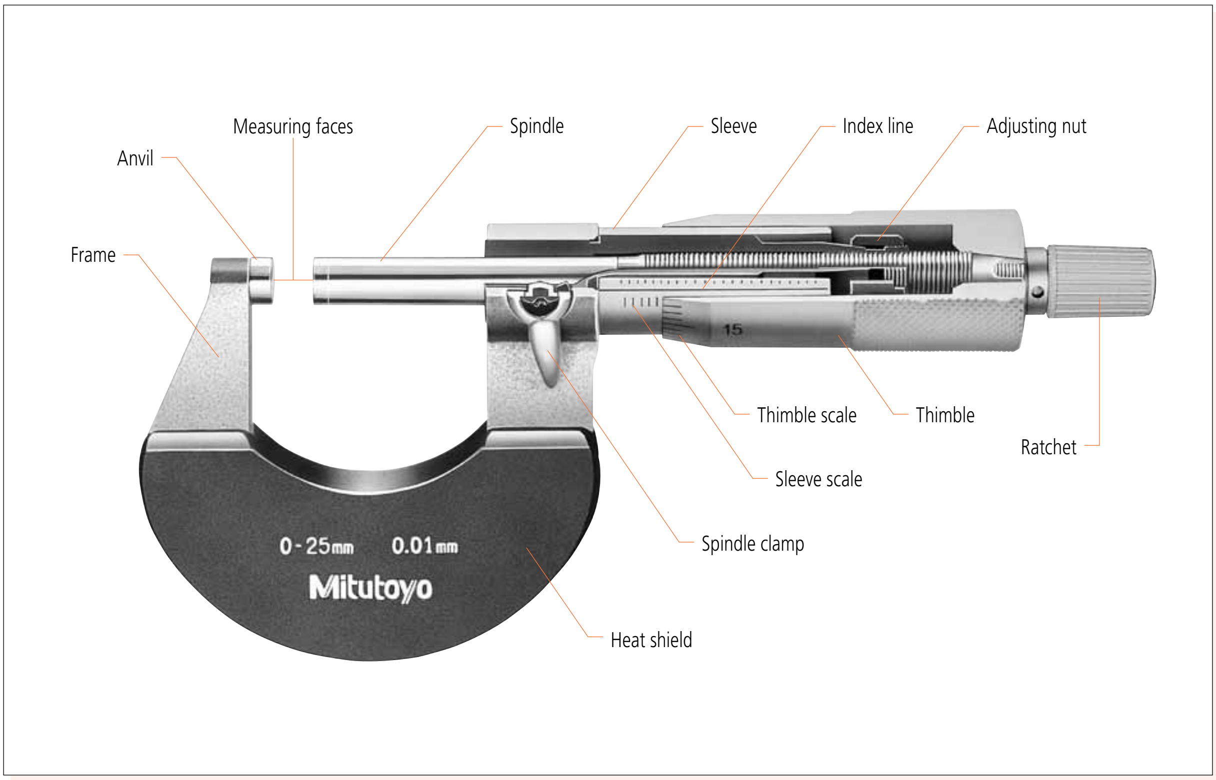
**Note:** This part has been written by Mitutoyo based on its own interpretation of the JIS Quality Control Handbook published by the Japanese Standards Association. References: JIS Quality Control Handbook (Japanese Standards Association) Z8101: 1981, Z8101-1: 1999, Z8101-2: 1999, Z9020: 1999, Z9021: 1998.

# Micrometers



## Nomenclature

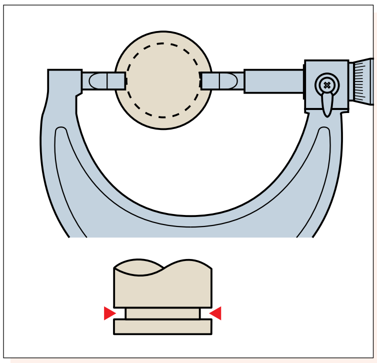
Standard analogue outside micrometer




Digital outside micrometer

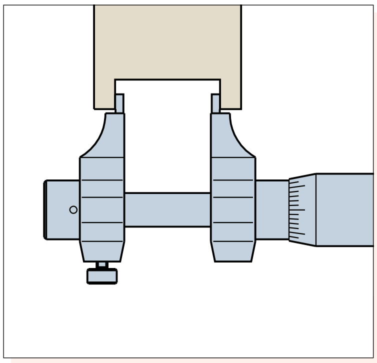
## Special purpose micrometer applications

### Blade micrometer



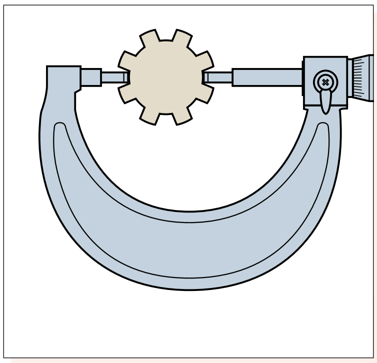
> For diameter inside narrow groove measurement.

### Inside micrometer, caliper type



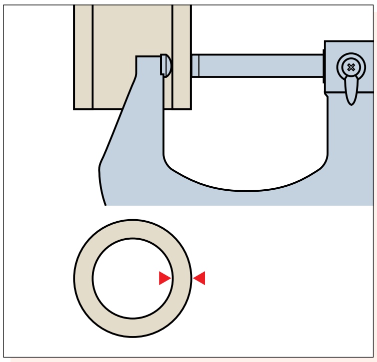
> For small internal diameter, and groove width measurement.

### Spline micrometer



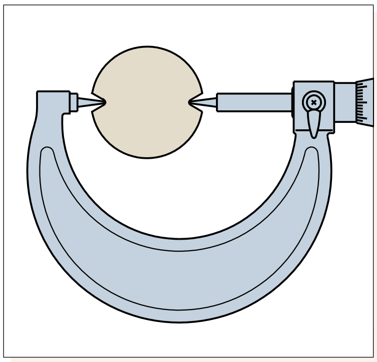
> For splined shaft diameter measurement.

### Tube micrometer



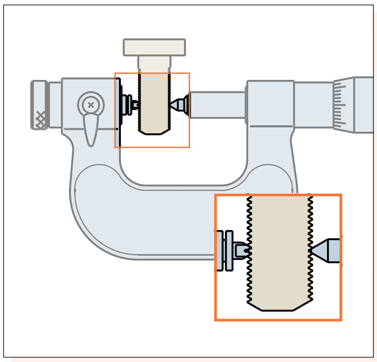
> For pipe thickness measurement.

### Point micrometer



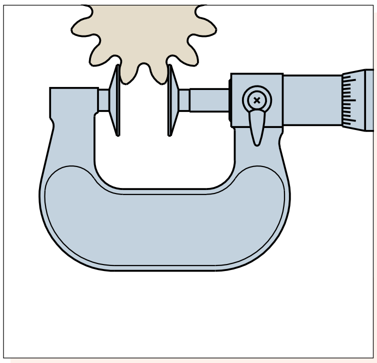
> For root diameter measurement.

### Screw thread micrometer



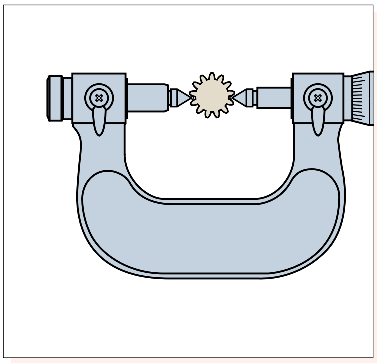
> For effective thread diameter measurement.

### Disc type outside micrometer



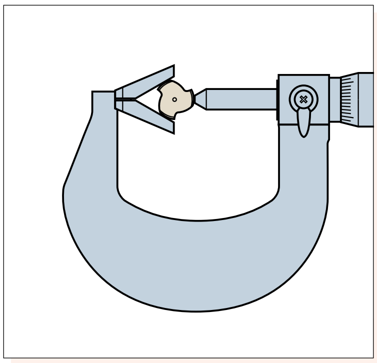
> For root tangent measurement on spur gears and helical gears.

### Gear tooth micrometer



> Measurement of gear over-pin diameter.

### V-anvil micrometer

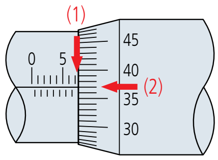


> For measurement of 3- or 5-flute cutting tools.

# Micrometers

## How to read the scales

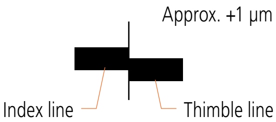
■ Micrometer with standard scale (graduation: 0.01 mm)

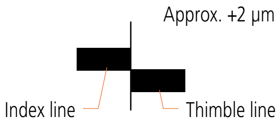



| | | |
|---|---|---|
| (1) Sleeve scale reading | | 7.00 mm |
| (2) Thimble scale reading | | 0.37 mm |
| Micrometer reading | | 7.37 mm |

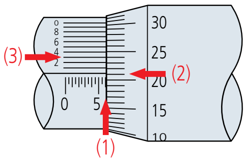
Note: 0.37 mm (2) is read from the thimble scale where it intersects the index line.

The thimble scale can be read directly to 0.01 mm, as shown above, but may also be estimated to 0.001 mm when the lines are nearly coincident because the line thickness is 1/5 of the spacing between them.



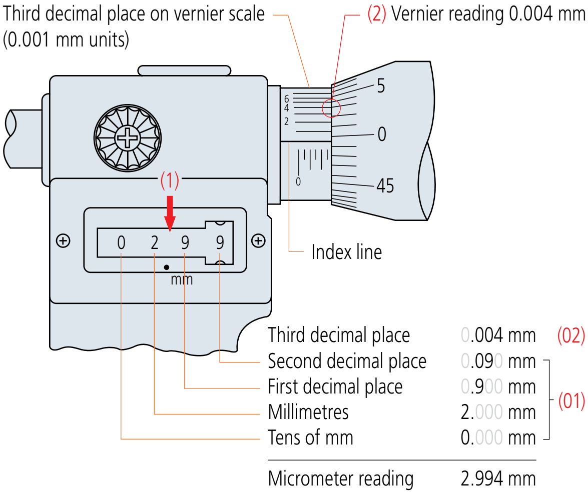

■ Micrometer with vernier scale (graduation: 0.001 mm)




| | | |
|---|---|---|
| (1) Sleeve scale reading | | 6.000 mm |
| (2) Thimble scale reading | | 0.210 mm |
| (3) Vernier scale reading | | 0.003 mm |
| Micrometer reading | | 6.213 mm |

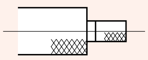
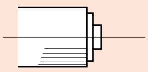
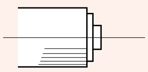
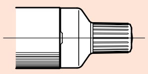
Note: 0.21 mm (2) is read at the position where the index line is between two graduations (21 and 22 in this case). 0.003 mm (3) is read at the position where one of the vernier graduations aligns with one of the thimble graduations.

■ Micrometer with mechanical-digit display (digital step: 0.001 mm)

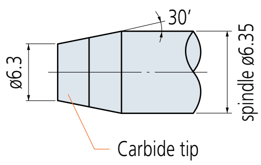


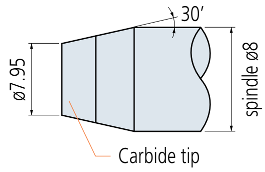

Note: 0.004 mm (2) is read at the position where a vernier graduation line corresponds with one of the thimble graduation lines.

## Measuring force limiting device

| Type | Audible in operation | One-handed operation | Remarks |
|---|---|---|---|
| Ratchet stop  | Yes | Unsuitable | Audible clicking operation causes micro-shocks |
| Friction thimble (F type)  | No | Suitable | Smooth operation without shock or sound |
| Ratchet thimble (T type)  | Yes | Suitable | Audible operation provides confirmation of constant measuring force |
| Ratchet thimble  | Yes | Suitable | Audible operation provides confirmation of constant measuring force |

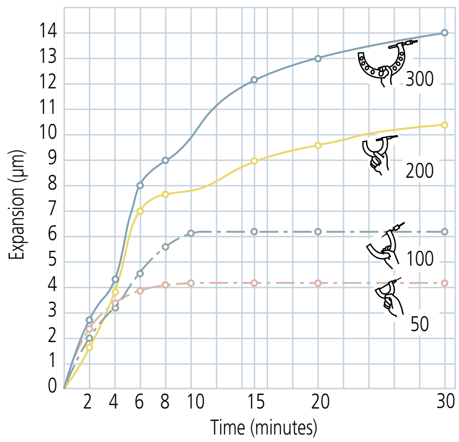
## Measuring face detail



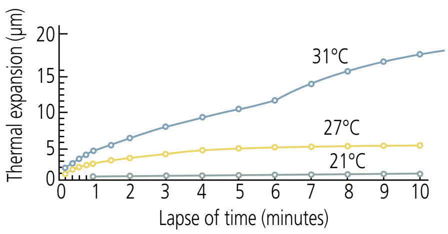

These drawings above are for illustration only and are not to scale.

## Micrometer expansion due to holding frame with the bare hand



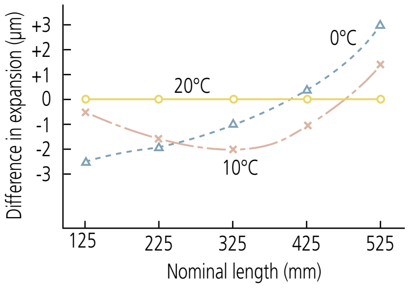

The above graph shows micrometer frame expansion due to heat transfer from hand to frame when the frame is held in the bare hand which, as can be seen, may result in a significant measurement error due to temperature-induced expansion. If the micrometer must be held by hand during measurement then try to minimize contact time. A heat insulator will reduce this effect considerably if fitted, or gloves may be worn. (Note that the above graph shows typical effects, and is not guaranteed.)

## Length standard expansion with change of temperature (for 200 mm bar initially at 20°C)




The above experimental graph shows how a particular micrometer standard expanded with time as people whose hand temperatures were different (as shown) held the end of it at a room temperature of 20°C. This graph shows that it is important not to set a micrometer while directly holding the micrometer standard but to make adjustments only while wearing gloves or lightly supporting the length standard by its heat insulators. When performing a measurement, note also that it takes time until the expanded micrometer standard returns to the original length. (Note that the graph values shown are illustrative and are not guaranteed.)

## Difference in thermal expansion between micrometer and length standard



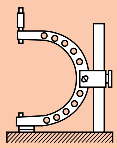
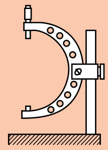

In the above experiment, after the micrometer and its standard were left at a room temperature of 20°C for about 24 hours for temperature stabilization, the start point was adjusted using the micrometer standard. Then, the micrometer with its standard were left at the temperatures of 0°C and 10°C for about the same period of time, and the start point was tested for shift. The above graph shows the results for each of the sizes from 125 through 525 mm at each temperature. This graph shows that both the micrometer and its standard must be left at the same location for at least several hours before adjusting the start point. (Note that the graph values are not guaranteed values but experimental values.)

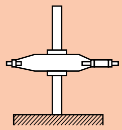
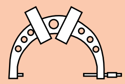
## Hooke's law

Hooke's law states that strain in an elastic material is proportional to the stress causing that strain, providing the strain remains within the elastic limit for that material.

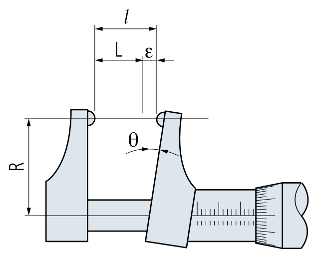
## Effect of changing support method and orientation

Changing the support method and/or orientation of a micrometer after zero setting affects subsequent measuring results. The tables below highlight the measurement errors to be expected in three other cases after micrometers are zero set in the 'Supported at the bottom and centre' case. These actual results show that it is best to set and measure using the same orientation and support method.

| Maximum measuring length (mm) | Measurement error (μm) | |
|---|---|---|
| |  Supported at the bottom and centre |  Supported only at the centre |
| 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 |

| Maximum measuring length (mm) | Measurement error (μm) | |
|---|---|---|
| |  Supported at the centre in a lateral orientation |  Supported by hand downward |
| 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 |

## Abbe's principle

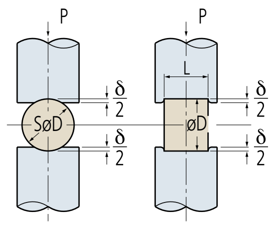



Abbe's principle states that 'maximum accuracy is obtained when the scale and the measurement axes are common'. This is because any variation in the relative angle (θ) of the moving measuring jaw on an instrument, such as a caliper jaw micrometer, causes displacement that is not measured on the instrument's scale and this is an Abbe error ($\varepsilon = l - L$ in the diagram). Spindle straightness error, play in the spindle guide or variation of measuring force can all cause (θ) to vary and the error increases with R.

# Micrometers

## Hertz's formulae

Hertz's formulae give the apparent reduction in diameter of spheres and cylinders due to elastic compression when measured between plane surfaces. These formulae are useful for determining the deformation of a workpiece caused by the measuring force in point and line contact situations.




(a) Sphere between two planes

(b) Cylinder between two planes

Assuming that the material is steel and units are as follows:

Modulus of elasticity: E = 205 GPa
Amount of deformation: δ (μm)
Diameter of sphere or cylinder: D (mm)
Length of cylinder: L (mm)
Measuring force: P (N)

a) Apparent reduction in diameter of sphere:

$\delta = 0.82\sqrt[3]{P^2/D}$

b) Apparent reduction in diameter of cylinder:

$\delta = 0.094\ P/L\sqrt[3]{1/D}$

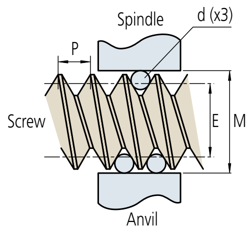
## Screw pitch diameter measurement

### Three-wire method

The screw pitch diameter can be measured with the three-wire method as shown in the figure. Calculate the pitch diameter (E) using the appropriate formula (1) or (2) as shown below.

(1) Metric thread or unified screw (60°): E = M - 3d + 0.866025P
(2) Whitworth thread (55°): E = M - 3.16568d + 0.960491P

d = Wire diameter
E = Screw pitch diameter (or Effective Diameter)
M = Micrometer reading over the three wires
P = Screw pitch




| Thread type | Optimum wire size |
|---|---|
| Metric thread or unified screw (60°) | 0.577P |
| Whitworth thread (55°) | 0.564P |

## Major measurement errors of the screw micrometer

| Error cause | Maximum possible error | Precautions for eliminating errors | Error that might not be eliminated even with precautions |
|---|---|---|---|
| Micrometer feed error | 3 μm | 1. Correct the micrometer before use. | ±1 μm |
| Anvil angle error | ±5 μm assuming the half-angle error is 15 minutes | 1. Measure the angle error and correct the micrometer reading.<br>2. Adjust the micrometer using the same thread gauge as the workpiece. | ±3 μm |
| Misaligned contact points | +10 μm | | +3 μm |
| Influence of measuring force | ±10 μm | 1. Use a micrometer with a low measuring force if possible.<br>2. Always use the ratchet stop.<br>3. Adjust the micrometer using a thread gauge with the same pitch. | +3 μm |
| Angle error of thread gauge | ±10 μm | 1. Perform correction calculation (angle).<br>2. Correct the error.<br>3. Adjust the micrometer using the same thread gauge as the workpiece. | +3 μm |
| Length error of thread gauge | | 1. Perform correction calculation.<br>2. Adjust the micrometer using the same thread gauge as the workpiece. | ±1 μm |
| Workpiece thread angle error | JIS 2 grade half-angle error of ±23 minutes -91 μm + 71 μm | 1. Minimize the angle error as much as possible.<br>2. Measure the angle error and perform correction calculation.<br>3. Use the three-wire method in the case of a large angle error. | ±8 μm assuming the half-angle error is ±23 minutes |
| Cumulative error | (±117 + 40) μm | | +26 μm<br>-12 μm |

## Major measurement errors of the three-wire method

| Error cause | Precautions for eliminating errors | Possible error | Error that might not be eliminated even with precautions |
|---|---|---|---|
| Pitch error (workpiece) | 1. Correct the pitch error (δp = δE)<br>2. Measure several points and adopt their average.<br>3. Reduce single pitch errors. | ±18 μm assuming that the pitch error is 0.02 mm. | ±3 μm |
| Error of half angle (workpiece) | 1. Use wires of the optimum size.<br>2. No correction is needed. | ±0.3 μm | ±0.3 μm |
| Anvil misalignment | 1. Use wires of the optimum size.<br>2. Use the wire which has a diameter close to the average at the one wire side. | ±8 μm | +1 μm |
| Wire diameter error | 1 Use the predetermined measuring force appropriate for the pitch.<br>2. Use the calibrated section of the wires.<br>3. Use a stable measuring force. | -3 μm | -1 μm |
| Cumulative error | | In the worst case<br>+20 μm<br>-35 μm | When measured carefully<br>+3 μm<br>-5 μm |

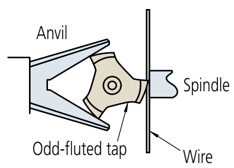
### One-wire method

The pitch diameter of an odd-fluted tap can be measured using a V-anvil micrometer with a single wire as shown. Obtain the measured value ($M_1$) and calculate M with equation (3) or (4).

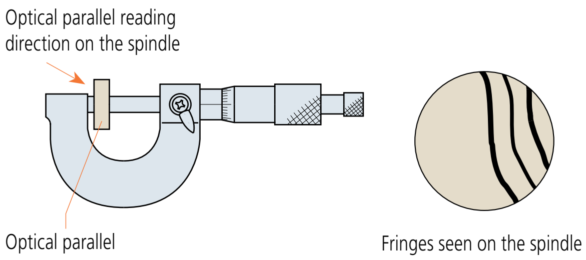
(3) Tap with three flutes : $M = 3M_1 - 2D$
(4) Tap with five flutes : $M = 2.2360M_1 - 1.23606D$

$M_1$ = Micrometer reading over the single wire (at cutting edge)
D = Diameter of tap (at cutting edge)

Then, assign the calculated M to the appropriate formula (1) or (2) as shown above and calculate the pitch diameter (E).



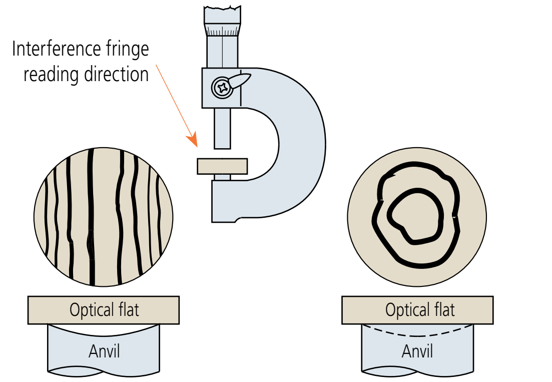
## Testing parallelism of micrometer measuring faces




Parallelism can be estimated using an optical parallel held between the faces. Firstly, wring the parallel to the anvil measuring face. Then close the spindle on the parallel using normal measuring force and count the number of red interference fringes seen on the measuring face of the spindle in white light. Each fringe represents a half wavelength difference in height (0.32 µm for red fringes). In the above figure a parallelism of approximately 1 µm is obtained from 0.32 µm x 3 = 0.96 µm.

## Testing flatness of micrometer measuring faces

Flatness can be estimated using an optical flat (or parallel) held against a face. Count the number of red interference fringes seen on the measuring face in white light. Each fringe represents a half wavelength difference in height (0.32 µm for red).

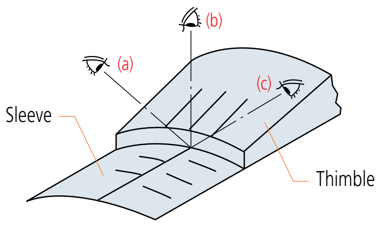



Measuring face is curved by approximately 1.3 µm. (0.32 µm x 4 paired red fringes.)

Measuring face is concave (or convex) approximately 0.6 µm deep. (0.32 µm x 2 continuous fringes.)

## General notes on using the micrometer

1. Carefully check the type, measuring range, accuracy, and other specifications to select the appropriate model for your application.
2. Leave the micrometer and workpiece at room temperature long enough for their temperatures to equalize before making a measurement.
3. Look directly at the index line when taking a reading against the thimble graduations. If the graduations are viewed from an angle, the reading will be incorrect due to parallax error.



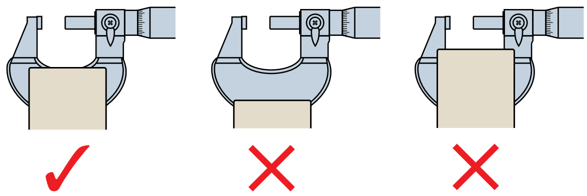

(a) From above the index line

(b) Looking directly at the index line

(c) From below the index line

4. Wipe off the measuring faces of both the anvil and spindle with lint-free paper and set the start (zero) point before measuring.

5. Wipe away any dust, swarf and other debris from the circumference and measuring face of the spindle as part of daily maintenance. In addition, wipe off any stains or fingerprints on each part with a dry cloth.
6. Use the constant-force device correctly so that measurements are performed with the correct measuring force.
7. When mounting the micrometer onto a micrometer stand, the stand should clamp the centre of the micrometer frame. Do not clamp it too tightly.



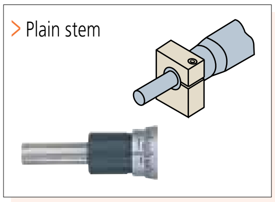
8. Be careful not to drop or bump the micrometer on anything. Do not rotate the micrometer thimble using excessive force. If you believe a micrometer may have been damaged due to accidental mishandling, ensure that it is inspected for accuracy before further use.
9. After a long storage period or when there is no protective oil film visible, lightly apply anti-corrosion oil to the micrometer by wiping with a cloth soaked in it.
10. Notes on storage:
- Avoid storing the micrometer in direct sunlight.
- Store the micrometer in a ventilated place with low humidity.
- Store the micrometer in a place with little dust.
- Store the micrometer in a case or other container, which should not be kept on the floor.
- Do not store the micrometer in a clamped state, always leave a small gap (0.1 to 1 mm) between the measuring faces.

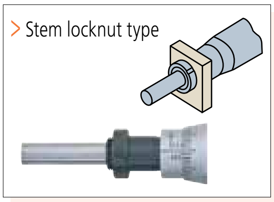
# Micrometer heads

## Key factors in selection

Key factors in selecting a micrometer head are the measuring range, types of spindle face, stem diameter, graduations, thimble diameter, etc.

## Stem


> Plain stem


> Stem locknut type

- The stem used to mount a micrometer head is classified as a *plain type* or *locknut type* as illustrated above. The stem diameter is manufactured to a nominal Metric or Imperial size with an h6 tolerance.
- The locknut stem allows fast and secure clamping of the micrometer head. The plain stem has the advantage of wider application and slight positional adjustment in the axial direction on final installation, although it does requires a split-fixture clamping arrangement or adhesive fixing.
- General-purpose mounting fixtures are available as optional accessories.

## Spindle face

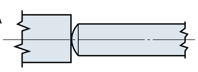

> Flat face


> Spherical face

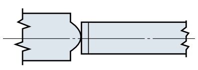

> Anti-rotation device

- A flat measuring face is often specified where a micrometer head is used in measurement applications.
- When a micrometer head is used as a feed device, a spherical face can minimize errors due to misalignment (Figure A). Alternatively, a flat face on the spindle can bear against a sphere, such as a carbide ball (Figure B).
- A non-rotating spindle type micrometer head, or one fitted with an anti-rotation device on the spindle (Figure C), can be used if a twisting action on the workpiece must be avoided.
- If a micrometer head is used as a stop then a flat face both on the spindle and the face it contacts provides durability.

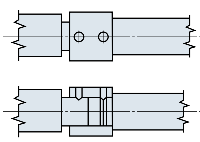
> Figure A



> Figure B



> Figure C



## Non-rotating spindle

A non-rotating spindle type head does not exert a twisting action on a workpiece, which may be an important factor in some applications.

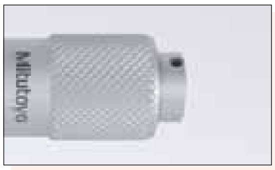
## Spindle thread pitch

- The standard Metric micrometer head has 0.5 mm pitch.
- The 1 mm-pitch type is quicker to set than the standard type and avoids the possibility of a 0.5 mm reading error. Excellent load-bearing characteristics due to larger screw thread.
- The 0.25 mm or 0.1 mm-pitch type is the best for fine-feed or fine-positioning applications.

## Constant-force device

- A micrometer head fitted with a constant-force device (ratchet or friction thimble) is recommended for measurement applications.
- If using a micrometer head as a stop, or where saving space is a priority, a head without a ratchet is probably the best choice.

> Micrometer head with constant-force device




> Micrometer head without constant-force device (no ratchet)

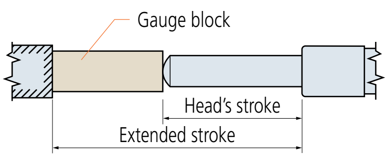
## Spindle lock

If a micrometer head is used as a stop it is desirable to use a head fitted with a spindle lock so that the setting will not change even under repeated shock loading.

## Measuring range (stroke)

- When choosing a measuring range for a micrometer head, allow an adequate margin in consideration of the expected measurement stroke. Six stroke ranges, 5 to 50 mm, are available for standard micrometer heads.
- Even if an expected stroke is small, such as 2 to 3 mm, it will be cost effective to choose a 25 mm-stroke model as long as there is enough space for installation.
- If a long stroke of over 50 mm is required, the concurrent use of a gauge block can extend the effective measuring range (Figure D).

> Figure D



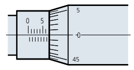
## Ultra-fine feed applications

Dedicated micrometer heads are available for manipulator applications, etc., which require ultra-fine feed or adjustment of spindle.

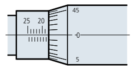
## Thimble diameter

The diameter of a thimble greatly affects its usability and the *fineness* of positioning. A small-diameter thimble allows quick positioning whereas a large-diameter thimble allows fine positioning and easy reading of the graduations. Some models combine the advantages of both by mounting a coarse-feed thimble (speeder) on the large-diameter thimble.

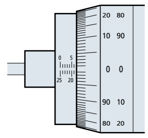
## Graduation styles



Normal graduation style



Reverse graduation style

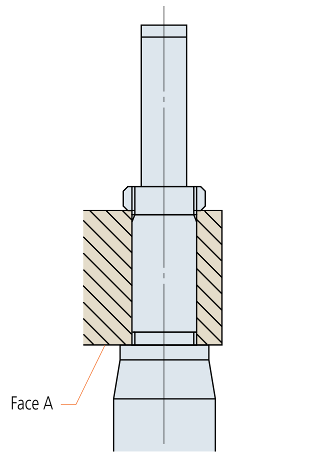
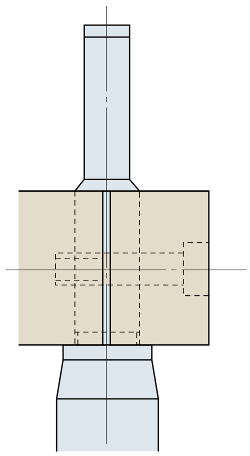
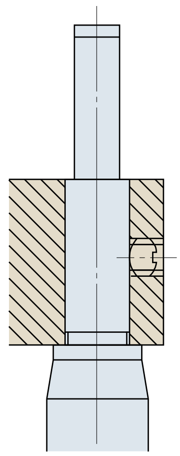


Bidirectional graduation style

- In the *normal graduation* style, as used on a standard non-digital micrometer, the reading increases as the spindle advances out of the micrometer frame..
- In the *reverse graduation* style the reading increases as the spindle retracts into the micrometer frame.
- The *bidirectional graduation* style is intended to facilitate measurement in either direction by using black numerals for normal, and red numerals for reverse, operation.
- Micrometer heads with a mechanical or electronic digital display, which allow direct reading of a measurement value, are also available. These types are generally free from misreading errors. A further advantage is that the electronic digital display type can enable computer-based storage and statistical processing of measurement data.

## Guidelines for self-made fixtures

A micrometer head should be mounted by the stem in an accurately machined hole using a clamping method that does not exert excessive compression on the stem. There are three common mounting methods as shown below. Method 3 is not recommended for the reason given above. Adopt methods (1) or (2) wherever possible.

| | Mounting method | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (1) Locknut | | | | (2) Split-body clamp | | | | (3) Setscrew clamp | | | |
| |  | | | |  | | | |  | | | |
| Stem diameter | ø9.5 | ø10 | ø12 | ø18 | ø9.5 | ø10 | ø12 | ø18 | ø9.5 | ø10 | ø12 | ø18 |
| Mounting hole | G7 | | | | G7 | | | | H5 | | | |
| Fitting tolerance | +0.005 to +0.020 | | +0.006 to +0.024 | | +0.005 to +0.020 | | +0.006 to +0.024 | | 0 to +0.006 | | 0 to +0.008 | |
| Precautions | Care should be taken to make *Face A* square to the mounting hole. | | | | Remove burrs generated on the wall of the mounting hole by the slitting operation. | | | | M3 x 0.5 or M4 x 0.7 is an appropriate size for the setscrew. Use a brass plug under setscrew (if thickness of fixture allows) to avoid damaging stem. | | | |

# Micrometer heads

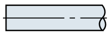


## Custom-built products (product example introductions)

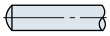
Micrometer heads have applications in many fields of science and industry and Mitutoyo offers a wide range of standard models to meet customers' needs. However, in those cases where the standard product is not suitable, Mitutoyo can custom build a head incorporating features better suited to your special application. Please feel free to contact Mitutoyo about the possibilities - even if only one custom-manufactured piece is required.

### 1. Spindle-end types

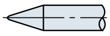
> Standard



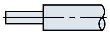
> Spherical



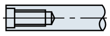
> Pointed



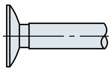
> Spline



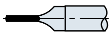
> Tapped



> Flanged



> Blade (for non-rotating spindle types only)

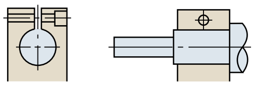


Long spindle types are also available. Please consult Mitutoyo.

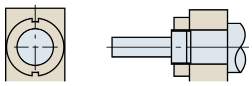
### 2. Stem types

A custom stem can be manufactured to suit the mounting fixture.

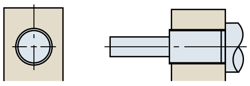
> Plain



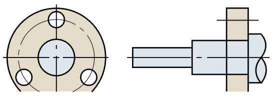
> Locknut



> Threaded



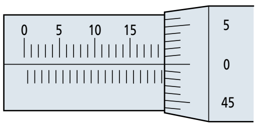
> Flanged



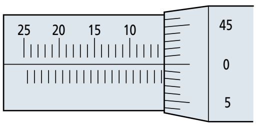
### 3. Scale graduation schemes

Various barrel and thimble scale graduation schemes, such as reverse and vertical, are available. Please consult Mitutoyo for ordering a custom scheme not shown here.

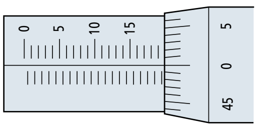
> Standard



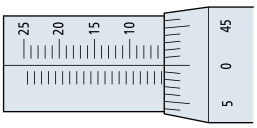

> Reverse



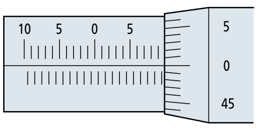

> Vertical



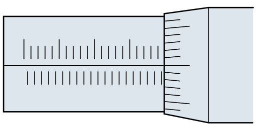

> Reverse vertical




> Offset zero




> Graduations only

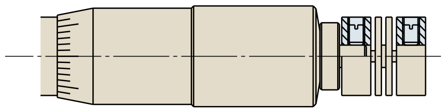


### 4. Logo engraving

A specific logo can be engraved as required.

### 5. Motor coupling

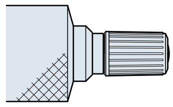
Couplings for providing motor drive to a head can be designed.



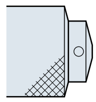
### 6. Thimble mounting

Thimble mounting methods including ratchet, setscrew, and hex-socket head screw types are available.

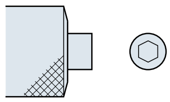
> Ratchet



> Setscrew



> Hex-socket head screw



### 7. Spindle-thread pitch

Pitches of 1 mm for fast-feed applications or 0.25 mm for fine-feed can be supplied as alternatives to the standard 0.5 mm. Inch pitches are also supported. Please consult Mitutoyo for details.

### 8. Lubricant for spindle threads

Lubrication arrangements can be specified by the customer.

### 9. All-stainless construction

All components of a head can be manufactured in stainless steel.

### 10. Simple packaging

Large-quantity orders of micrometer heads can be delivered in simple packaging for OEM purposes.

## Maximum loading capacity on micrometer heads

The maximum loading capacity of a micrometer head depends mainly on the method of mounting and whether the loading is static or dynamic (used as a stop, for example). Therefore the maximum loading capacity of each model cannot be definitively specified. The loading limits recommended by Mitutoyo (at less than 100,000 revolutions if used for measuring within the guaranteed accuracy range) and the results of static load tests using a small micrometer head are given below.



### 1. Recommended maximum loading limit

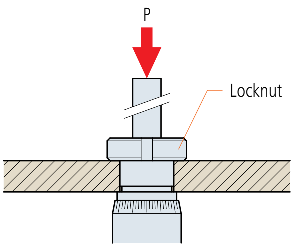
| Type | | Maximum loading limit |
|---|---|---|
| Standard | Spindle pitch: 0.5 mm | Up to approx. 4 kgf * |
| High-functionality | Spindle pitch: 0.1 mm / 0.25 mm | Up to approx. 2 kgf |
| | Spindle pitch: 0.5 mm | Up to approx. 4 kgf |
| | Spindle pitch: 1.0 mm | Up to approx. 6 kgf |
| | Non-rotating spindle | Up to approx. 2 kgf |
| | MHF micro-fine feed type (with a differential mechanism) | |

* Up to approx. 2 kgf only for MHT

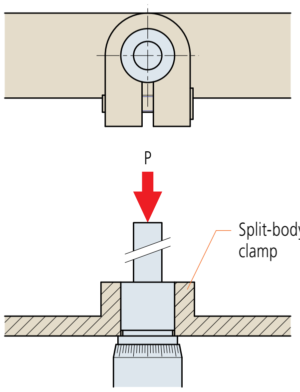
### 2. Static load test for micrometer heads (using MHS for this test)

Micrometer heads were set up as shown and the force at which the head was damaged or pushed out of the fixture when a static load was applied, in direction P, was measured. (In the tests no account was taken of the guaranteed accuracy range.)

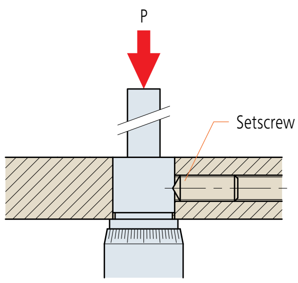
(1) Locknut




(2) Split-body clamp

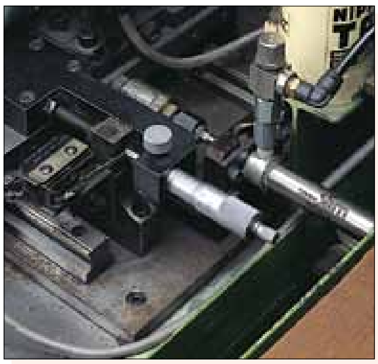



(3) Setscrew clamp



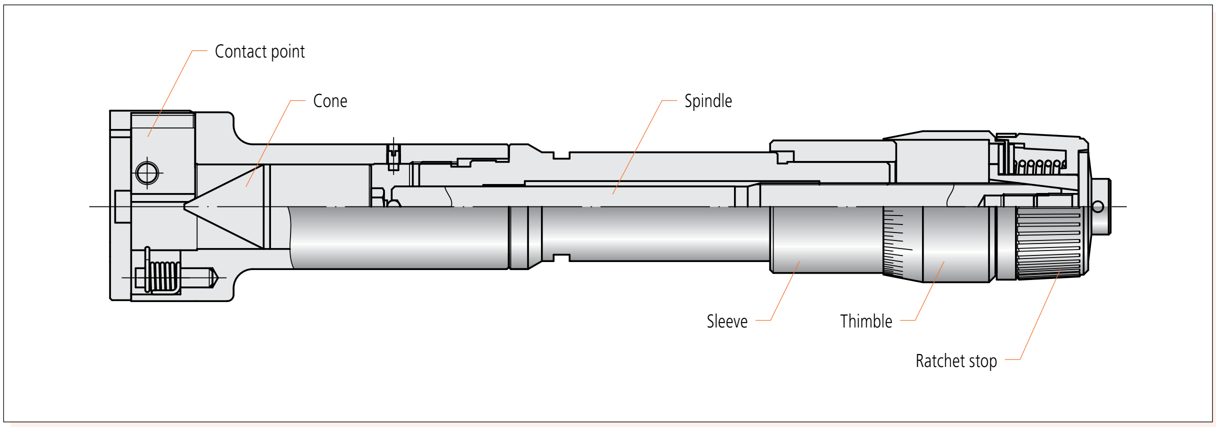

| Mounting method | Damaging / dislodging load* |
|---|---|
| (1) Locknut | Damage to the head occurred at 8.63 to 9.8 kN (880 to 1000 kgf) |
| (2) Split-body clamp | The head was pushed out of the fixture at 0.69 to 0.98 kN (70 to 100 kgf) |
| (3) Setscrew clamp | Damage to the setscrew occurred at 0.69 to 1.08 kN (70 to 110 kgf) |

* These load values should only be viewed as an approximate guide.



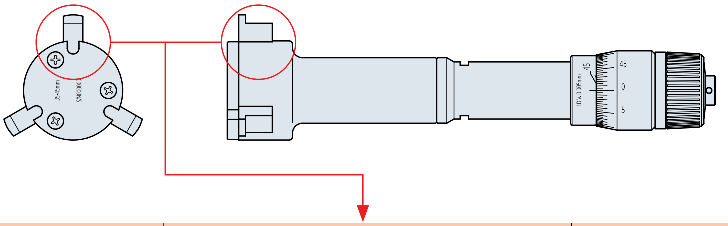
# Bore micrometers

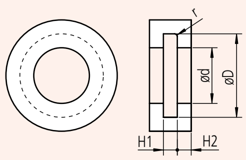
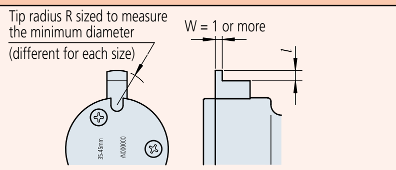
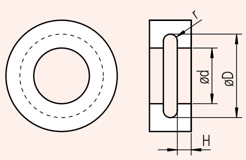
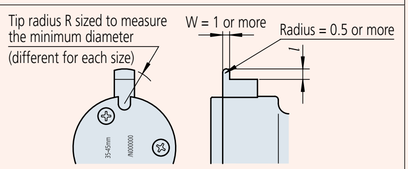
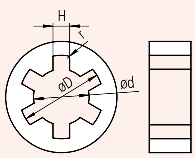
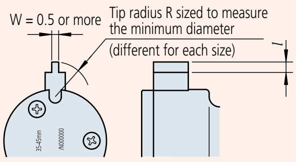
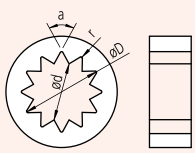
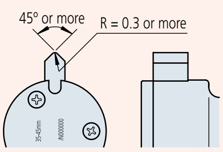
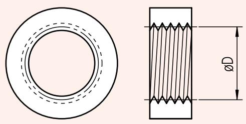
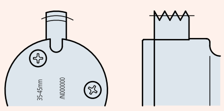
## Nomenclature




## Custom-ordered products (Holtest / Borematic)

Mitutoyo can custom-build a bore micrometer best suited to your special application. Please feel free to contact Mitutoyo about the possibilities – even if only one custom-manufactured piece is required. Please note that, depending on circumstances, such a micrometer will usually need to be used with a master setting ring for accuracy assurance. (A custom-ordered micrometer can be made compatible with a master ring supplied by the customer. Please consult Mitutoyo.)



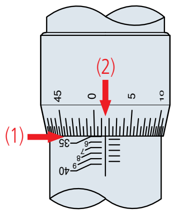
| Type of feature | Workpiece profile (example) | Contact point tip profile (example) | Remarks |
|---|---|---|---|
| Square groove |  |  | ■ Allows measurement of the diameter of variously shaped inside grooves and splines.<br>■ Minimum measurable groove diameter is approximately 16 mm (differs depending on the workpiece profile.)<br>■ Dimension *l* should be as follows:<br>For W = less than 2 mm: *l* = less than 2 mm<br>For W = 2 mm or more: *l* = 2 mm as the standard value which can be modified according to circumstances.<br>■ The number of splines or serrations is limited to a multiple of 3.<br>■ Details of the workpiece profile should be provided at the time of placing a custom-order.<br>■ If your application needs a measuring range different from that of the standard bore micrometer an additional initial cost for the master ring gauge will be required. |
| Round groove |  |  | |
| Spline |  |  | |
| Serration |  |  | |
| Threaded hole |  |  | ■ Allows measurement of the effective diameter of an internal thread.<br>■ Measurable internal threads are restricted according to the type, nominal dimension, and pitch of the thread. Please contact Mitutoyo with the specification of the thread to be measured for advice. |

## How to read the scale

Graduation: 0.005 mm

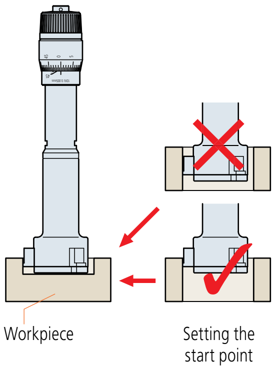
(1) Sleeve scale reading 35.000 mm
(2) Thimble scale reading 0.015 mm

Micrometer reading 35.015 mm



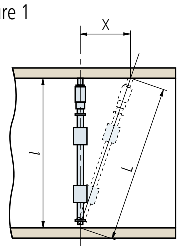

## Changes in measured values at different measuring points

When Holtest is used, the measured value differs between measurement across the anvil and measurement using only the tips of the anvils due to the product mechanism. Set the start point under the same conditions as the measurement.




## Misalignment errors

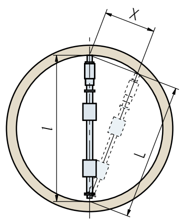
> Figure 1




$l$ : Inside diameter to be measured
L : Length measured with axial offset X
X : Offset in axial direction
$\Delta l$: Error in measurement

$\Delta l$: $L - l = \sqrt{l^2 + X^2} - l$

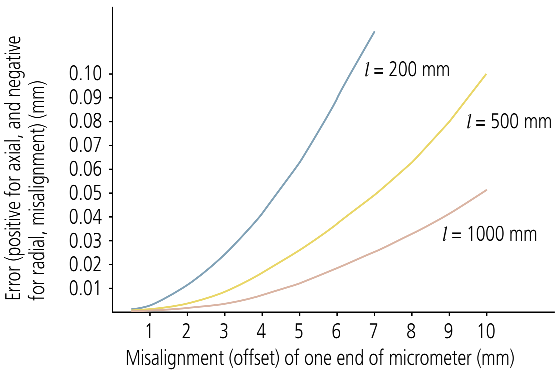
> Figure 2




$l$ : Inside diameter to be measured
L : Length measured with radial offset X
X : Offset in radial direction
$\Delta l$: Error in measurement

$\Delta l$: $L - l = \sqrt{l^2 - X^2} - l$

If an inside micrometer is misaligned in the axial or radial direction by an offset distance X when a measurement is taken, as in *Figures 1* and *2*, then that measurement will be in error as shown in the graph below (constructed from the formulae given above). The error is positive for axial misalignment and negative for radial misalignment.

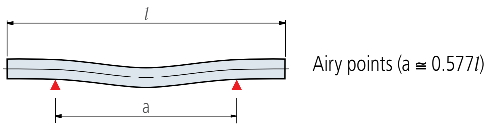



## Measurement error due to temperature variation of micrometer

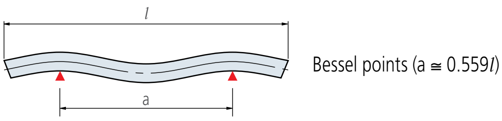
Heat transfer from the operator to the micrometer should be minimized to avoid any significant measuring error due to temperature difference between the workpiece and micrometer. If the micrometer is held directly by hand when measuring, use gloves or hold the heat-insulator (if fitted).

## Airy and bessel points

When a length standard bar or internal micrometer lies horizontally, supported as simply as possible at two points, it bends under its own weight into a shape that depends on the spacing of those points. There are two distances between the points that control this deformation in useful ways, as shown below.



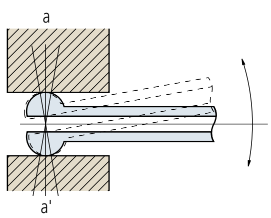

The ends of a bar (or micrometer) can be made exactly horizontal by spacing the two supports symmetrically as shown above. These points are known as the *airy points* and are commonly used to ensure that the ends of a length bar are parallel to one another, so that the length is well defined.



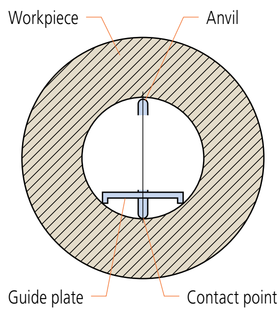

The change in length of a bar (or micrometer) due to bending can be minimized by spacing the two supports symmetrically as shown above. These points are known as the *bessel points* and may be useful when using a long inside micrometer.

## Bore gauges

Mitutoyo bore gauges for small holes feature contact surfaces with a large curvature so they can be easily positioned for measuring the true diameter (in the direction a-a') of a hole. The true diameter is the minimum value seen on the dial while rocking the bore gauge as indicated by the arrow.




The spring-loaded guide plate on a Mitutoyo two-point bore gauge automatically ensures radial alignment so that only an axial rocking movement is needed to find the minimum reading (true diameter).

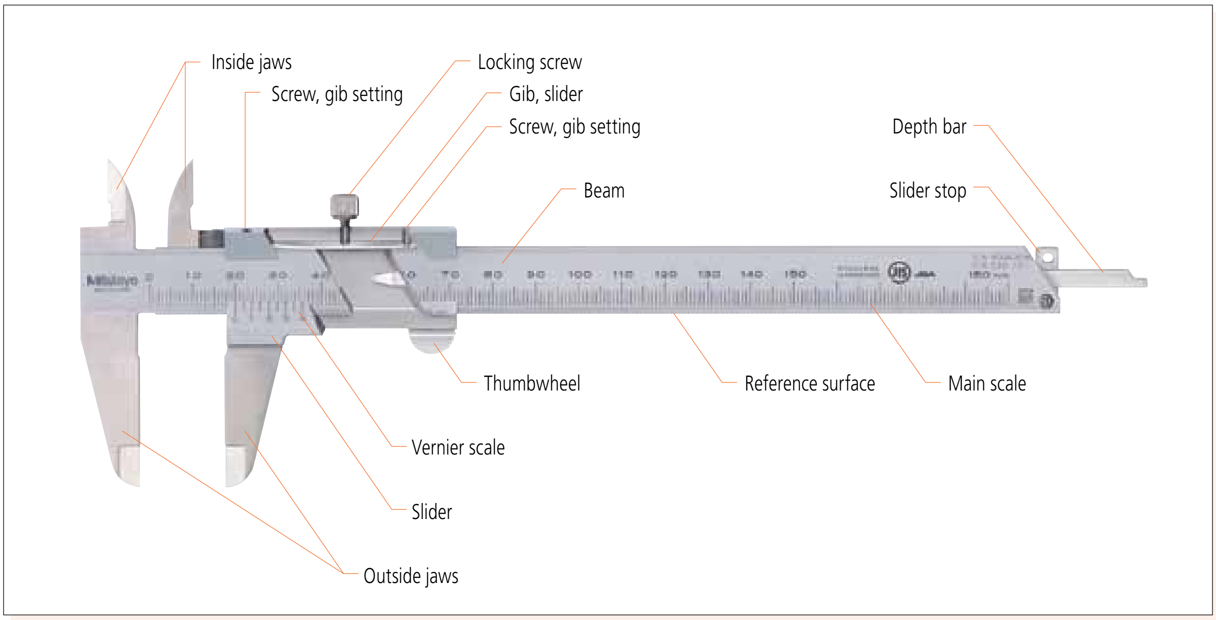


# Calipers

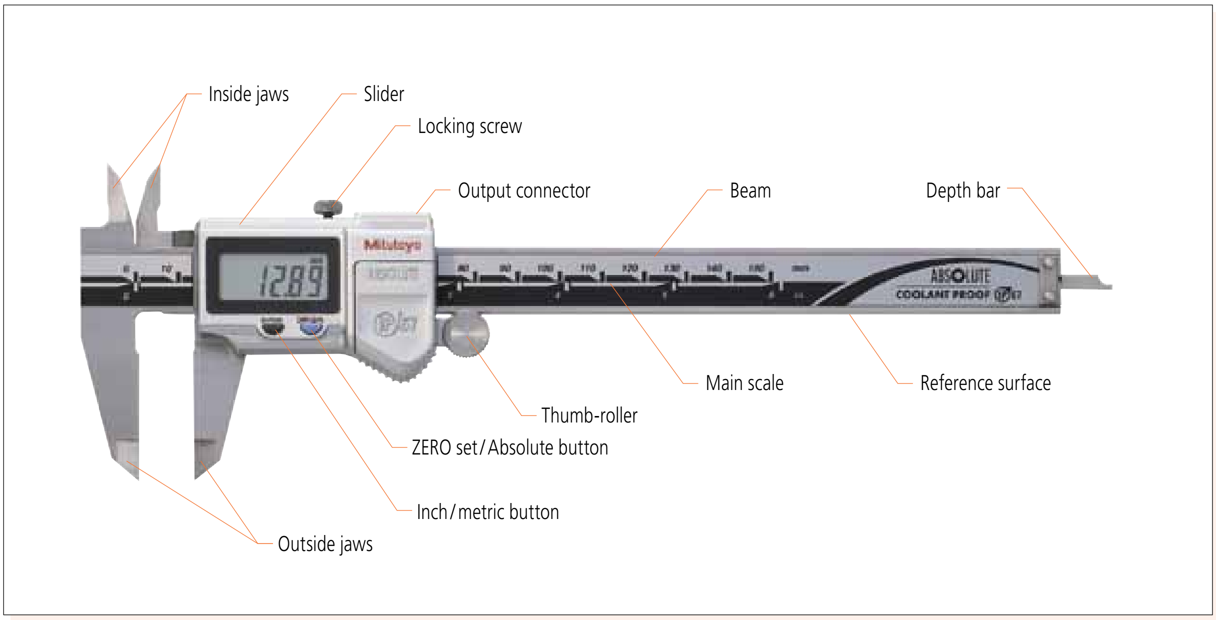


## Nomenclature

### Vernier caliper

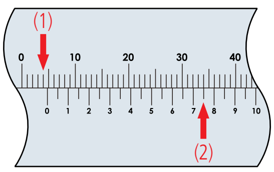



### Absolute digimatic caliper




## How to read the scale

### Vernier calipers

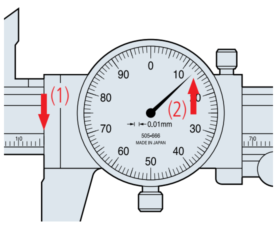



Graduation : 0.05 mm

| | |
|---|---|
| (1) Main scale reading | 4.00 mm |
| (2) Vernier scale reading | 0.75 mm |
| Caliper reading | 4.75 mm |

Note: 0.75 mm (2) is read at the position where a main scale graduation corresponds with a vernier graduation.

### Dial calipers

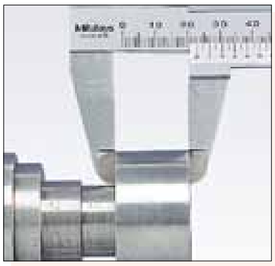



Graduation : 0.01 mm

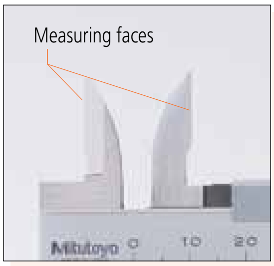
| | |
|---|---|
| (1) Main scale reading | 16.00 mm |
| (2) Dial face reading | 0.13 mm |
| Caliper reading | 16.13 mm |

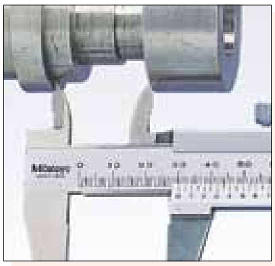
## Measurement examples

### Outside measurement

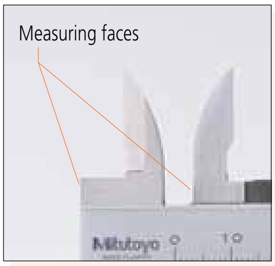



### Inside measurement

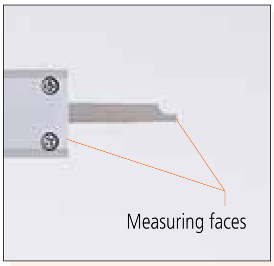


### Step measurement

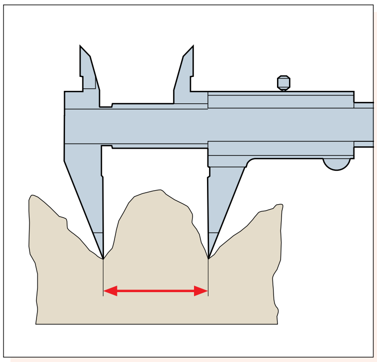



### Depth measurement



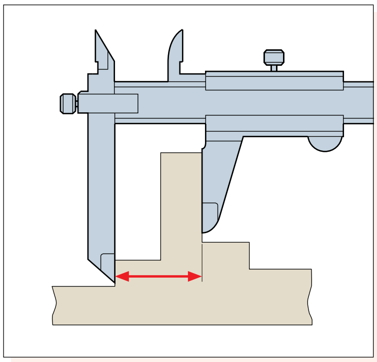

## Special purpose caliper applications

### Point jaw type



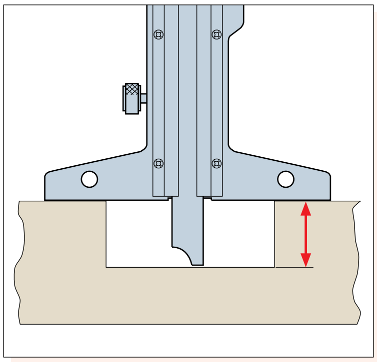
> For uneven surface measurement.

### Offset jaw type



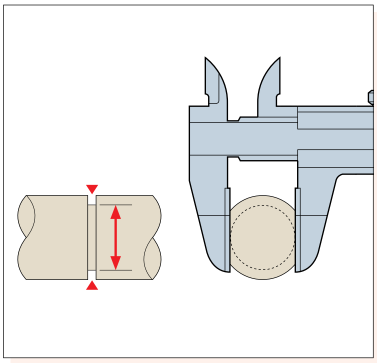
> For stepped feature measurement.

### Depth type



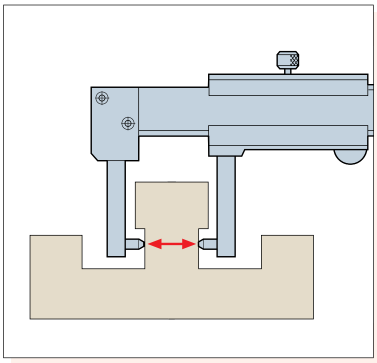
> For depth measurement.

### Blade jaw type



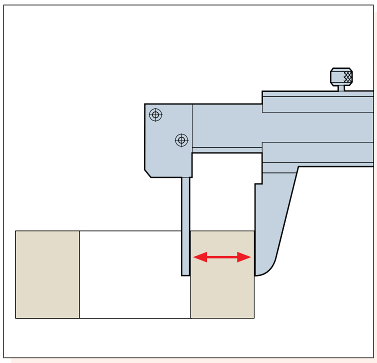
> For diameter of narrow groove measurement.

### Neck type



> For outside diameter measurement such as thickness of recess.

### Tube thickness type



> For tube or pipe thickness measurement.

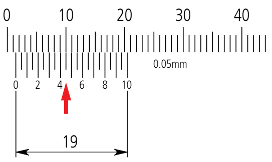
# Calipers



## Types of vernier scale

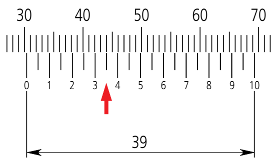
The Vernier scale is attached to the caliper's slider and each division on this scale is made 0.05 mm shorter than one main scale division of 1 mm. This means that, as the caliper jaws open, each successive movement of 0.05 mm brings the succeeding vernier scale line into coincidence with a main scale line and so indicates the number of 0.05 mm units to be counted (although for convenience the scale is numbered in fractions of a mm). Alternatively, one vernier division may be made 0.05 mm shorter than two divisions of the main scale to make a long vernier scale. This makes the scale easier to read but the principle, and graduation, is still the same.

> Standard vernier scale (graduation 0.05 mm)




Reading 1.45 mm

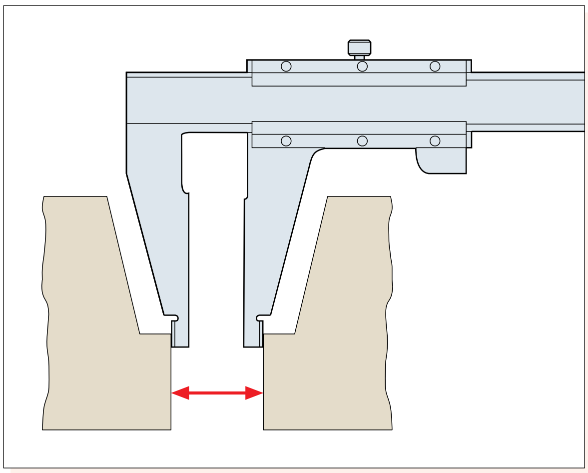
> Long vernier scale (graduation 0.05 mm)




Reading 30.35 mm

## About long calipers

Steel rules are commonly used to roughly measure large workpieces but if a little more accuracy is needed then a long caliper is suitable for the job. A long caliper is very convenient for its user friendliness but does require some care in use. In the first place it is important to realize there is no relationship between resolution and accuracy. For details, refer to the values in our catalogue. Resolution is constant whereas the accuracy obtainable varies dramatically according to how the caliper is used. The measuring method with this instrument is a concern since distortion of the main beam causes a large amount of the measurement error, so accuracy will vary greatly depending on the method used for supporting the caliper at the time. Also, be careful to use only the minimum measuring force necessary when using the outside measuring faces as they are furthest away from the main beam, so errors will be at a maximum here. This precaution is also necessary when using the tips of the outside measuring faces of a long-jaw caliper.



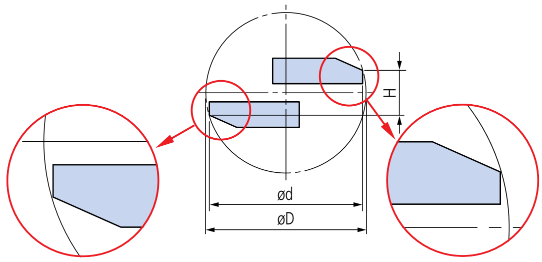
## Small hole measurement with an M-type caliper

Due to the thickness and separation of caliper knife-edge jaws, the line between the jaw contact points is offset relative to the scale axis when measuring a hole diameter, which means that a small *Abbe* correction needs to be added to the indicated measurement value to ensure the most accurate result obtainable from this method. The table below shows typical correction values against offset (H).

øD = True internal diameter
ød = Indicated internal diameter
Δd = Measurement error (øD – ød)

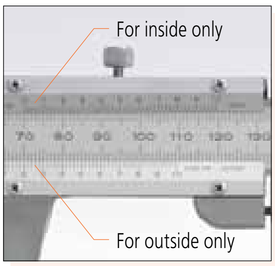
Correction to be added for øD = 5 mm

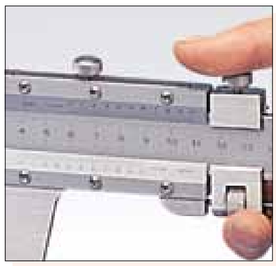
| H | 0.3 | 0.5 | 0.7 |
|---|---|---|---|
| Δd | 0.009 | 0.026 | 0.047 |




## Inside measurement with a CM-type caliper

Because the inside measuring faces of a CM-type caliper are at the tips of the jaws the measuring face parallelism is heavily affected by measuring force, and this becomes a large factor in the measurement accuracy attainable. In contrast to an M-type caliper, a CM-type caliper cannot measure a very small hole diameter because it is limited to the size of the stepped jaws, although normally this is no inconvenience as it would be unusual to have to measure a very small hole with this type of caliper. Of course, the radius of curvature on the inside measuring faces is always small enough to allow correct hole diameter measurements right down to the lowest limit (jaw closure). Mitutoyo CM-type calipers are provided with an extra scale on the slider for inside measurements so they can be read directly without the need for calculation, just as for an outside measurement. This useful feature eliminates the possibility of error that occurs when having to add the inside-jaw-thickness correction on a single-scale caliper.

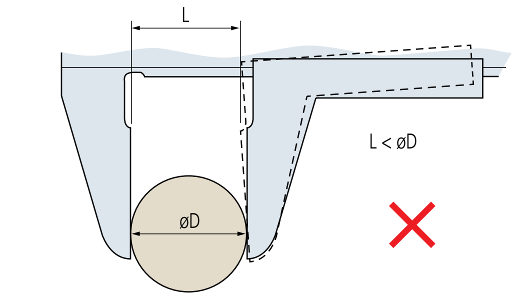


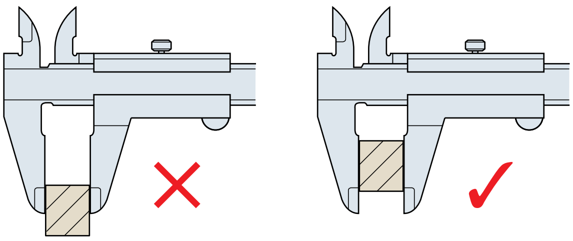



## General notes on use of calipers

1. Potential causes of error

A variety of factors can cause errors when measuring with a caliper. Major factors include parallax effects when reading the scales, excessive measuring force combined with a failure to measure as close as possible to the beam (a caliper does not conform to Abbe's Principle), differential thermal expansion due to a temperature difference between the caliper and workpiece, and the effect of the thickness of the knife-edge jaws and the clearance between these jaws during measurement of the diameter of a small hole. Although there are also other error factors such as graduation accuracy, reference edge straightness, main scale flatness on the beam, and squareness of the jaws, these factors are included within the instrumental error tolerances. Therefore, these factors do not cause problems as long as the caliper satisfies the instrumental error tolerances.



## 2. Inside measurement

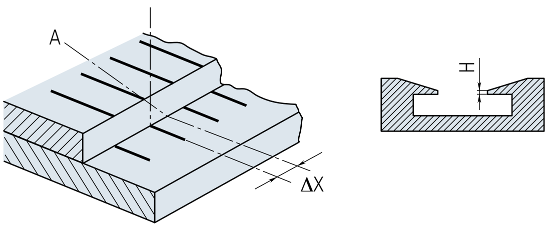
- Insert the inside jaw as deeply as possible before measurement.
- Read the maximum indicated value during inside measurement.
- Read the minimum indicated value during groove width measurement.

## 3. Depth measurement

Read the minimum indicated value during depth measurement.

## 4. Parallax error when reading the scales

Look straight at the vernier graduation line when checking the alignment of vernier graduation lines to the main scale graduation lines. If you look at a vernier graduation line from an oblique direction (A), the apparent alignment position is distorted by $\Delta X$ (as shown in the figure below) due to a parallax effect caused by the step height (H) between the planes of the vernier graduations and the main scale graduations, resulting in a reading error of the measured value. To help avoid this error some vernier calipers are made with H as small as possible, ideally less than 0.3 mm.

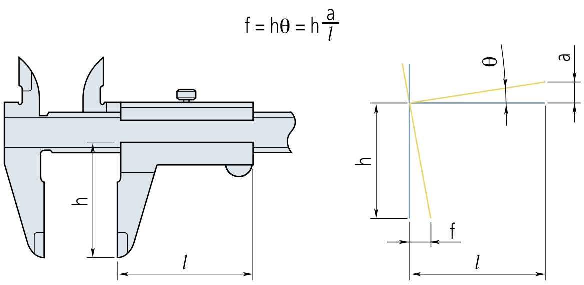



## 5. Relationship between measurement and temperature

The main scale of a caliper is engraved (or mounted on) stainless steel, and although the linear thermal expansion coefficient is equal to that of the most common workpiece material, steel, i.e. (10.2 ±1) x$10^{-6}$/K, note that other workpiece materials, the room temperature and the workpiece temperature may affect measurement accuracy.

## 6. Moving jaw tilt error

If the moving jaw becomes tilted out of parallel with the fixed jaw, either through excessive force being used on the slider or lack of straightness in the reference edge of the beam, a measurement error will occur as shown in the figure. This error may be substantial due to the fact that a caliper does not conform to Abbe's Principle.




**Example:** Assume that the error slope of the jaws due to tilt of the slider is 0.01 mm in 50 mm and the outside measuring jaws are 40 mm deep, then the error (at the jaw tip) is calculated as (40/50) x 0.01 mm = 0.008 mm. If the guide face is worn then an error may be present even using the correct measuring force.

## 7. Handling

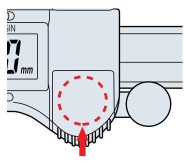
- Caliper jaws are sharp, and therefore the instrument must be handled with care to avoid personal injury.
- Avoid damaging the scale of a digital caliper and do not engrave an identification number or other information on it with an electric marker pen.
- Avoid damaging a caliper by subjecting it to impact with hard objects or by dropping it on a bench or the floor.

## 8. Maintenance of beam sliding surfaces and measuring faces

Wipe away dust and dirt from the sliding surfaces and measuring faces with a dry soft cloth before using the caliper.

## 9. Checking and setting the origin before use

Clean the measuring surfaces by gripping a sheet of clean paper between the outside jaws and then slowly pulling it out. Close the jaws and ensure that the vernier scale (or display) reads zero before using the caliper. When using a digimatic caliper, reset the origin (ORIGIN button) after replacing the battery.




## 10. Handling after use

- After using the caliper, completely wipe off any water and oil. Then, lightly apply anti-corrosion oil and let it dry before storage.
- Wipe off water from a waterproof caliper as well because it may also rust.

## 11. Notes on storage

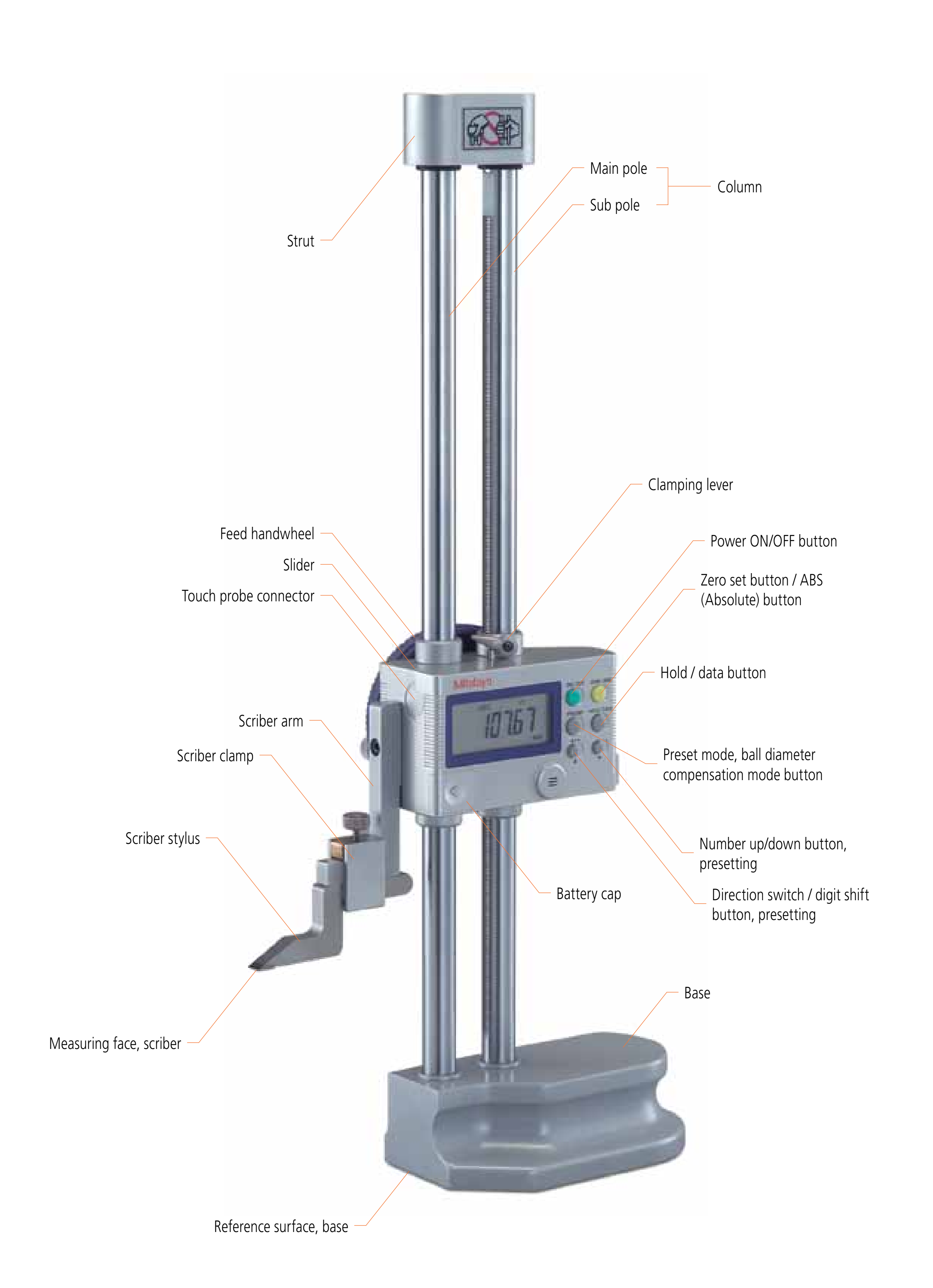
- Avoid direct sunlight, high temperatures, low temperatures, and high humidity during storage.
- If a digital caliper will not be used for more than three months, remove the battery before storage.
- Do not leave the jaws of a caliper completely closed during storage.

# Height gauges

## Nomenclature

Digimatic height gauges



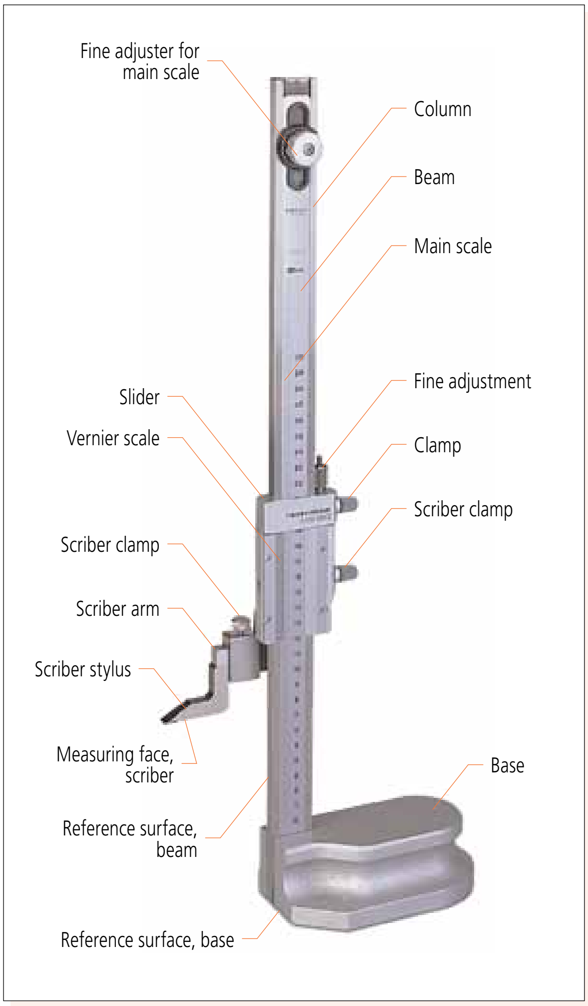



> Digimatic data socket.

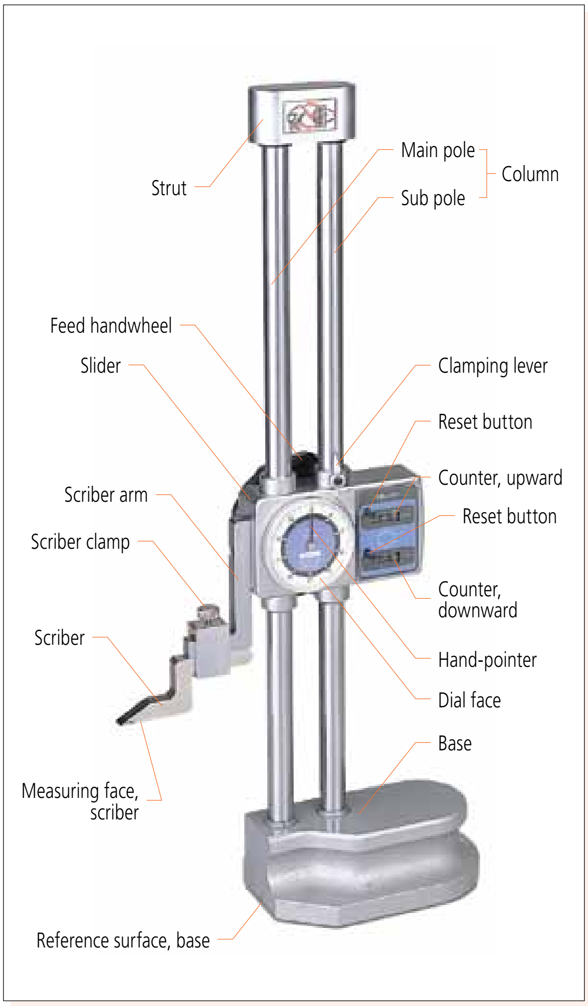

> Slider clamping lever.


> Slider handwheel.

## Vernier height gauges




## Mechanical digit height gauges

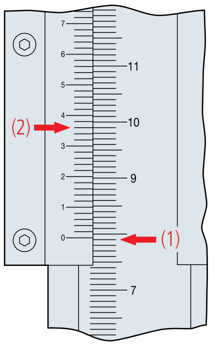


# Height gauges



## How to read the scale

### Vernier height gauge

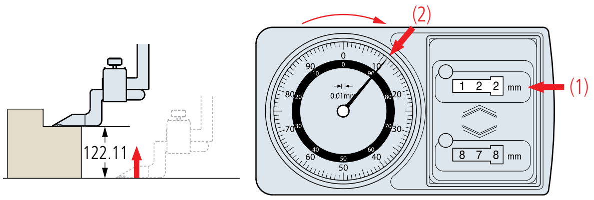



Graduation : 0.02 mm

| | |
|---|---|
| (1) Main scale reading | 79.00 mm |
| (2) Vernier scale reading | 0.36 mm |
| Height gauge reading | 79.36 mm |

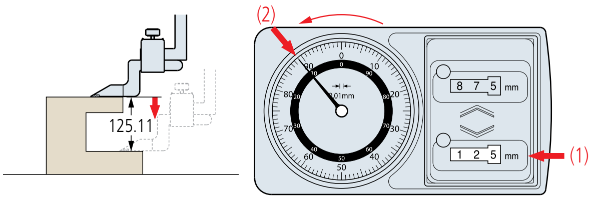
### Mechanical digit height gauge

> Measuring upwards from a reference surface.




| | |
|---|---|
| (1) Counter reading | 122.00 mm |
| (2) Dial face reading | 0.11 mm |
| Height gauge reading | 122.11 mm |

> Measuring downwards from a reference surface.




| | |
|---|---|
| (1) Counter reading | 125.00 mm |
| (2) Dial face reading | 0.11 mm |
| Height gauge reading | 125.11 mm |

## General notes on use of height gauges

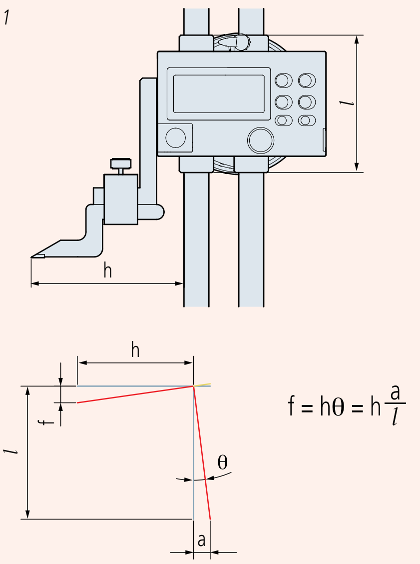
1. Potential causes of error

Like the caliper, the error factors involved include parallax effects, error caused by excessive measuring force (mainly because a height gauge does not conform to Abbe's Principle), and differential thermal expansion due to a temperature difference between the height gauge and workpiece. There are also other error factors caused by the structure of the height gauge. In particular, the error factors related to a warped reference edge and scriber installation described below should be studied before use.

2. Reference edge (column) warping and scriber installation

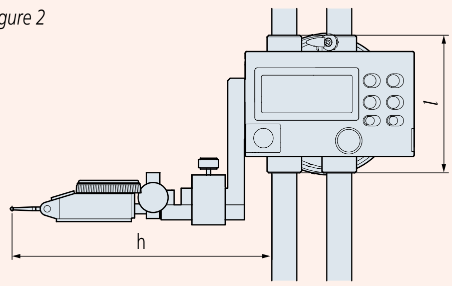
Like the caliper, and as shown in the *Figure 1*, measurement errors result when using the height gauge if the reference column, which guides the slider, becomes warped. This error can be represented by the same calculation formula for errors caused by nonconformance to *Abbe's Principle*. Installing the scriber (or a lever-type dial indicator as shown in *Figure 2*) requires careful consideration because it affects the size of any error due to a warped reference column by increasing dimension *h* in *Figure 1*. In other words, if an optional long scriber or lever-type dial indicator is used, the measurement error becomes larger.

> *Figure 1*




$$f = h\theta = h\frac{a}{l}$$

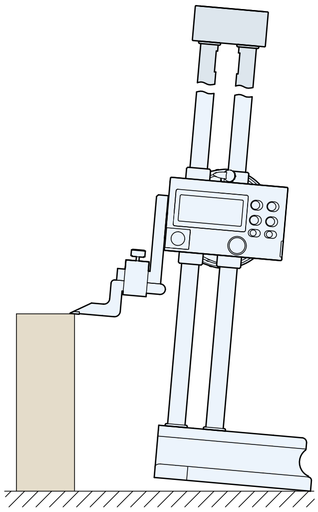
> *Figure 2*




**Example:** Effect of measuring point position.
When *h* is 150 mm, the error is 1.5 times larger than when *h* is 100 mm.

3. Lifting of the base from the reference surface

When setting the scriber height from a gauge block stack, or from a workpiece feature, the base may lift from the surface plate if excessive downwards force is used on the slider, and this results in measurement error. For accurate setting, move the slider slowly downwards while moving the scriber tip to and fro over the gauge block surface (or feature). The correct setting is when the scriber is just felt to lightly touch as it moves over the edge of the surface. It is also necessary to make sure that the surface plate and height gauge base reference surface are free of dust or burrs before use.



4. Error due to inclination of the main scale (column)

According to JIS standards, the perpendicularity of the column reference edge to the base reference surface should be better than:

$$(0.01 + \frac{L}{1000})\ \text{mm} \qquad L = \text{measured length in mm}$$

This is not a very onerous specification. For example, the perpendicularity limit allowable is 0.61 mm when L is 600 mm. This is because this error factor has a small influence and does not change the inclination of the slider, unlike a warped column.

5. Relationship between accuracy and temperature

Height gauges are made of several materials. Note that some combinations of workpiece material, room temperature, and workpiece temperature may affect measuring accuracy if this effect is not allowed for by performing a correction calculation.

6. The tip of a height gauge scriber is very sharp and must be handled carefully if personal injury is to be avoided.

7. Do not damage a digital height gauge scale by engraving an identification number or other information on it with an electric marker pen.

8. Carefully handle a height gauge so as not to drop it or bump it against anything.

9. Keep the column, which guides the slider, clean. If dust or dirt accumulates on it, sliding becomes difficult, leading to errors in setting and measuring.

10. When scribing, securely lock the slider in position using the clamping arrangements provided. It is advisable to confirm the setting after clamping because the act of clamping on some height gauges can alter the setting slightly. If this is so, allowance must be made when setting to allow for this effect.

11. Parallelism between the scriber measuring face and the base reference surface should be 0.01 mm or better. Remove any dust or burrs on the mounting surface when installing the scriber or lever-type dial indicator before measurement. Keep the scriber and other parts securely fixed in place during measurement.

12. If the main scale of the height gauge can be moved, move it as required to set the zero point, and securely tighten the fixing nuts.

13. Errors due to parallax error are not negligible. When reading a value, always look straight at the graduations.

14. Handling after use

Completely wipe away any water and oil. Lightly apply a thin coating of anti-corrosion oil and let dry before storage.

15. Notes on storage:

- Avoid direct sunlight, high temperatures, low temperatures, and high humidity during storage.
- If a digital height gauge will not be used for more than three months, remove the battery before storage.
- If a protective cover is provided, use the cover during storage to prevent dust from adhering to the column.

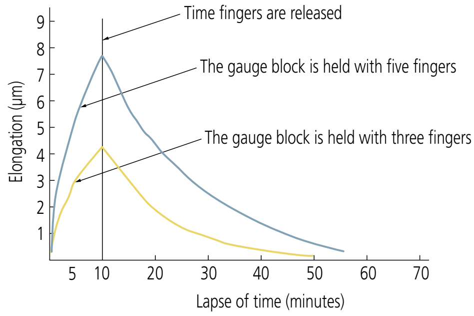
# Gauge blocks

## Definition of the metre

The 17th General Conference of Weights and Measures in 1983 decided on a new definition of the meter unit as the length of the path travelled by light in a vacuum during a time interval of 1/299 792 458 of a second. The gauge block is the practical realization of this unit and as such is used widely throughout industry.

## Thermal stabilization time

The following figure shows the degree of dimensional change when handling a 100 mm steel gauge block with bare hands.



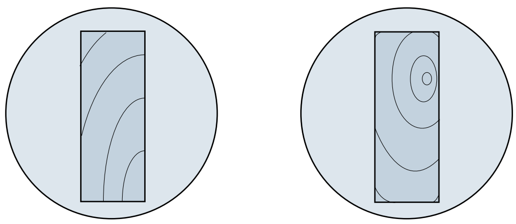

## Selection, preparation and assembly of a gauge block stack

Select gauge blocks to be combined to make up the size required for the stack.

1. Take the following points into account when selecting gauge blocks.
   a. Use the minimum number of blocks whenever possible.
   b. Select thick gauge blocks whenever possible.
   c. Select the size from the one that has the least significant digit required, and then work back through the more significant digits.

2. Clean the gauge blocks with an appropriate cleaning agent.

3. Check the measuring faces for burrs by using an optical flat as follows:

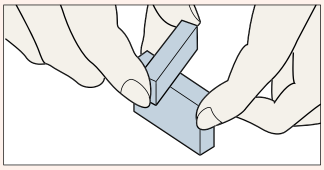


   a. Wipe each measuring face clean.
   b. Gently place the optical flat on the gauge block measuring face.
   c. Lightly slide the optical flat until interference fringes appear.
   *Judgement 1*: If no interference fringes appear, it is assumed that there is a large burr or contaminant on the measuring face.
   d. Lightly press the optical flat to check if the interference fringes disappear.
   *Judgement 2*: If the interference fringes disappear, no burr exists on the measuring face.
   *Judgement 3*: If some interference fringes remain locally while the flat is gently moved to and fro, a burr exists on the measuring face. If the fringes move along with the optical flat, there is a burr on the optical flat.
   e. Remove burrs, if any, from the measuring face using a flat, fine-grained abrasive stone such as a Ceraston or Arkansas stone.

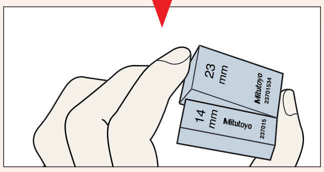
4. Apply a very small amount of oil to the measuring face and spread it evenly across the face. (Wipe the face until the oil film is almost removed.) Grease, spindle oil, Vaseline, etc., are commonly used.

5. Gently overlay the faces of the gauge blocks to be wrung together. There are three methods to use (*i*, *ii* and *iii* as shown below) according to the size of blocks being wrung:

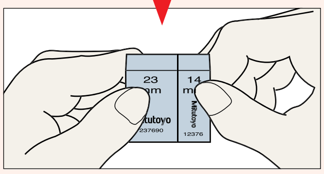
### i) Wringing thick gauge blocks



Cross the gauge blocks at 90° in the middle of the measuring faces.

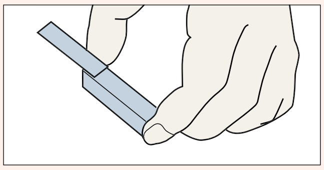


Rotate the gauge blocks while applying slight force to them. You will get a sense of wringing by sliding the blocks.

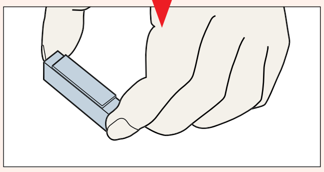


Align the measuring faces with each other.

### ii) Wringing a thick gauge block to a thin gauge block

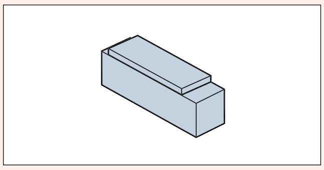


Overlap one side of a thin gauge block on one side of a thick gauge block.

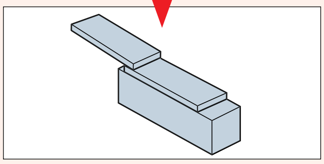


Slide the thin gauge block while pressing the entire overlapped area to align the measuring faces with each other.

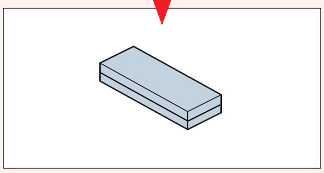
### iii) Wringing thin gauge blocks



To prevent thin gauge blocks from bending, first wring a thin gauge block onto a thick gauge block.

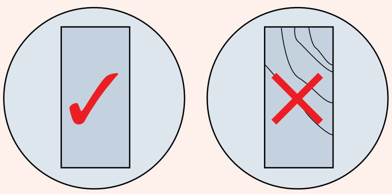


Then, wring the other thin gauge block onto the first thin gauge block.

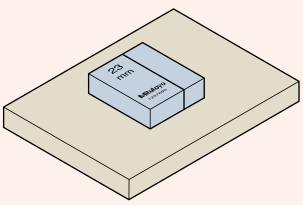


Finally, remove the thick gauge block from the stack.

Apply an optical flat to the surface of one thin gauge block to check the wringing state.



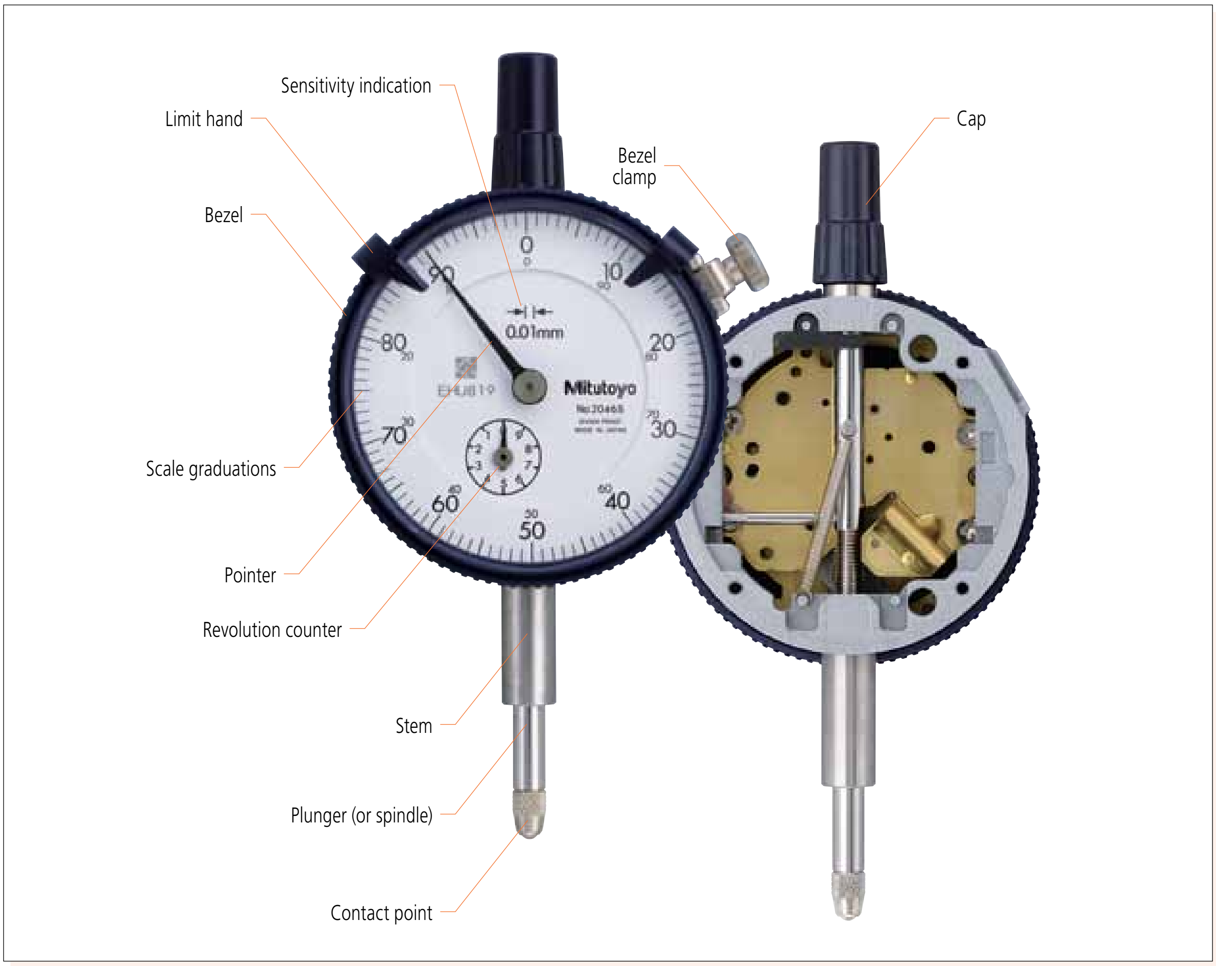
Irregular interference fringes



Wipe the exposed measuring face(s) and continue building up the stack, in the same manner as above, until complete.

# Dial gauges and digital indicators

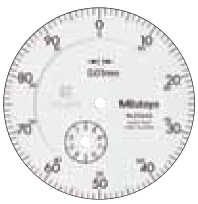
## Nomenclature




## Dial faces

Dial gauges intended for measurement of lengths comparable with the range of a micrometer are generally multi-revolution types with a continuously graduated dial, with the numerals increasing clockwise. Some also have numerals increasing anticlockwise, for measuring in the reverse direction. A purely reverse-reading dial is for use on depth or bore gauges. Those gauges intended for comparison measurement have a balanced dial with the numerals increasing in both directions from zero, for reading small differences from a reference surface, and may be limited to one revolution to aid error-free reading.

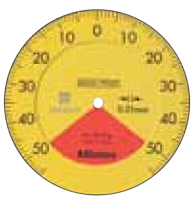
### 0.01 mm types



> Bi-directional (multi-revolution)

> Balanced (multi-revolution)

> Reverse reading (multi-revolution)



> Balanced (one revolution)

### 0.001 mm types (high sensitivity)

> Standard scale spacing

> Balanced (multi-revolution)

> Double scale spacing

> Balanced (one revolution)

## Dial indicator standard B7503 : 2011 (extract from JIS/Japanese Industrial Standards)

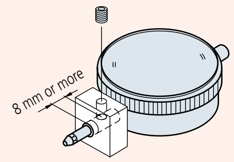
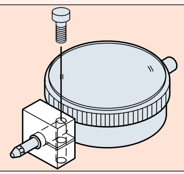
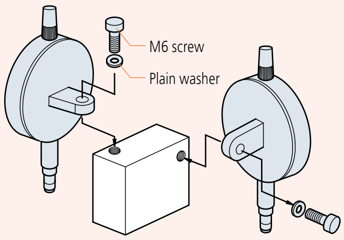
Maximum permissible error

| | Maximum permissible error (MPE) in measurement characteristics – dial indicators with ø50 mm bezel or larger | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Graduation (mm) | 0.01 | | | | | | | | 0.005 | 0.001 | | |
| Measuring range (mm) | 1 or less | Over 1 and up to 3 | Over 3 and up to 5 | Over 5 and up to 10 | Over 10 and up to 20 | Over 20 and up to 30 | Over 30 and up to 50 | Over 50 and up to 100 | 5 or less | 1 or less | Over 1 and up to 2 | Over 2 and up to 5 |
| Retrace error | 3 | 3 | 3 | 3 | 5 | 7 | 8 | 9 | 3 | 2 | 2 | 3 |
| Repeatability | 3 | 3 | 3 | 3 | 4 | 5 | 5 | 5 | 3 | 0.5 | 0.5 | 1 |
| Indication error – Arbitrary 1/10 revolution | 5 | 5 | 5 | 5 | 8 | 10 | 10 | 12 | 5 | 2 | 2 | 3.5 |
| Indication error – Arbitrary 1/2 revolution | 8 | 8 | 9 | 9 | 10 | 12 | 12 | 17 | 9 | 3.5 | 4 | 5 |
| Indication error – Arbitrary one revolution | 8 | 9 | 10 | 10 | 15 | 15 | 15 | 20 | 10 | 4 | 5 | 6 |
| Indication error – Entire measuring range | 8 | 10 | 12 | 15 | 25 | 30 | 40 | 50 | 12 | 5 | 7 | 10 |
| MPE for one revolution type dial indicators does not define the indication error of arbitrary 1/2 and 1 revolution | | | | | | | | | | | | |

| | Maximum permissible error (MPE) in measurement characteristics – dial indicators with bezel smaller than ø50 mm and back plunger type dial indicators | | | | | | |
|---|---|---|---|---|---|---|---|
| Graduation (mm) | 0.01 | | | | 0.005 | 0.002 | 0.001 |
| Measuring range (mm) | 1 or less | Over 1 and up to 3 | Over 3 and up to 5 | Over 5 and up to 10 | 5 or less | 1 or less | 1 or less |
| Retrace error | 4 | 4 | 4 | 5 | 3.5 | 2.5 | 2 |
| Repeatability | 3 | 3 | 3 | 3 | 3 | 1 | 1 |
| Indication error – Arbitrary 1/10 revolution | 8 | 8 | 8 | 9 | 6 | 2.5 | 2.5 |
| Indication error – Arbitrary 1/2 revolution | 11 | 11 | 12 | 12 | 9 | 4.5 | 4 |
| Indication error – Arbitrary one revolution | 12 | 12 | 14 | 14 | 10 | 5 | 4.5 |
| Indication error – Entire measuring range | 15 | 16 | 18 | 20 | 12 | 6 | 5 |
| MPE for one revolution type dial indicators does not define the indication error of arbitrary 1/2 and 1 revolution | | | | | | | |

**Note:** Values in the tables above apply at 20ºC.
The measurement characteristics of a dial indicator have to meet both maximum permissible error (MPE) and measurement force permissible limits (MPL) at any position within the measuring range in any posture when the measurement characteristics are not specified by the manufacturer.

## Mounting a dial gauge

| Mounting method | Example | Note |
|---|---|---|
| Clamping the stem directly with a screw |   | ■ Mounting hole tolerance: ø8G7(+0.005 to 0.02)<br>■ Clamping screw: M4 to M6<br>■ Clamping position: 8 mm or more from the lower edge of the stem<br>■ Maximum clamping torque: 150N·cm when clamping with a single M5 screw<br>■ Note that excessive clamping torque may adversely affect spindle movement. |
| Clamping the stem by split-clamp fastening |  | ■ Mounting hole tolerance: ø8G7(+0.005 to 0.02) |
| Lug mounting |   | ■ Lugs can be changed 90 degrees in orientation according to the application. (The lug is set horizontally when shipped.)<br>■ Lugs of some Series 1 models (No.1911,1913-10&1003), however, cannot be altered to horizontal.<br>■ To avoid cosine-effect error, ensure that any type of gauge or indicator is mounted with its plunger in line with the intended measurement direction. |

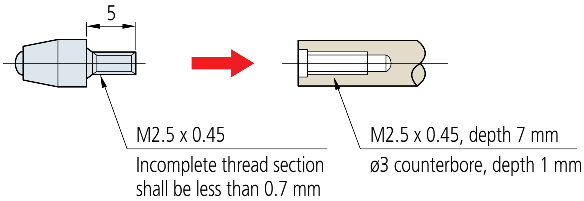
## Care of the plunger

- Do not lubricate the plunger. Doing so might cause dust to accumulate, resulting in a malfunction.
- If the plunger movement is poor, wipe the upper and lower plunger surfaces with a dry or alcohol-soaked cloth. If the movement is not improved by cleaning, contact Mitutoyo for repair.
- Before making a measurement or calibration, confirm that the plunger moves upward and downward smoothly, and the stability of the zero point.

# Dial gauges and digital indicators

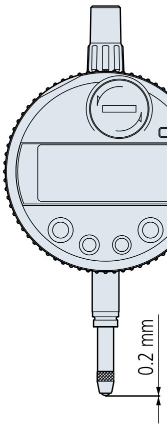
## Contact point

Screw thread is standardized on M2.5 x 0.45 (length: 5 mm). Incomplete thread section at the root of the screw shall be less than 0.7 mm when fabricating a contact point.

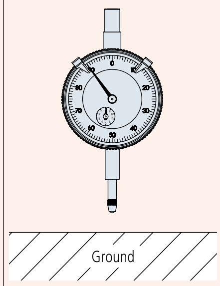
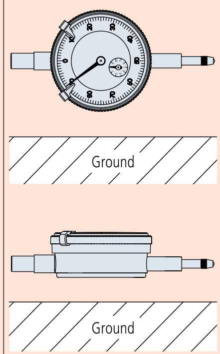
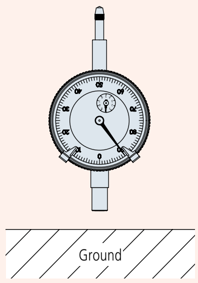



## Setting the origin of a digital indicator

The specification in the range of 0.2 mm from the end of the stroke is not guaranteed for digital indicators. When setting the zero point or presetting a specific value, be sure to lift the spindle at least 0.2 mm from the end of the stroke.




## Effect of orientation on measuring force

| Position | Example | Remarks |
|---|---|---|
| Plunger pointing downward (normal position) |   | — |
| Plunger horizontal |   | If measurement is performed with the plunger horizontal the measuring force is less than when it is pointing downward. In this case be sure to check the operation and repeatability of the indicator or digital display. For guaranteed-operation specifications according to orientation of digital indicators and dial gauges, refer to the product descriptions in a general catalogue. |
| Plunger pointing upward |   | If measurement is performed with the plunger is pointing upward the measuring force is less than when it pointing downward. In this case be sure to check the operation and repeatability of the indicator or digital display. For guaranteed-operation specifications according to orientation of digital indicators and dial gauges, refer to the product descriptions in a general catalogue. |

## Dial test indicator standard B7533 : 1990 (extract from JIS/Japanese Industrial Standards)

### Accuracy of indication

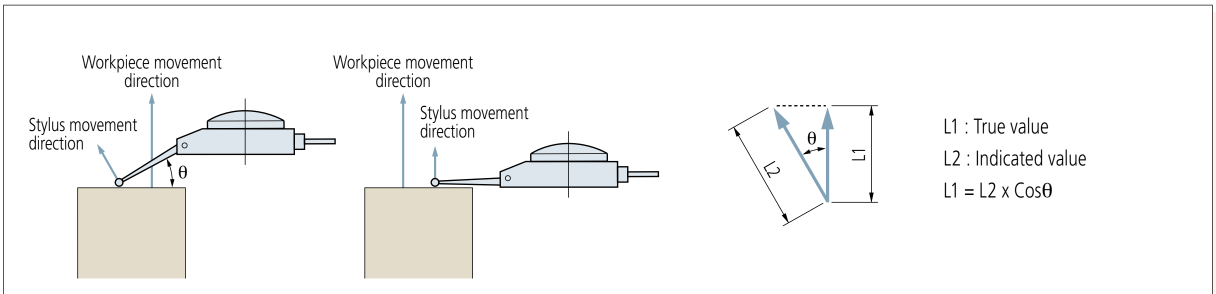
Permissible indication errors of dial test indicators are as per the table below.

| Graduation (mm) | Measuring range (mm) | Wide range accuracy | Adjacent error | Repeatability | Retrace error |
|---|---|---|---|---|---|
| 0.01 | 0.5 | 5 | 5 | 3 | 3 |
| | 0.8 | 8 | | | |
| | 1.0 | 10 | | | 4* |
| 0.002 | 0.2 | 3 | 2 | 1 | 2 |
| | 0.28 | | | | |

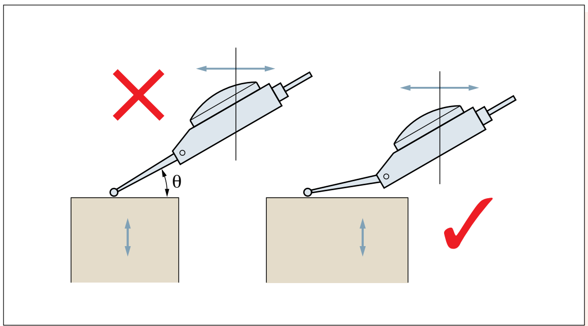
* Applies to indicators with a stylus over 35 mm long.
**Note:** Values in the table above apply at 20°C.

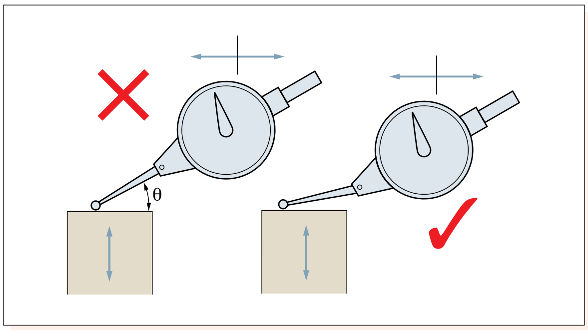
## Dial test indicators and the cosine effect

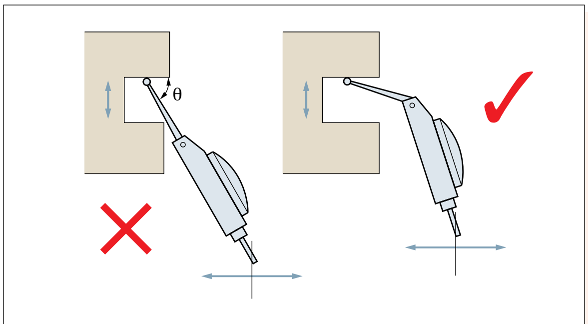
The reading of any indicator will not represent an accurate measurement if its measuring direction is misaligned with the intended direction of measurement (cosine effect). Because the measuring direction of a dial test indicator is at right angles to a line drawn through the contact point and the stylus pivot, this effect can be minimized by setting the stylus to minimize angle θ (as shown in the figures). If necessary, the dial reading can be compensated for the actual θ value by using the table below to give the result of measurement. True value = indicated value x compensation factor.

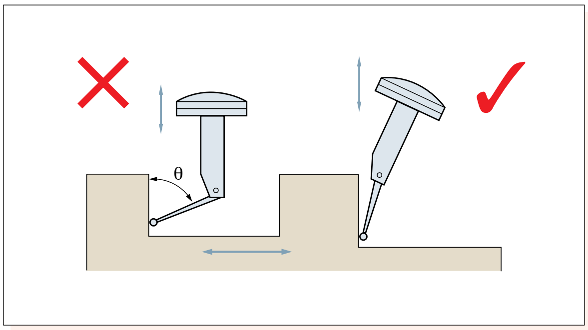



Always minimize the angle between movement directions during use.




### Compensating for a non-zero angle

**Examples**

If a 0.200 mm measurement is indicated on the dial at various values of θ, the true measurements are:

| Angle | Compensation value |
|---|---|
| 10° | 0.98 |
| 20° | 0.94 |
| 30° | 0.86 |
| 40° | 0.76 |
| 50° | 0.64 |
| 60° | 0.50 |

For θ = 10°,
0.200 mm x 0.98 = 0.196 mm

For θ = 20°,
0.200 mm x 0.94 = 0.188 mm

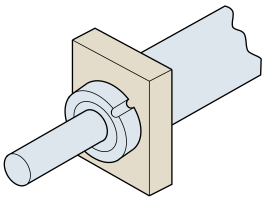
For θ = 30°,
0.200 mm x 0.86 = 0.172 mm

**Note:** A special contact point of involute form can be used to apply compensation automatically and allow measurement to be performed without manual compensation for any angle from 0 to 30°. (This type of contact point is custom-made.)

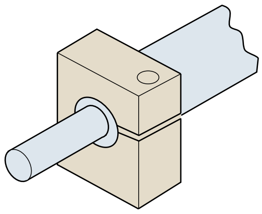
# Linear gauges

## Plain stem and stem with locknut

The stem used to mount a linear gauge head is classified as a *plain type* or *locknut type* as illustrated below. The locknut stem allows fast and secure clamping of the linear gauge head. The plain stem has the advantage of wider application and slight positional adjustment in the axial direction on final installation, although it does requires a split-fixture clamping arrangement or adhesive fixing. However, take care so as not to exert excessive force on the stem.



> Stem locknut type



> Plain stem

## Measuring force

This is the force exerted on a workpiece during measurement by the contact point of a linear gauge head, at its stroke end, expressed in newtons.

## Ingress Protection codes

IP54

| Type | Level | Description |
|---|---|---|
| Protects the human body and protects against foreign objects. | 5: Dust protected | Protection against harmful dust. |
| Protects against exposure to water. | 4: Splash-proof type | Water splashing against the enclosure from any direction shall have no harmful effect. |

IP66

| Type | Level | Description |
|---|---|---|
| Protection against contact with the human body and foreign objects. | 6: Dust tight | Protection from dust ingress. Complete protection against contact. |
| Protects against exposure to water. | 6: Water-resistant type | Water jets directed against the enclosure from any direction shall have no harmful effect. |

## Precautions in mounting a gauge head

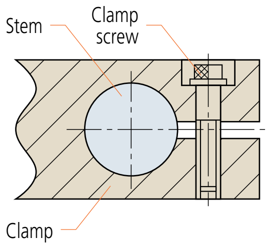
- Insert the stem of the gauge into the mounting clamp of a measuring unit or a stand and tighten the clamp screw.
- Notice that excessively tightening the stem can cause problems with spindle operation.
- Never use a mounting method in which the stem is clamped by direct contact with a screw.
- Never mount a linear gauge by any part other than the stem.
- Mount the gauge head so that it is in line with the intended direction of measurement. Mounting the head at an angle to this direction will cause an error in measurement.
- Exercise care so as not to exert a force on the gauge through the cable.

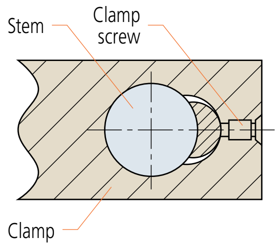
## Comparative measurement

A measurement method where a workpiece dimension is found by measuring the difference in size between the workpiece and a master gauge representing the nominal workpiece dimension.

## Precautions in mounting a Laser Hologage

To fix the Laser Hologage, insert the stem into the dedicated stand or fixture.



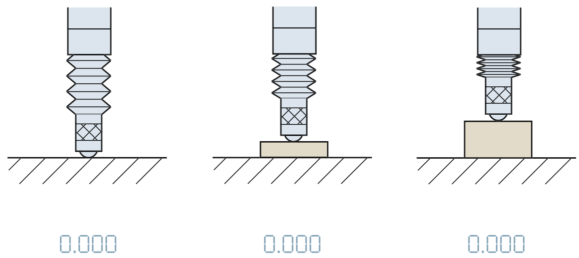




Recommended hole diameter on the fixing side: 15 mm +0.034/-0.014

- Machine the clamping hole so that its axis is parallel with the measuring direction. Mounting the gauge at an angle will cause a measuring error.
- When fixing the Laser Hologage, do not clamp the stem too tightly. Over-tightening the stem may impair the sliding ability of the plunger.
- If measurement is performed while moving the Laser Hologage, mount it so that the cable will not be strained and no undue force will be exerted on the gauge head.

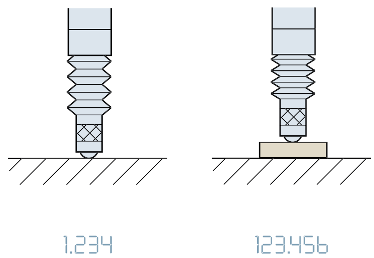
## Zero-setting

The display unit can be set to read 0 (zero) at any position of the plunger.



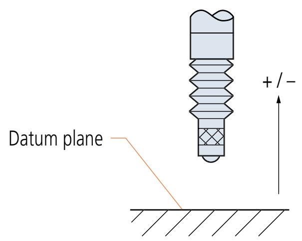

## Presetting

Any numeric value can be set on the display unit for starting the count from this value.



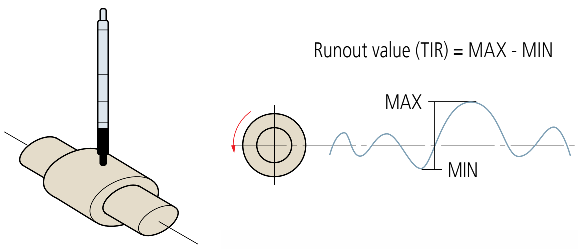
## Direction changeover

The measuring direction of the gauge plunger can be set so that the output increases as the plunger is pushed inward, or vice versa.




## MAX, MIN, TIR settings

The display unit can hold the maximum (MAX) and minimum (MIN) values, and MAX - MIN value during measurement.




## Tolerance setting

Tolerance limits can be set in various display units for automatically indicating if a measurement falls within those limits.

## Open collector output

An external load, such as a relay or a logic circuit, can be driven from the collector output of a transistor inside the display unit which is itself controlled by a tolerance judgement result, etc.

## Relay output

Access to the contacts of a single pole 2-way relay inside the display unit are provided. The relay state can be controlled by a tolerance judgement result, etc.

## Digimatic code

A communication protocol for connecting the output of measuring tools with various Mitutoyo data processing units. This allows output connection to a Digimatic Mini Processor DP-1VR for performing various statistical calculations and creating histograms, etc.

## BCD output

A system for outputting data in binary-coded decimal notation from the display unit.

## RS-232C output

A serial communication interface in which data can be transmitted bidirectionally under the EIA standards. For the transmission procedure, refer to the specifications of each measuring instrument.

# Laser scan micrometers

## Compatibility

A laser scan micrometer is adjusted together with an ID Unit supplied with the measuring unit. The ID Unit, which has the same code number and the same serial number as the measuring unit, must be installed in the display unit.

## The workpiece and measuring conditions

Measurement errors may be caused due to the difference between visible and invisible lasers and the shape or surface roughness of a workpiece. To minimize this possibility, calibrate the instrument using a master of the same shape and the same value of surface roughness as the workpiece whenever possible. If measurements show unacceptable dispersion, it is possible to improve accuracy by making as many measurements as possible on a workpiece and averaging the results.

## Electrical interference

To avoid operational errors, do not route the signal cable and relay cable of the laser scan micrometer alongside a high-voltage line or other cable capable of inducing noise current in nearby conductors. Ground all appropriate units and cable shields.

## Connection to a computer

If the laser scan micrometer is to be connected to an external personal computer via the RS-232C interface, ensure that the cable connections conform to the specification.

## Laser safety

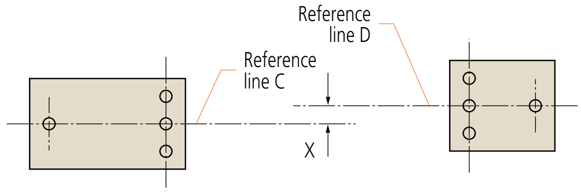
Mitutoyo laser scan micrometers use a low-power visible laser for measurement. The laser is a CLASS 2 EN/IEC60825-1 (2007) device. Warning and explanation labels, as shown below, are attached to the laser scan micrometers as is appropriate.


## Re-assembly after removal from the base

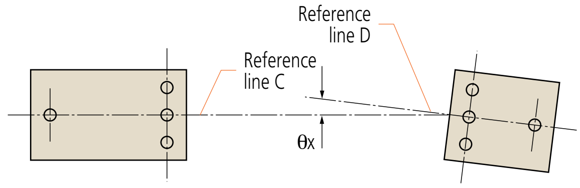
Observe the following limits when re-assembling the emission unit and reception unit to minimize measurement errors due to misalignment of the laser's optical axis with the reception unit.

### Alignment within the horizontal plane

a) Parallel deviation between reference lines C and D:
X (in the transverse direction)

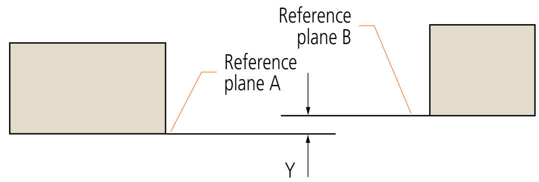



b) Angle between reference lines C and D:
θx (angle)

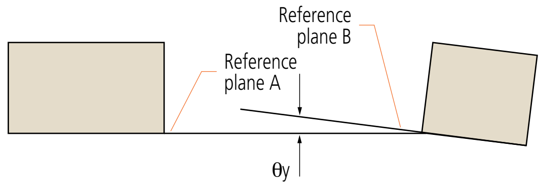



### Alignment within the vertical plane

c) Parallel deviation between reference planes A and B:
Y (in height)



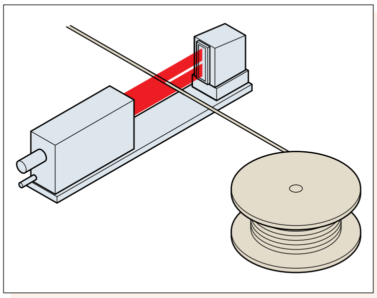

d) Angle between reference planes A and B:
θy (angle)



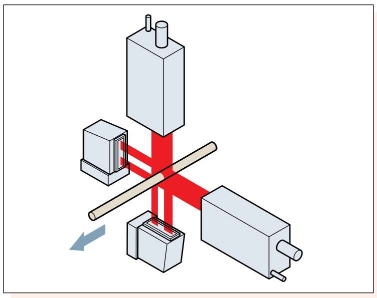

### Allowable limits of optical axis misalignment

| Model | Distance between emission unit and reception unit | X and Y | θx and θy |
|---|---|---|---|
| LSM-501S | 68 mm (2.68") or less | within 0.5 mm (.02") | within 0.4° (7.0 mrad) |
| | 100 mm (3.94") or less | within 0.5 mm (.02") | within 0.3° (5.2 mrad) |
| LSM-503S | 130 mm (5.12") or less | within 1.0 mm (.04") | within 0.4° (7.0 mrad) |
| | 350 mm (13.78") or less | within 1.0 mm (.04") | within 0.16° (2.8 mrad) |
| LSM-506S | 273 mm (10.75") or less | within 1.0 mm (.04") | within 0.2° (3.5 mrad) |
| | 700 mm (27.56") or less | within 1.0 mm (.04") | within 0.08° (1.4 mrad) |
| LSM-512S | 321 mm (12.64") or less | within 1.0 mm (.04") | within 0.18° (3.6 mrad) |
| | 700 mm (27.56") or less | within 1.0 mm (.04") | within 0.08° (1.4 mrad) |
| LSM-516S | 800 mm (31.50") or less | within 1.0 mm (.04") | within 0.09° (1.6 mrad) |

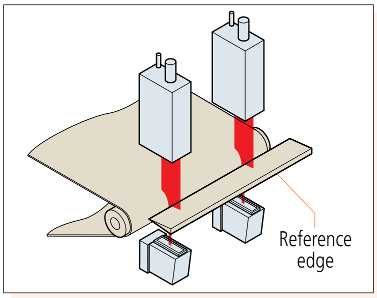
## Measurement examples



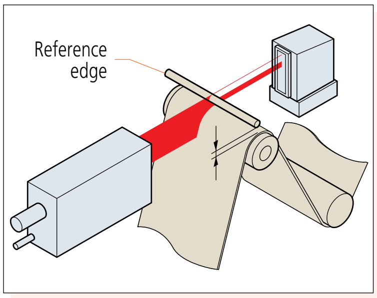
> In-line measurement of glass fibre or fine wire diameter.



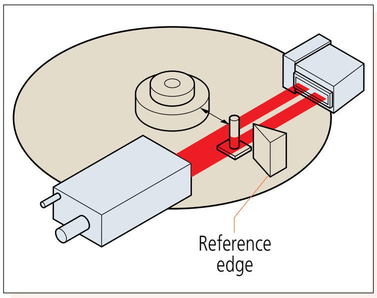
> X- and Y-axis measurement of electrical cables and fibres.



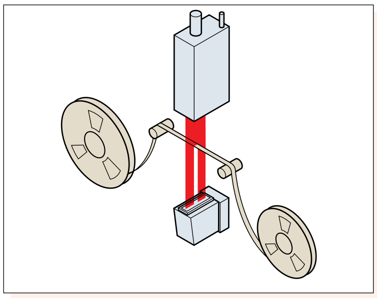

> Measurement of thickness variation of film or sheet.



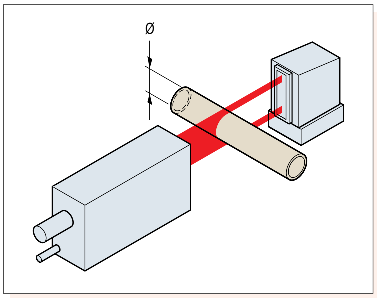

> Measurement of film or sheet thickness.



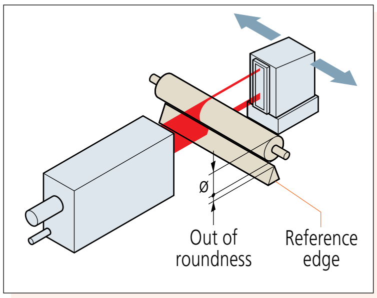

> Measurement of laser disk and magnetic disk head movement.



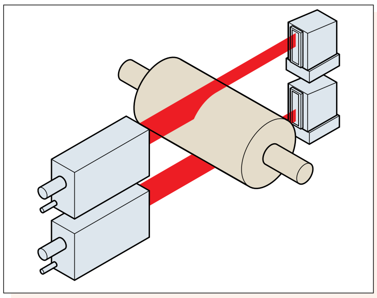
> Measurement of tape width.



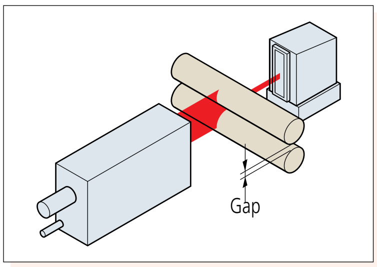

> Measurement of outer diameter of cylinder.



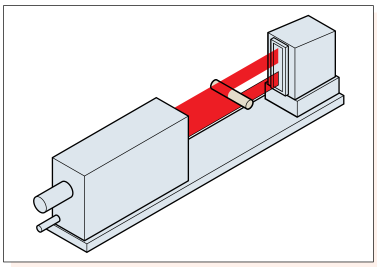

> Measurement of outer diameter and roundness of cylinder.



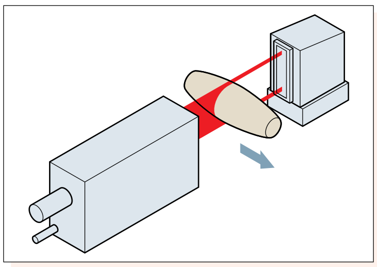
> Dual system for measuring a large outside diameter.



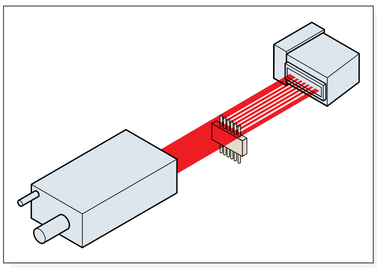

> Measurement of gap between rollers.



> Measurement of outer diameter of optical connector and ferrule.



> Measurement of form.



> Measurement of spacing of IC chip leads.

# Linear scales

## Glossary

- **Absolute system**
  A measurement mode in which every point measurement is made relative to a fixed origin point.

- **Incremental system**
  A measurement mode in which every point measurement is made relative to a certain stored reference point, which is subject to change according to the requirements of the workpiece dimensioning scheme.

- **Origin offset**
  A function that enables the origin point of a coordinate system to be translated to another point offset from the fixed origin point. For this function to work, a system needs a permanently stored origin point.

- **Restoring the origin point**
  A function that stops each axis of a machine accurately in position specific to the machine while slowing it with the aid of integrated limit switches.

- **Sequence control**
  A type of control that sequentially performs control steps according to a prescribed order.

- **Numerical control**
  A way of controlling the movements of a machine by encoded commands created and implemented with the aid of a computer (CNC). A sequence of commands typically forms a *part program* that instructs a machine to perform a complete operation on a workpiece.

- **Binary output**
  Refers to output of data in binary form (ones and zeros) that represent numbers as integer powers of 2.


- **RS-232C**
  An interface standard that uses an asynchronous method of serial transmission of data over an unbalanced transmission line for data exchange between transmitters located relatively close to each other. It is a means of communication mainly used for connecting a personal computer with peripherals.

- **Line driver output**
  This output features fast operating speeds of several tens to several hundreds of nanoseconds and a relatively long transmission distance of several hundreds of metres. A differential-voltmeter line driver (RS422A compatible) is used as an I/F to the NC controller in the linear scale system.

- **BCD**
  A notation of expressing the numerals 0 through 9 for each digit of a decimal number by means of four-bit binary sequence. Data transmission is one-way output by means of TTL or open collector.

- **RS-422**
  An interface standard that uses serial transmission of bits in differential form over a balanced transmission line. RS-422 is superior in its data transmission characteristics and in its capability of operating with only a single power supply of +5V.

- **Accuracy**
  The accuracy specification of a scale is given in terms of the maximum error to be expected between the indicated and true positions at any point, within the range of that scale, at a temperature of 20°C. Since there is no international standard defined for scale units, each manufacturer has a specific way of specifying accuracy. The accuracy specifications given in our catalogue have been determined using laser interferometry.

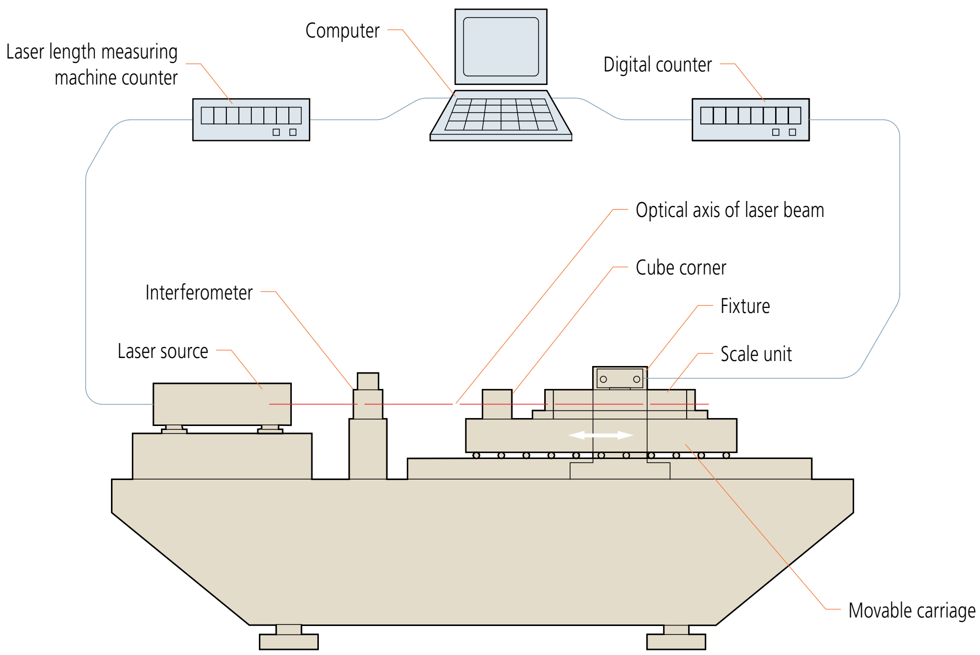
- **Narrow range accuracy**
  Scale gratings on a scale unit normally adopt 20 µm pitch though it varies according to the kind of scale. The narrow range accuracy refers to the accuracy determined by measuring one pitch of each grating at the limit of resolution (1 µm for example).

## Specifying linear scale accuracy

Positional indication accuracy

The accuracy of a linear scale is determined by comparing the positional value indicated by the linear scale with the corresponding value from a laser length measuring machine at regular intervals using the accuracy inspection system as shown in the figure below. As the temperature of the inspection environment is 20°C, the accuracy of the scale applies only in an environment at this temperature. Other inspection temperatures may be used to comply with internal standards.

> Overview of accuracy inspection system.



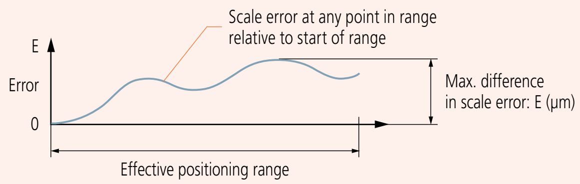

The accuracy of the scale at each point is defined in terms of an error value that is calculated using the following formula:

*Error = Value indicated by the linear scale - corresponding value indicated by the laser inspection system*

A graph in which the error at each point in the effective positioning range is plotted is called an accuracy diagram. There are two methods used to specify the accuracy of a scale, unbalanced or balanced, described below.

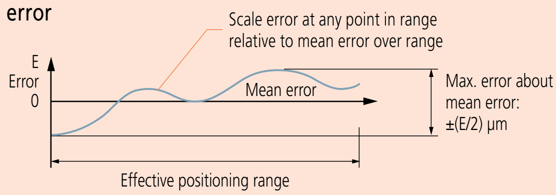
### 1) Unbalanced accuracy specification: maximum minus minimum error

This method simply specifies the maximum error minus the minimum error from the accuracy graph, as shown below. It is of the form: $E = (\alpha + \beta L)$ μm. L is the effective positioning range (mm), and $\alpha$ and $\beta$ are factors specified for each model. For example, if a particular type of scale has an accuracy specification of (3 + 3L/1000) μm and an effective measuring range of 1000 mm, E is 6 μm.




### 2) Balanced accuracy specification: plus and minus about the mean error

This method specifies the maximum error relative to the mean error from the accuracy graph. It is of the form: $e = \pm(E/2)$ μm. This is mainly used in separate-type (retrofit) scale unit specifications.

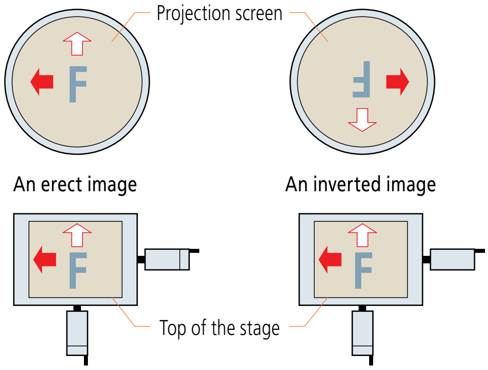



A linear scale detects displacement based on graduations of constant pitch. Two-phase sine wave signals with the same pitch as the graduations are obtained by detecting the graduations. Interpolating these signals in the electrical circuit makes it possible to read a value smaller than the graduations by generating pulse signals that correspond to the desired resolution. For example, if the graduation pitch is 20 μm, interpolated values can generate a resolution of 1 μm. The accuracy of this processing is not error-free and is called interpolation accuracy. The linear scale's overall positional accuracy specification depends both on the pitch error of the graduations and interpolation accuracy.

# Profile projectors

## Erect image and inverted image

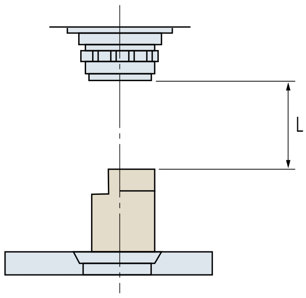
An image of an object projected onto a screen is erect if it is orientated the same way as the object on the stage. If the image is reversed top to bottom, left to right and by movement with respect to the object on the stage (as shown in the figure below) it is referred to as an inverted image (also known as a reversed image, which is probably more accurate).




F = workpiece, ➡ = X-axis movement, ⇨ = Y-axis movement

## Working distance

Refers to the distance from the face of the projection lens to the surface of a workpiece in focus. It is represented by L in the diagram below.




## Magnification accuracy

The magnification accuracy of a projector when using a certain lens is established by projecting an image of a reference object and comparing the size of the image of this object, as measured on the screen, with the expected size (calculated from the lens magnification) to produce a percentage magnification accuracy figure. The reference object is often in the form of a small, graduated glass scale called a *stage micrometer* or *standard scale*, and the projected image of this is measured with a larger glass scale known as a *reading scale*.

**Note:** that magnification accuracy is not the same as measuring accuracy.

$$\Delta M(\%) = \frac{L - lM}{lM} \times 100$$

$\Delta M(\%)$: Magnification accuracy expressed as a percentage of the nominal lens magnification
L : Length of the projected image of the reference object measured on the screen
*l*: Length of the reference object
M : Magnification of the projection lens

## Type of illumination

- **Contour illumination**
  An illumination method to observe a workpiece by transmitted light and is used mainly for measuring the magnified contour image of a workpiece.

- **Coaxial surface illumination**
  An illumination method whereby a workpiece is illuminated by light transmitted coaxially through the lens for the observation/measurement of the surface. (A half-mirror or a projection lens with a built-in half-mirror is needed.)

- **Oblique surface illumination**
  A method of illumination by obliquely illuminating the workpiece surface. This method provides an image of enhanced contrast, allowing it to be observed three-dimensionally and clearly. However, note that an error is apt to occur in dimensional measurement with this method of illumination. (An oblique mirror is needed. Models in the PJ-H30 series are supplied with an oblique mirror.)

## Field of view

The maximum diameter of object space that can be projected using a particular lens.

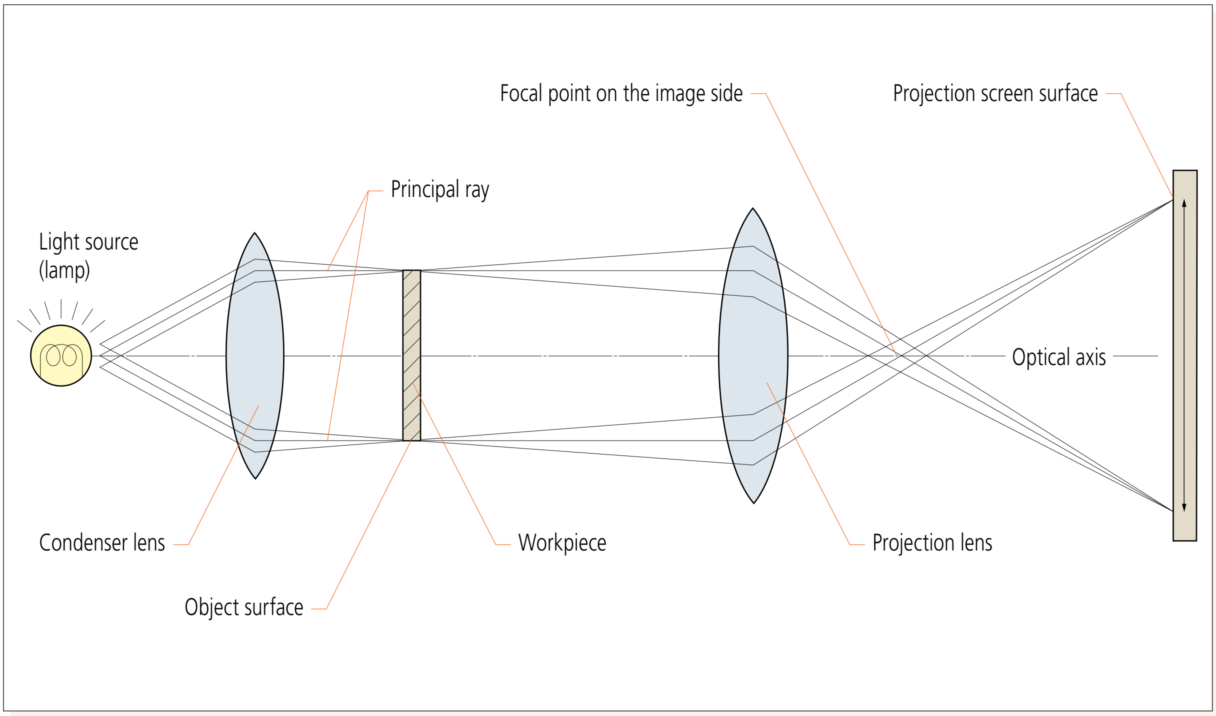
$$\text{Field of view diameter} = \frac{\text{Screen diameter of profile projector}}{\text{Magnification of projection lens used}}$$

**Example:** If a 5X magnification lens is used for a projector with a screen of ø500 mm:
Field of view diameter is given by $\frac{500\text{ mm}}{5} = 100\text{ mm}$

## Telecentric optical system

An optical system where the illuminating rays of light are parallel to the optical axis in object and/or image space. This means that magnification is nearly constant over a range of working distances, therefore almost eliminating perspective error. The image does not vary in size though the image blurs as the object is shifted along the optical axis. For measuring projectors and measuring microscopes, an identical effect is obtained by placing a lamp filament at the focal point of a condenser lens instead of a lens stop so that the object is illuminated with parallel rays of light. (See the figure below.)

> Telecentric contour illumination




# Microscopes



## Numerical aperture (NA)

The NA figure is important because it indicates the resolving power of an objective lens. The larger the NA value the finer the detail that can be seen. A lens with a larger NA also collects more light and will normally provide a brighter image with a shallower depth of focus than one with a smaller NA value.

$NA = n \cdot Sin\theta$

The formula above shows that NA depends on *n*, the refractive index of the medium that exists between the front of an objective and the specimen (for air, $n = 1.0$), and angle $\theta$, which is the half-angle of the maximum cone of light that can enter the lens.

## Resolving power (R)

The minimum detectable distance between two image points, representing the limit of resolution. Resolving power (R) is determined by numerical aperture (NA) and wavelength ($\lambda$) of the illumination.

$$R = \frac{\lambda}{2(NA)^2} \ (\mu m)$$

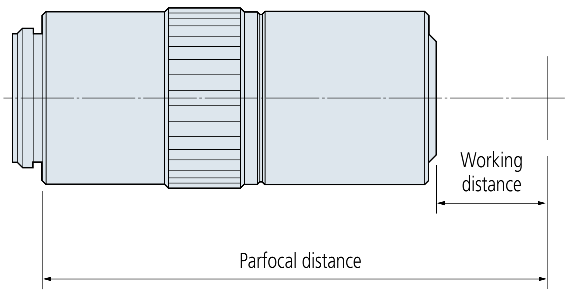
$\lambda = 0.55\ \mu m$ is often used as the reference wavelength

## Working distance (WD)

The distance between the front end of a microscope objective and the surface of the workpiece at which the sharpest focusing is obtained.

## Parfocal distance

The distance between the mounting position of a microscope objective and the surface of the workpiece at which the sharpest focusing is obtained. Objective lenses mounted together in the same turret should have the same parfocal distance so that when another objective is brought into use the amount of refocussing needed is minimal.

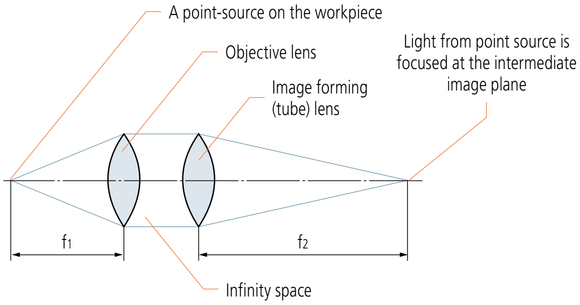



## Focal point

Light rays travelling parallel to the optical axis of a converging lens system and passing through that system will converge (or focus) to a point on the axis known as the rear focal point, or image focal point.

## Infinity optical system

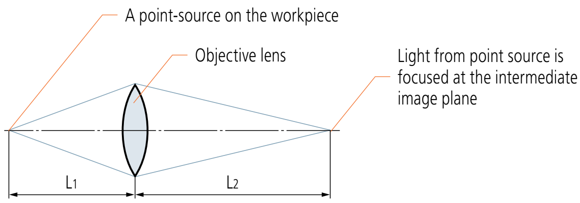
An optical system where the objective forms its image at infinity and a tube lens is placed within the body tube between the objective and the eyepiece to produce the intermediate image. After passing through the objective the light effectively travels parallel to the optical axis to the tube lens through what is termed the *infinity space* within which auxiliary components can be placed, such as differential interference contrast (DIC) prisms, polarizers, etc., with minimal effect on focus and aberration corrections.




**Note:** Magnification of the objective = $f_2/f_1$

## Finite optical system

An optical system that uses an objective to form the intermediate image at a finite position. Light from the workpiece passing through the objective is directed toward the intermediate image plane (located at the front focal plane of the eyepiece) and converges in that plane.




**Note:** Magnification of the objective = $L_2/L_1$

## Focal length (f)

The distance from the principal point to the focal point of a lens: if $f_1$ represents the focal length of an objective and $f_2$ represents the focal length of an image forming (tube) lens then magnification is determined by the ratio between the two. (In the case of the infinity-correction optical system.)

$$\text{Objective magnification} = \frac{\text{Focal length of the image-forming (tube) lens}}{\text{Focal length of the objective}}$$

**Example:** $1X = \frac{200}{200}$ **Example:** $10X = \frac{200}{20}$

## Depth of focus (DOF)

Also known as *depth of field*, this is the distance (measured in the direction of the optical axis) between the two planes which define the limits of acceptable image sharpness when the microscope is focused on an object. As the numerical aperture (NA) increases, the depth of focus becomes shallower, as shown by the expression below:

$$DOF = \frac{\lambda}{2(NA)^2}$$

**Note:** $\lambda$ = 0.55 µm is often used as the reference wavelength

**Example:** For an *M Plan Apo 100X* lens (NA = 0.7).
The depth of focus of this objective is:

$$\frac{0.55\ \mu m}{2 \times 0.7^2} = 0.6\ \mu m$$

## Bright-field illumination and dark-field illumination

In brightfield illumination a full cone of light is focused by the objective on the specimen surface. This is the normal mode of viewing with an optical microscope. With darkfield illumination, the inner area of the light cone is blocked so that the surface is only illuminated by light from an oblique angle. Darkfield illumination is good for detecting surface scratches and contamination.

## Apochromat objective and achromat objective

- An apochromat objective is a lens corrected for chromatic aberration (colour blur) in three colours (red, blue, yellow).
- An achromat objective is a lens corrected for chromatic aberration in two colours (red, blue).

## Magnification

The ratio of the size of a magnified object image created by an optical system to that of the object. Magnification commonly refers to lateral magnification although it can mean lateral, vertical, or angular magnification.

## Principal ray

A ray considered to be emitted from an object point off the optical axis and passing through the centre of an aperture diaphragm in a lens system.

## Aperture diaphragm

An adjustable circular aperture which controls the amount of light passing through a lens system. It is also referred to as an aperture stop and its size affects image brightness and depth of focus.

## Field stop

A stop which controls the field of view in an optical instrument.

## Telecentric system

An optical system where the light rays are parallel to the optical axis in object and/or image space. This means that magnification is nearly constant over a range of working distances, therefore almost eliminating perspective error.

## Erect image

An image in which the orientations of left, right, top, bottom and moving directions are the same as those of a workpiece on the workstage.

## Field number (FN), real field of view, and monitor display magnification

The observation range of the sample surface is determined by the diameter of the eyepiece's field stop. The value of this diameter in millimetres is called the field number (FN). In contrast, the real field of view is the range on the workpiece surface when actually magnified and observed with the objective lens. The real field of view can be calculated with the following formula:

1. The range of the workpiece that can be observed with the microscope (diameter)

$$\text{Real field of view} = \frac{\text{FN of eyepiece}}{\text{Objective lens magnification}}$$

**Example:** The real field of view of a 1X lens is 24 = $\frac{24}{1}$

**Example:** The real field of view of a 10X lens is 2.4 = $\frac{24}{10}$

2. Monitor observation range

$$\text{Monitor observation range} = \frac{\text{The size of the camera image sensor (diagonal length)}}{\text{Objective lens magnification}}$$

| Format | Size of image sensor | | |
|---|---|---|---|
| | Diagonal length | Length | Height |
| 1/3" | 6.0 | 4.8 | 3.6 |
| 1/2" | 8.0 | 6.4 | 4.8 |
| 2/3" | 11.0 | 8.8 | 6.6 |

3. Monitor display magnification

$$\text{Objective lens magnification} = \frac{\text{Display diagonal length on the monitor}}{\text{Diagonal length of camera image sensor}}$$

# Vision measuring machines

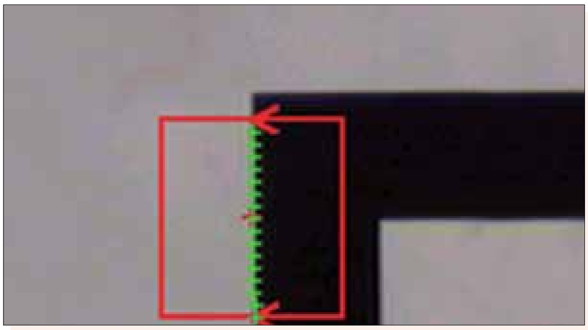


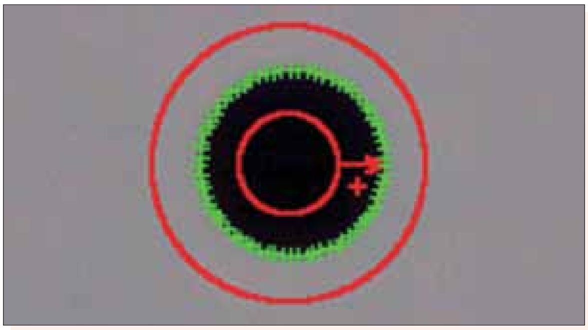
## Vision measurement

Vision measuring machines mainly provide the following processing capabilities.

- Edge detection

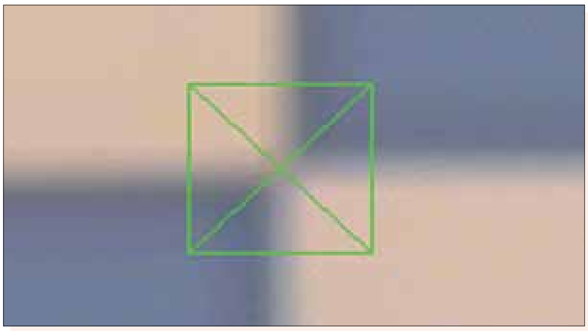
  Detecting/measuring edges in the XY plane.

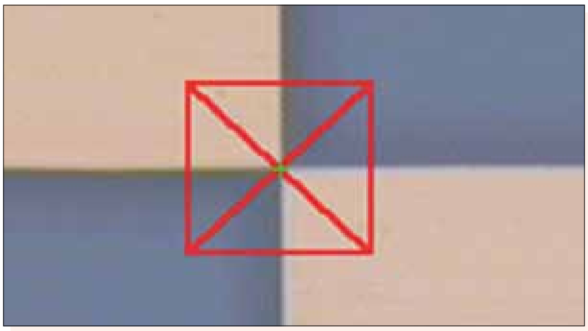




- Auto focusing

  Focusing and Z measurement.



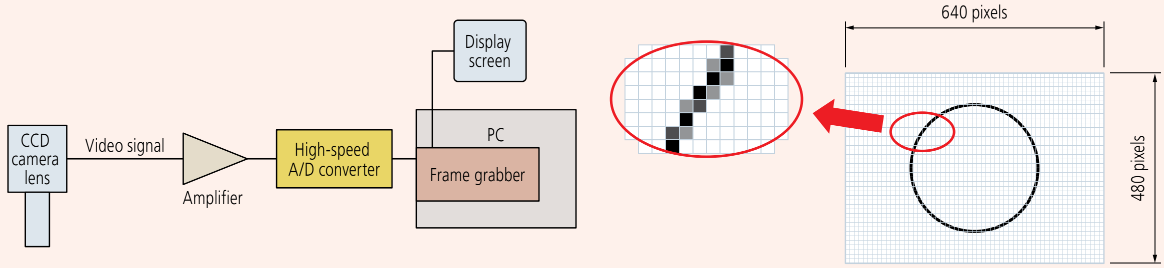


- Pattern recognition

  Alignment, positioning, and checking a feature.

## Image storage

An image is comprised of a regular array of pixels. This is just like a picture on fine plotting paper with each square solid-filled differently.

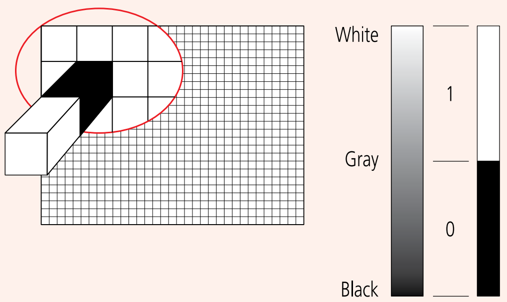


## Grey scale

A PC stores an image after internally converting it to numeric values. A numeric value is assigned to each pixel of an image. Image quality varies depending on how many levels of grey scale are defined by the numeric values. The PC provides two types of grey scale: two-level and multi-level. The pixels in an image are usually displayed as 256-level grey scale.

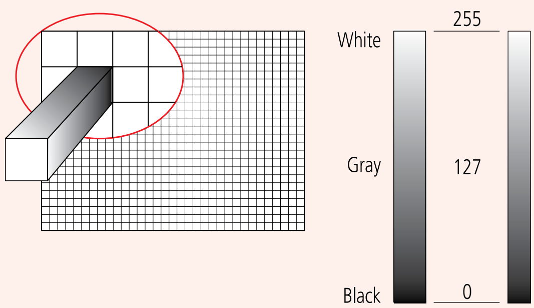


> 2-level grey scale




Pixels in an image brighter than a given level are displayed as white and all other pixels are displayed as black.

> Multi-level grey scale




Each pixel is displayed as one of 256 levels between black and white. This allows high-fidelity images to be displayed.

## Difference in image quality

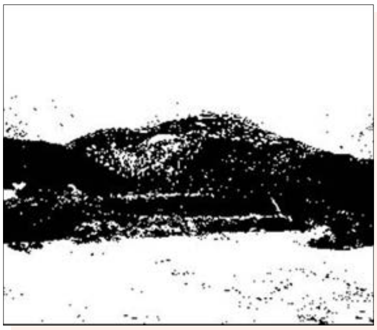
Difference between 2-level and 256-level grey-scale images.

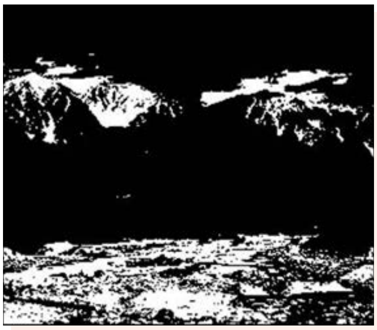
> Sample image displayed in 2-level grey scale.

> Sample image displayed in 256-level grey scale.

## Variation in image depending on threshold level

The three pictures below are the same image displayed as 2-level grey scale at different slice levels (threshold levels). In a 2-level grey-scale image, different images are provided as shown above due to a difference in slice level. Therefore, the 2-level grey scale is not used for high-precision vision measurement since numeric values will change depending on the threshold level that is set.

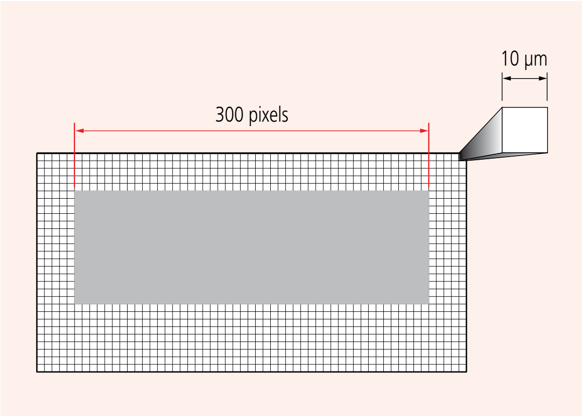




# Vision measuring machines

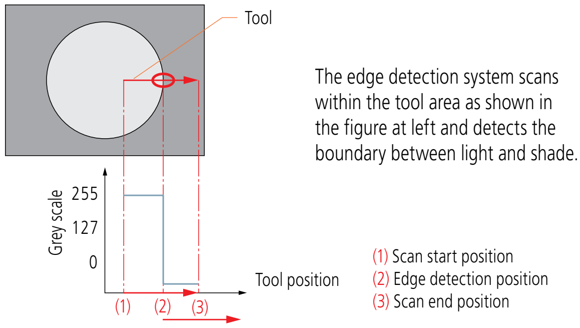
## Dimensional measurement

An image consists of pixels. If the number of pixels in a section to be measured is counted and multiplied by the size of a pixel, then the section can be converted to a numeric value in length. For example, assume that the total number of pixels in the lateral size of a square workpiece is 300 pixels as shown in the figure below. If a pixel size is 10 µm under imaging magnification, the total length of the workpiece is given by 10 µm x 300 pixels = 3000 µm = 3 mm.




## Edge detection

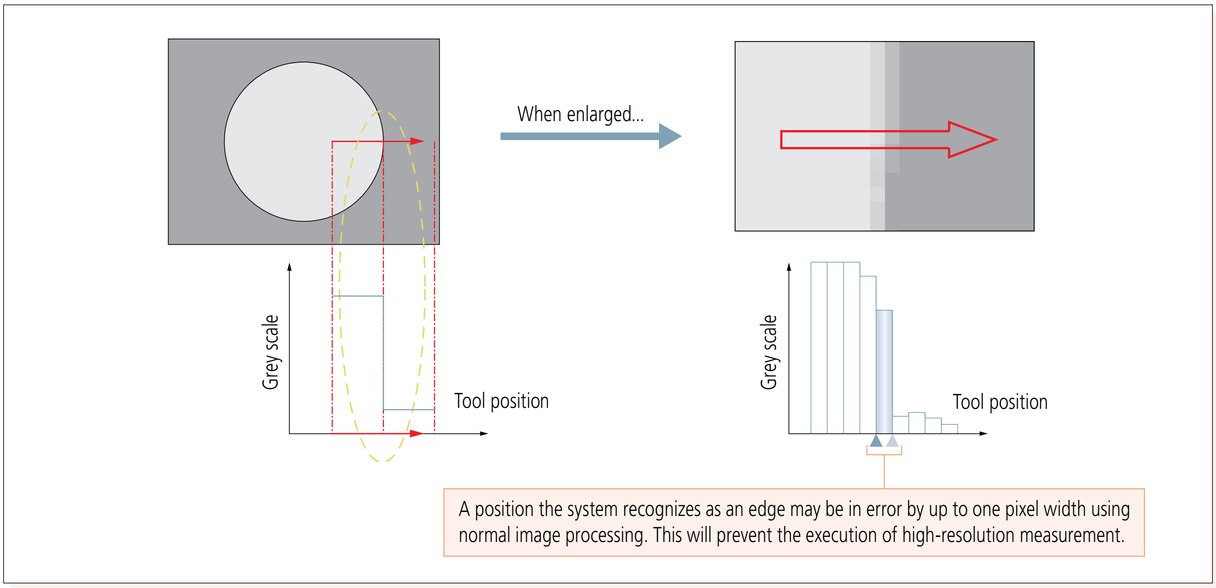
How to actually detect a workpiece edge in an image is described using the following monochrome picture as an example. Edge detection is performed within a given domain. A symbol which visually defines this domain is referred to as a tool. Multiple tools are provided to suit various workpiece geometries or measurement data.




> Example of numeric values assigned to pixels on the tool.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 244 | 241 | 220 | 193 | 97 | 76 | 67 | 52 | 53 | 53 |
| 243 | 242 | 220 | 195 | 94 | 73 | 66 | 54 | 53 | 55 |
| 244 | 246 | 220 | 195 | 94 | 75 | 64 | 56 | 51 | 50 |

## High-resolution measurement




To increase the accuracy in edge detection, sub-pixel image processing is used. An edge is detected by determining interpolation curve from adjacent pixel data as shown below. As a result, it allows measurement with a resolution higher than 1 pixel.

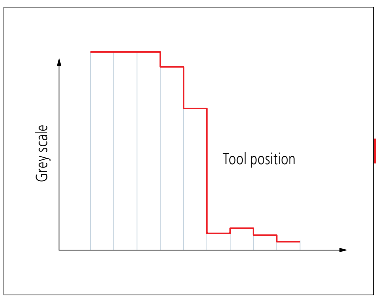



Image signal without sub-pixel processing.

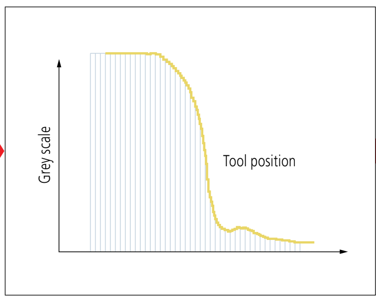
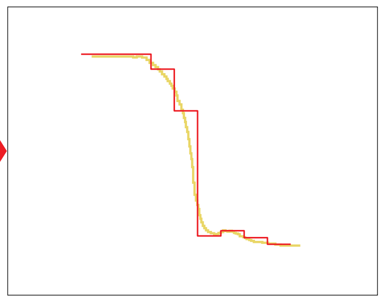


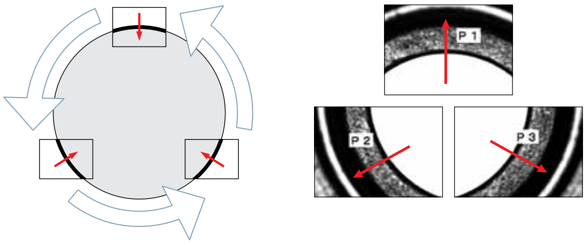

Image signal with sub-pixel processing.



The image signal profile approaches an analogue waveform like this.

## Measurement along multiple portions of an image

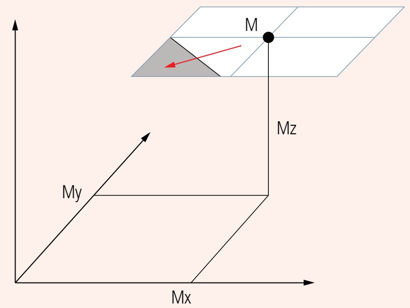
Large features that cannot be contained on one screen have to be measured by precisely controlling the position of the CCD sensor and stage so as to locate each reference point within individual images. By this means the system can measure even a large circle, as shown below, by detecting the edge while moving the stage across various parts of the periphery.




## Composite coordinates of a point

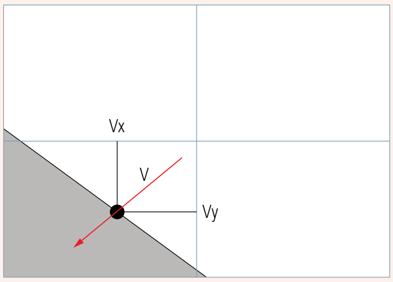
Since measurement is performed while individual measured positions are stored, the system can measure dimensions that cannot be included in one screen, without problems.

> Machine coordinate system




Measuring machine stage position: M = (Mx, My, Mz)

> Vision coordinate system

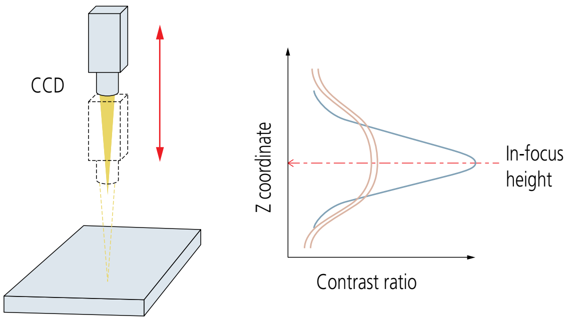



Detected edge position (from the centre of vision): V = (Vx, Vy)

Actual coordinates are given by X = (Mx + Vx), Y = (My + Vy), and Z = Mz, respectively.

## Principle of auto focusing

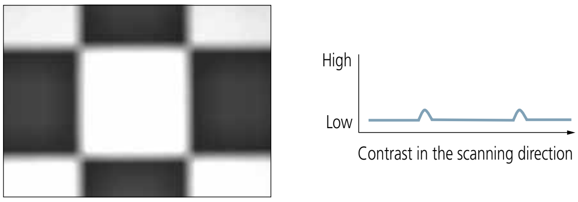
The system can perform XY-plane measurement, but cannot perform height measurement using only the CCD camera image. The system is commonly provided with the Auto Focus (AF) mechanism for height measurement. The following explains the AF mechanism that uses a common image, although some systems may use an AF laser.



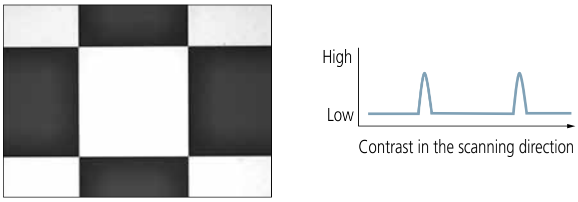

> The AF system analyses an image while moving the CCD up and down in the Z axis. In the analysis of image contrast, an image in sharp focus will show a peak contrast and one out of focus will show a low contrast. Therefore, the height at which the image contrast peaks is the just-in-focus height.

## Variation in contrast depending on the focus condition

Edge contrast is low due to out-of-focus edges.

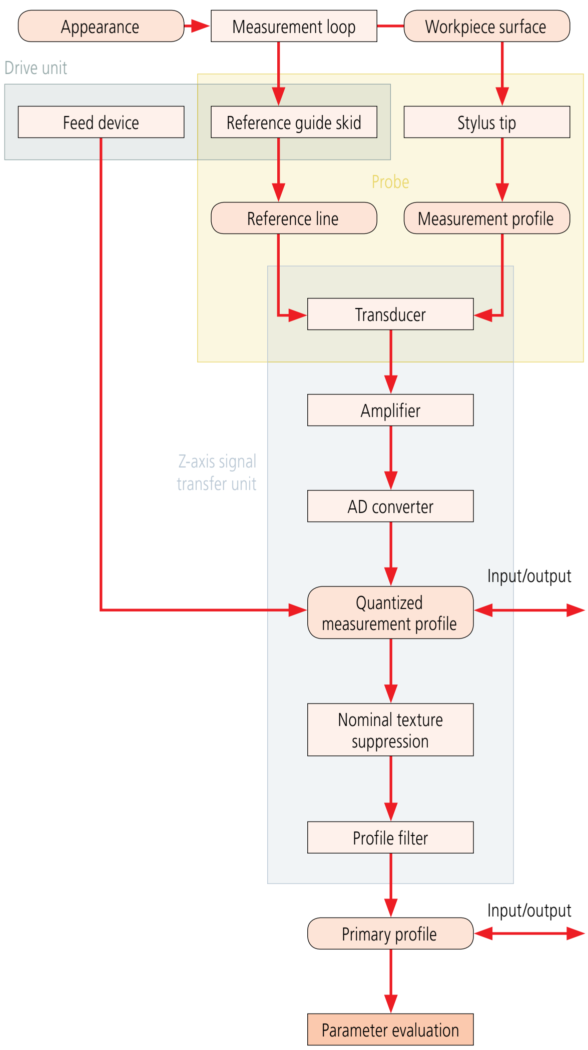



Edge contrast is high due to sharp, in-focus edges.



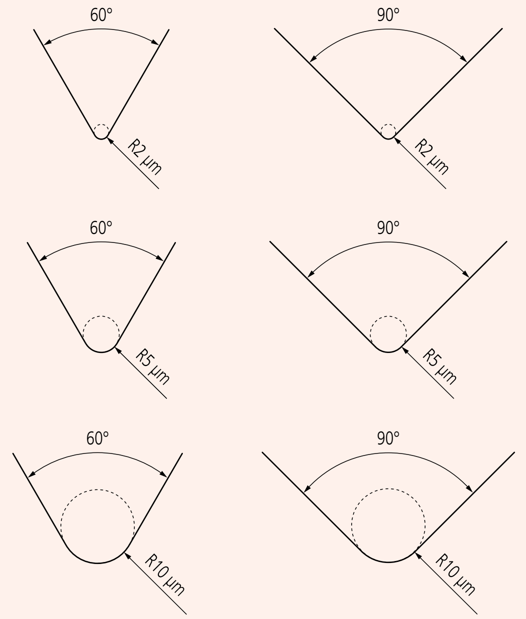
# Surface measurement

## Nominal characteristics of contact (stylus) instruments, ISO 3274: 1996




### Stylus shape

A typical shape for a stylus end is conical with a spherical tip.
Tip radius: $r_{tip}$ = 2 μm, 5 μm or 10 μm
Cone angle: 60°, 90°
In typical surface roughness testers, the taper angle of the stylus end is 60° unless otherwise specified.




### Static measuring force

| Nominal radius of curvature of stylus tip (μm) | Static measuring force at the mean position of stylus (mN) | Tolerance on static measuring force variations (mN/μm) |
|---|---|---|
| 2 | 0.75 | 0.035 |
| 5 | 0.75 (4.0)* | 0.2 |
| 10 | | |

* The maximum value of static measuring force at the average position of a stylus is to be 4.0 mN for a special structured probe including a replaceable stylus.

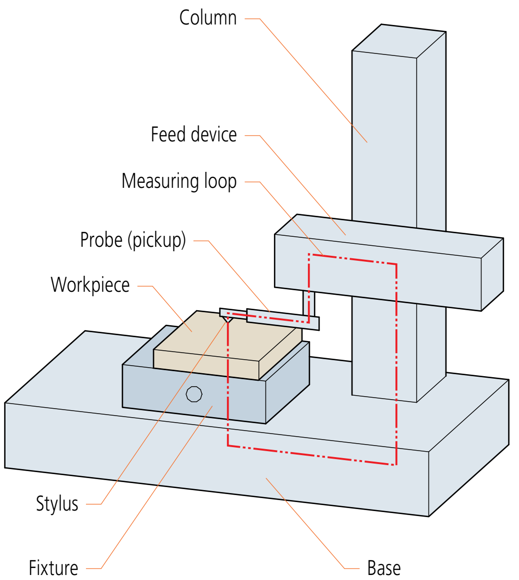
### Relationship between cutoff value and stylus tip radius

The following table lists the relationship between the roughness profile cutoff value λc, stylus tip radius $r_{tip}$, and cutoff ratio λc/λs.

| λc (mm) | λs (μm) | λc/ λs | Maximum $r_{tip}$ (μm) | Maximum sampling length (μm) |
|---|---|---|---|---|
| 0.08 | 2.5 | 30 | 2 | 0.5 |
| 0.25 | 2.5 | 100 | 2 | 0.5 |
| 0.8 | 2.5 | 300 | 2 *1 | 0.5 |
| 2.5 | 8.0 | 300 | 5 *2 | 1.5 |
| 8.0 | 25.0 | 300 | 10 *2 | 5.0 |

*1 For a surface with Ra>0.5 μm or Rz>3 μm, a significant error will not usually occur in a measurement even if $r_{tip}$ = 5 μm.
*2 If a cutoff value λs is 2.5 μm or 8 μm, attenuation of the signal due to the mechanical filtering effect of a stylus with the recommended tip radius appears outside the roughness profile pass band. Therefore, a small error in stylus tip radius or shape does not affect parameter values calculated from measurements. If a specific cutoff ratio is required, the ratio must be defined.

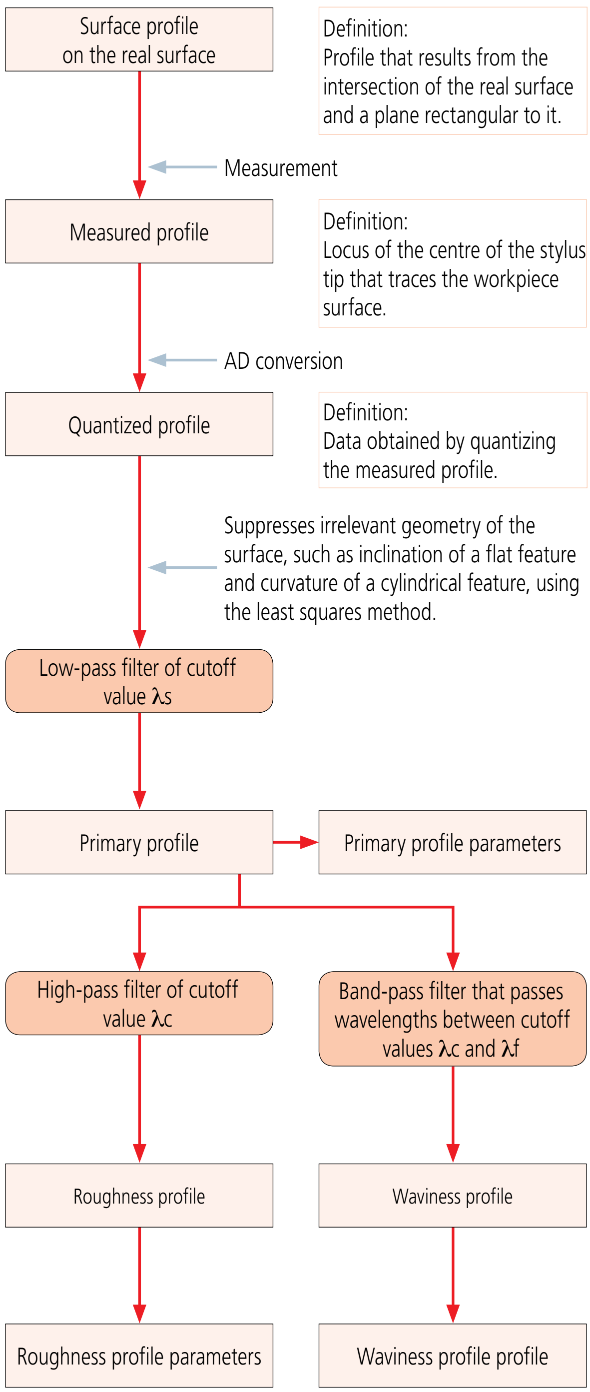
### Elements of a Surface Roughness Tester



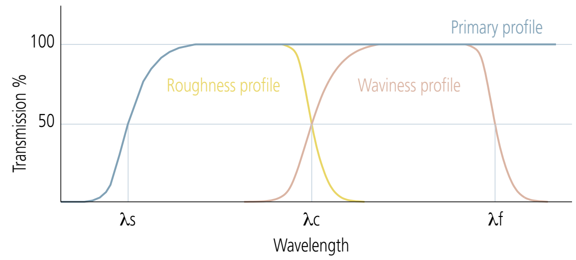
## **Metrological characterization of phase correct filters**, ISO 11562: 1996

A profile filter is a phase-correct filter without phase delay (cause of profile distortion dependent on wavelength). The weight function of a phase-correct filter shows a normal (Gaussian) distribution in which the amplitude transmission is 50% at the cutoff wavelength.

## Data processing flow

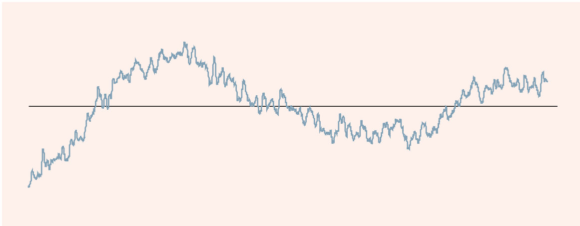



## **Surface profiles**, ISO 4287: 1997



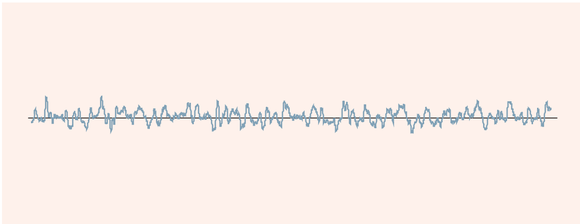

### Primary profile

Profile obtained from the measured profile by applying a low-pass filter with cutoff value λs to remove the shortest wavelength components that are of no relevance to measurement.



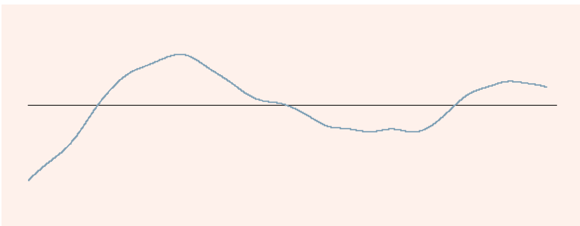
### Roughness profile

Profile obtained from the primary profile by suppressing the longer wavelength components using a high-pass filter of cutoff value λc.



### Waviness profile

Profile obtained by applying a band-pass filter to the primary profile to remove the longer wavelengths above λf and the shorter wavelengths below λc.

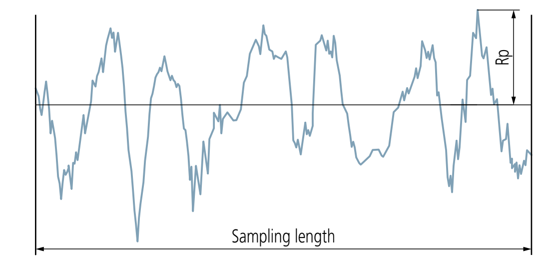


# Surface measurement

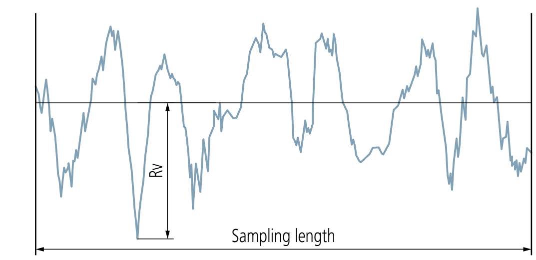
## Definition of parameters, ISO 4287: 1997

### Amplitude parameters (peak and valley)

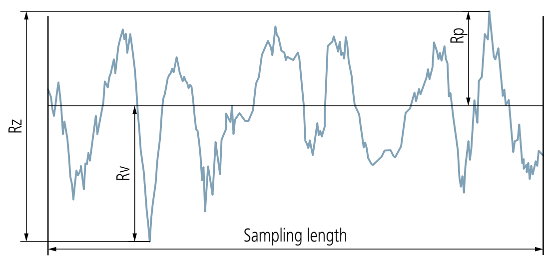
**Maximum peak height of the primary profile *P*p, the roughness profile *R*p and the waviness profile *W*p.**
Largest profile peak height *Z*p within a sampling length.




**Maximum valley depth of the primary profile *P*v, the roughness profile *R*v and the waviness profile *W*v.**
Largest profile valley depth *Z*v within a sampling length.



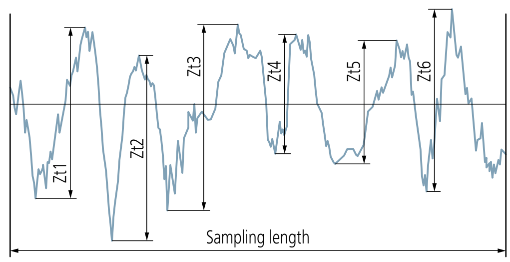

**Maximum height of the primary profile *P*z, the roughness profile *R*z and the waviness profile *W*z.**
Sum of height of the largest profile peak height *Z*p and the largest profile valley depth *Z*v within a sampling length.



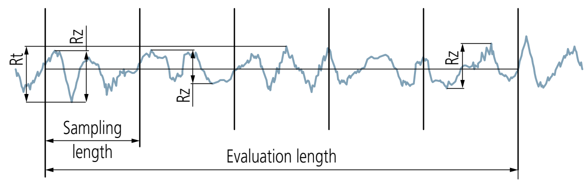

In old JIS and ISO 4287-1: 1984, *Rz* was used to indicate the *ten point height of irregularities*. Care must be taken because differences between results obtained according to the existing and old standards are not always negligibly small. (Be sure to check whether the drawing instructions conform to existing or old standards.)

**Mean height of the primary profile elements *P*c, the roughness profile elements *R*c and the waviness profile elements *W*c.**
Mean value of the profile element heights *Z*t within a sampling length.

$$Pc, Rc, Wc = \frac{1}{m} \sum_{i=1}^{m} Zt_i$$




**Total height of the primary profile *P*t, the roughness profile *R*t and the waviness profile *W*t.**
Sum of the height of the largest profile peak height *Z*p and the largest profile valley depth *Z*v within the evaluation length.




### Amplitude parameters (average of ordinates)

**Arithmetical mean deviation of the primary profile *P*a, the roughness profile *R*a and the waviness profile *W*a.**
Arithmetic mean of the absolute ordinate values *Z*(x) within a sampling length.

$$Pa, Ra, Wa = \frac{1}{l} \int_0^l |Z(x)|dx$$

With *l* as *l*p, *l*r, or *l*w according to the case

**Root mean square deviation of the primary profile *P*q, the roughness profile *R*q and the waviness profile *W*q.**
Root mean square value of the ordinate values *Z*(x) within a sampling length.

$$Pq, Rq, Wq = \sqrt{\frac{1}{l} \int_0^l Z^2(x)dx}$$

With *l* as *l*p, *l*r, or *l*w according to the case

**Skewness of the primary profile *P*sk, the roughness profile *R*sk and the waviness profile *W*sk.**
Quotient of the mean cube value of the ordinate values *Z*(x) and the cube of *P*q, *R*q, or *W*q respectively, within a sampling length.

$$Rsk = \frac{1}{Rq^3}\left[\frac{1}{lr}\int_0^{lr} Z^3(x)dx\right]$$

The above equation defines *R*sk. *P*sk and *W*sk are defined in a similar manner. *P*sk, *R*sk, and *W*sk are measures of the asymmetry of the probability density function of the ordinate values.

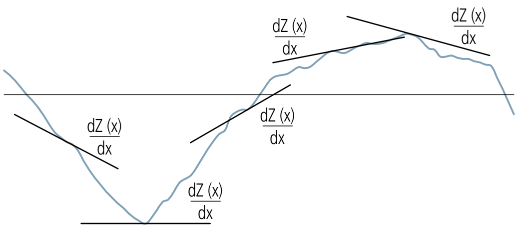
**Kurtosis of the primary profile *P*ku, the roughness profile *R*ku and the waviness profile *W*ku.**
Quotient of the mean quartic value of the ordinate values *Z*(x) and the fourth power of *P*q, *R*q, or *W*q respectively, within a sampling length.

$$Rku = \frac{1}{Rq^4}\left[\frac{1}{lr}\int_0^{lr} Z^4(x)dx\right]$$

The above equation defines *R*ku. *P*ku and *W*ku are defined in a similar manner. *P*ku, *R*ku, and *W*ku are measures of the sharpness of the probability density function of the ordinate values.

## Hybrid parameters

**Root mean square slope of the primary profile *P*Δq, the roughness profile *R*Δq and the waviness profile *W*Δq.**
Root mean square value of the ordinate slopes d*Z*/d*X* within a sampling length.

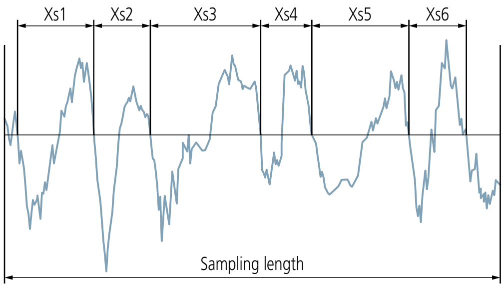




## Spacing parameters

**Mean width of the primary profile elements *P*Sm, the roughness profile elements *R*Sm and the waviness profile elements *W*Sm.**
Mean value of the profile element widths *X*s within a sampling length.

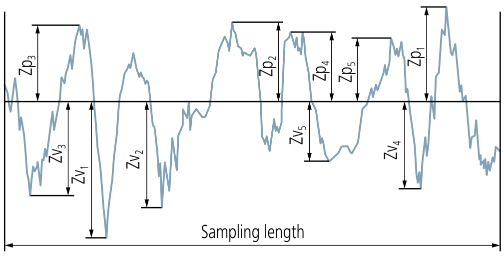
$$PSm, RSm, WSm = \frac{1}{m}\sum_{i=1}^{m} X_{Si}$$




## JIS specific parameters

**Ten-point height of irregularities, $Rz_{JIS}$.**
Sum of the absolute mean height of the five highest profile peaks and the absolute mean depth of the five deepest profile valleys, measured from the mean line within the sampling length of a roughness profile. This profile is obtained from the primary profile using a phase-correct band-pass filter with cutoff values of *l*c and *l*s.

$$Rz_{JIS} = \frac{(Zp_1 + Zp_2 + Zp_3 + Zp_4 + Zp_5) + (Zv_1 + Zv_2 + Zv_3 + Zv_4 + Zv_5)}{5}$$




| Symbol | Profile used |
|---|---|
| $Rz_{JIS}82$ | Surface profile as measured |
| $Rz_{JIS}94$ | Roughness profile derived from the primary profile using a phase-correct high-pass filter |

**Arithmetic mean deviation of the profile $Ra_{75}$.**
Arithmetic mean of the absolute values of the profile deviations from the mean line within the sampling length of the roughness profile (75%). This profile is obtained from a measurement profile using an analogue high-pass filter with an attenuation factor of 12db/octave and a cutoff value of λc.

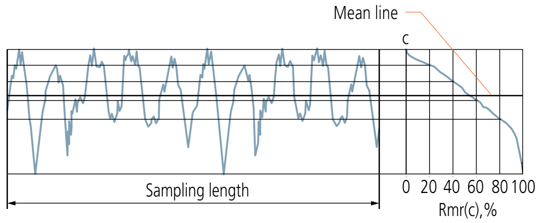
$$Ra_{75} = \frac{1}{ln}\int_0^{ln} |Z(x)|dx$$

# Surface measurement

## Definition of parameters (cont.)

### Curves, probability density function and related parameters

**Material ratio curve of the profile (Abbott-Firestone curve).**
Curve representing the material ratio of the profile as a function of section level c.

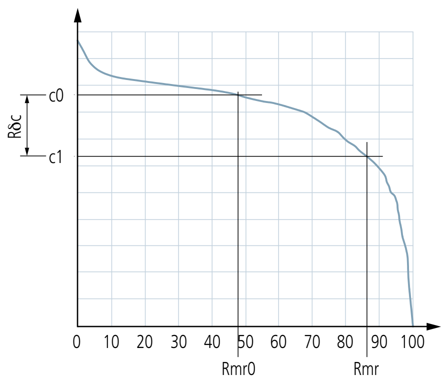



**Material ratio of the primary profile *Pmr*(c), the roughness profile *Rmr*(c) and the waviness profile *Wmr*(c).**
Ratio of the material length of the profile elements M*l*(c) at a given level c to the evaluation length.

$$Pmr(c), Rmr(c), Wmr(c) = \frac{Ml(c)}{ln}$$

**Section height difference of the primary profile *P*δc, the roughness profile *R*δc and the waviness profile *W*δc.**
Vertical distance between two section levels of a given material ratio.

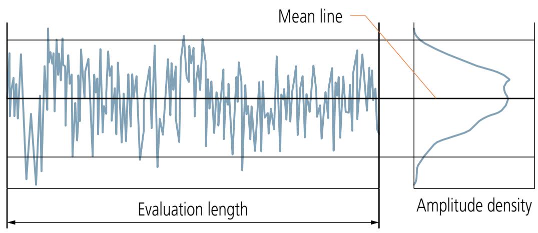
$$P\delta c = c\,(Rmr1) - c\,(Rmr2);\ Rmr1 < Rmr2$$




**Relative material ratio of the primary profile *Pmr*, the roughness profile *Rmr* and the waviness profile *Wmr*.**
Material ratio determined at a profile section level Rδc (or Pδc or Wδc), related to the reference section level c0.

$$Pmr, Rmr, Wmr = Pmr\,(c1), Rmr\,(c1), Wmr\,(c1)$$
where $c1 = c0 - R\delta c\ (R\delta c, W\delta c)$
$c0 = c\,(Pm0, Rmr0, Wmr0)$

**Probability density function (profile height amplitude distribution curve).**
Sample probability density function of the ordinate Z(x) within the evaluation length.




## Sampling length for surface roughness parameters, ISO 4288: 1996

**Table 1**: Sampling lengths for aperiodic profile roughness parameters (*Ra*, *Rq*, *Rsk*, *Rku*, *R*Δq), material ratio curve, probability density function, and related parameters.

| *Ra* (µm) | Sampling length *lr* (mm) | Evaluation length *ln* (mm) |
|---|---|---|
| (0.006)<*Ra*≤0.02 | 0.08 | 0.4 |
| 0.02<*Ra*≤0.1 | 0.25 | 1.25 |
| 0.1<*Ra*≤2 | 0.8 | 4.0 |
| 2<*Ra*≤10 | 2.5 | 12.5 |
| 10<*Ra*≤80 | 8.0 | 40.0 |

**Table 2**: Sampling lengths for aperiodic profile roughness parameters (*Rz*, *Rv*, *Rp*, *Rc*, *Rt*).

| *Rz*, *Rz*1max. (µm) | Sampling length *lr* (mm) | Evaluation length *ln* (mm) |
|---|---|---|
| (0.025)<*Rz*, *Rz*1max.≤0.1 | 0.08 | 0.4 |
| 0.1<*Rz*, *Rz*1max.≤0.5 | 0.25 | 1.25 |
| 0.5<*Rz*, *Rz*1max.≤10 | 0.8 | 4.0 |
| 10<*Rz*, *Rz*1max.≤50 | 2.5 | 12.5 |
| 50<*Rz*, *Rz*1max.≤200 | 8.0 | 40.0 |

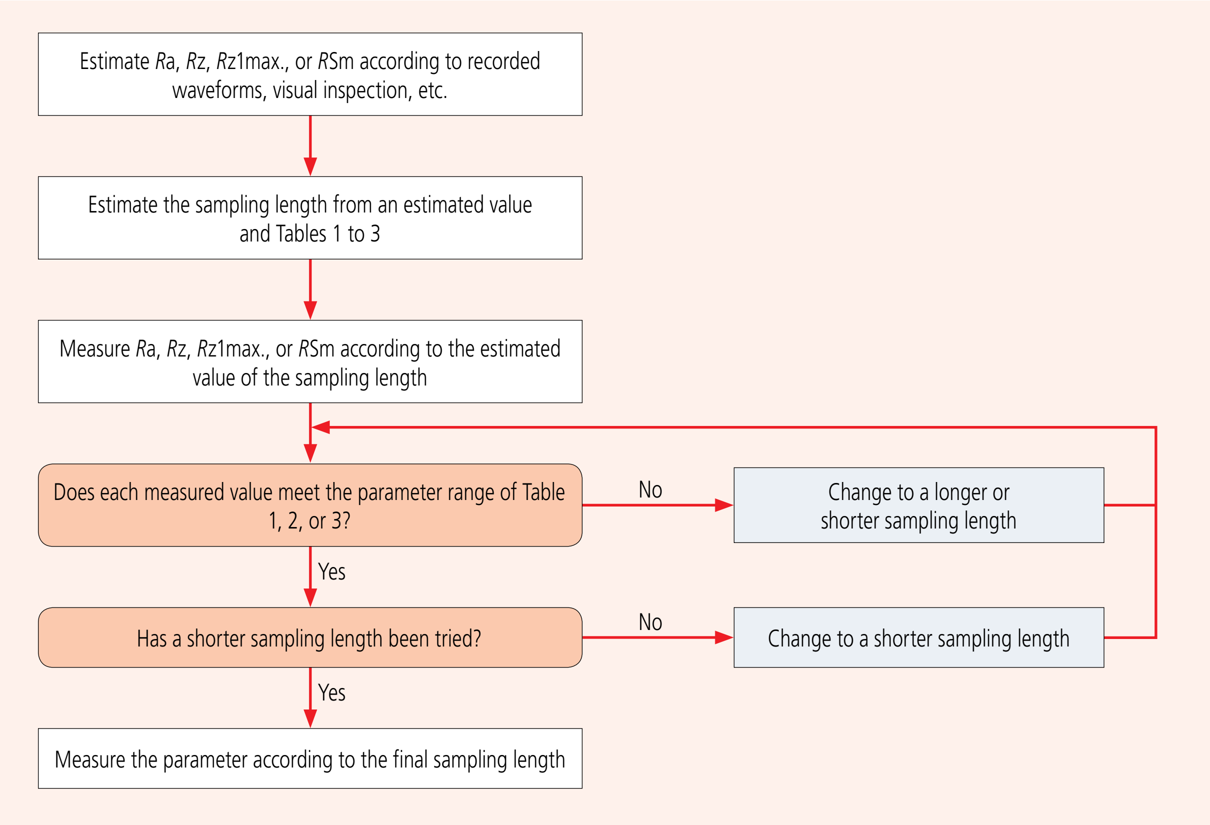
1) *Rz* is used for measurement of *Rz*, *Rv*, *Rp*, *Rc*, and *Rt*.
2) *Rz*1max. only used for measurement of *Rz*1max., *Rv*1max., *Rp*1max., and *Rc*1max.

**Table 3**: Sampling lengths for measurement of periodic roughness profile roughness parameters and periodic or aperiodic profile parameter *Rsm*.

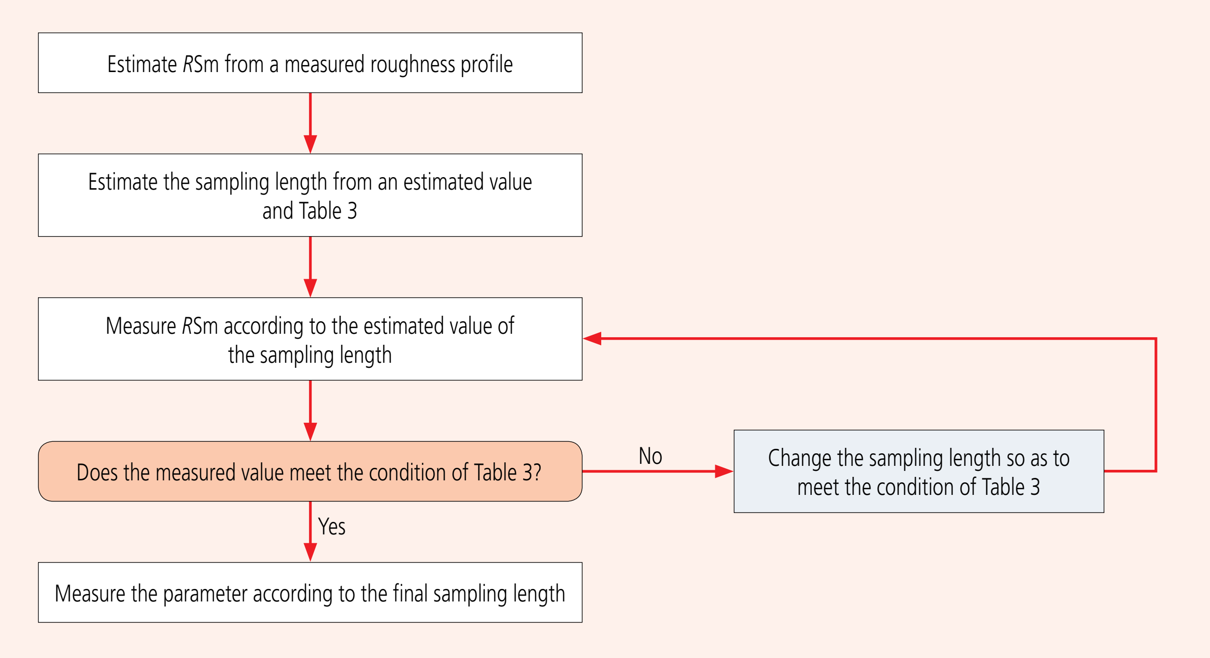
| *Rsm* (mm) | Sampling length *lr* (mm) | Evaluation length *ln* (mm) |
|---|---|---|
| 0.013<*Rsm*≤0.04 | 0.08 | 0.4 |
| 0.04<*Rsm*≤0.13 | 0.25 | 1.25 |
| 0.13<*Rsm*≤0.4 | 0.8 | 4.0 |
| 0.4<*Rsm*≤1.3 | 2.5 | 12.5 |
| 1.3<*Rsm*≤4 | 8.0 | 40.0 |

Procedure for determining a sampling length

> **Fig 1**: Procedure for determining the sampling length of an aperiodic profile if it is not specified.




> **Fig 2**: Procedure for determining the sampling length of a periodic profile if it is not specified.

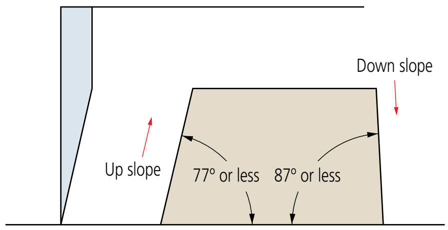


# Contour measurement



## Traceable angle

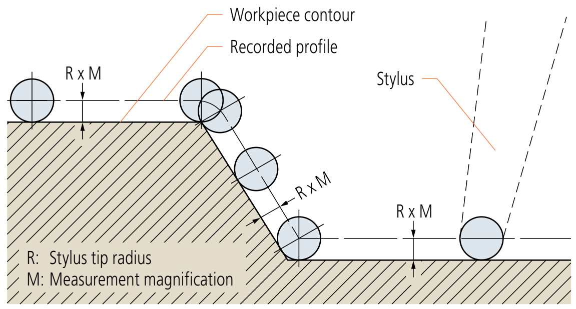
The maximum angle at which a stylus can trace upwards or downwards along the contour of a workpiece, in the stylus travel direction, is referred to as the traceable angle. A one-sided sharp stylus with a tip angle of 12° (as in the figure) below can trace a maximum 77° of up slope and a maximum 87° of down slope. For a conical stylus (30° cone), the traceable angle is smaller. An up slope with an angle of 77° or less overall may actually include an angle of more than 77° due to the effect of surface roughness. Surface roughness also affects the measuring force.




Example: For models CV-3200/4500, the same type of stylus (SPH-71: one-sided sharp stylus with a tip angle of 12°) can trace a maximum 77° up slope and a maximum 83° down slope.

## Compensating for stylus tip radius

A recorded profile represents the locus of the centre of the ball tip rolling on a workpiece surface. (A typical radius is 0.025 mm.) Obviously this is not the same as the true surface profile so, in order to obtain an accurate profile record, it is necessary to compensate for the effect of the tip radius through data processing.




If a profile is read from the recorder through a template or scale, it is necessary to compensate for the stylus tip radius beforehand according to the applied measurement magnification.

## Accuracy

As the detector units of the X and Z axes incorporate scales, the magnification accuracy is displayed not as a percentage but as the linear displacement accuracy for each axis.

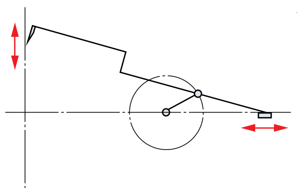
## Simple or complex arm guidance

In the case of a simple pivoted arm, the locus that the stylus tip traces during vertical movement (Z direction) is a circular arc that results in an unwanted offset in X, for which compensation has to be made. The larger the arc movement, the larger is the unwanted X displacement (δ) that has to be compensated (see figure below). The alternative is to use a complex mechanical linkage arrangement to obtain a linear translation locus in Z, and therefore avoid the need to compensate in X.

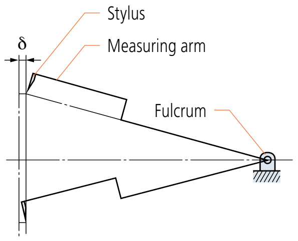
## Compensating for arm rotation

The stylus is carried on a pivoted arm so it rotates as the surface is traced and the contact tip does not track purely in the Z direction. Therefore it is necessary to apply compensation in the X direction to ensure accuracy. There are three methods of compensating for arm rotation.

*1: Mechanical compensation*



*2: Electrical compensation or 3: Software processing*




δ: Unwanted displacement in X to be compensated

To measure a workpiece contour that involves a large displacement in the vertical direction with high accuracy, one of these compensation methods needs to be implemented.

## Z axis measurement methods

Though the X axis measurement method commonly adopted is by means of a digital scale, the Z axis measurement divides into analogue methods (using a differential transformer, etc.) and digital scale methods. Analogue methods vary in Z axis resolution depending on the measurement magnification and measuring range. Digital scale methods have fixed resolution. Generally, a digital scale method provides higher accuracy than an analogue method.

## Overload safety cutout

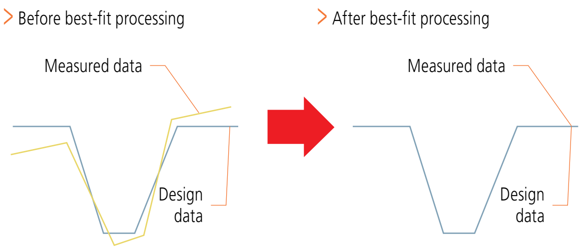
If an excessive force (overload) is exerted on the stylus tip due, perhaps, to the tip encountering a too-steep slope on a workpiece feature, or a burr, etc., a safety device automatically stops operation and sounds an alarm buzzer. This type of instrument is commonly equipped with separate safety devices for the tracing direction (X axis) load and vertical direction (Y axis) load. For example, models CV-3200/4500 are fitted with a safety device that functions if the arm comes off the detector mount.

## Contour analysis

The measured contour is input into the data processing section in real time and a dedicated program performs the analysis, controlled through the mouse and/or keyboard. Angle, radius, step, pitch and other data are directly displayed as numerical values. Analysis combining coordinate systems can be easily performed. Stylus tip-radius correction is applied and the result is output to a printer as the recorded profile.

## Best-fitting

If there is a standard for surface profile data, tolerancing with design data is performed according to the standard. If there is no standard, or if tolerancing only with shape is desired, best-fitting between design data and measurement data can be performed.



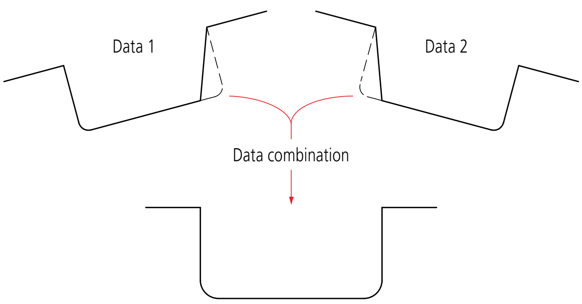

The best-fit processing algorithm searches for deviations between both sets of data and derives a coordinate system in which the sum of squares of the deviations is a minimum when the measured data is overlaid on the design data.

## Tolerancing with design data

Measured workpiece contour data can be compared with design data in terms of actual and designed shapes rather than just analysis of individual dimensions. In this technique each deviation of the measured contour from the intended contour is displayed and recorded. Also, data from one workpiece example can be processed so as to become the master design data to which other workpieces are compared. This function is particularly useful when the shape of a section greatly affects product performance, or when its shape has an influence on the relationship between mating or assembled parts.

## Data combination

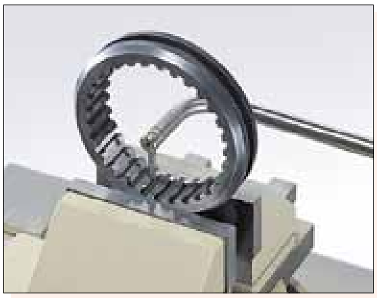
Conventionally, if tracing a complete contour is prevented by stylus traceable-angle restrictions then it has to be divided into several sections that are then measured and evaluated separately. This function avoids this undesirable situation by combining the separate sections into one contour by overlaying common elements (lines, points) onto each other. With this function the complete contour can be displayed and various analyses performed in the usual way.




## Measurement examples

> Aspheric lens contour.

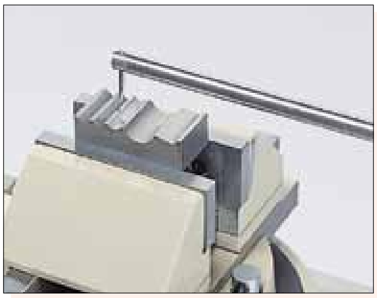
> Inner/outer ring contour of a bearing.



> Internal gear teeth.

> Female thread form.

> Male thread form.



> Gauge contour.

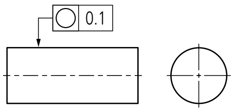
# Roundform measurement

The following overview is based on the ISO 1101: 2012 and ISO 4291: 1985 standards. Refer to these standards for more detail if required.

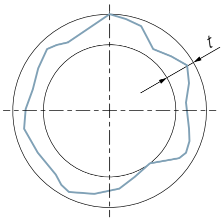
## ○ Roundness

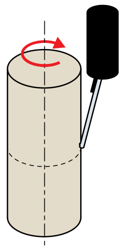
Any circumferential line must be contained within the tolerance zone formed between two coplanar circles with a difference in radii of *t*.

> Notation example.




> Tolerance zone.



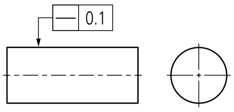



> Verification example using a roundness tester.

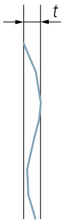
## — Straightness

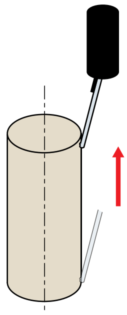
Any line on the surface must lie within the tolerance zone formed between two parallel straight lines a distance *t* apart and in the direction specified

> Notation example.




> Tolerance zone.



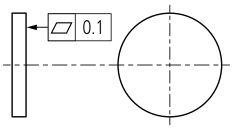



> Verification example using a roundness tester.

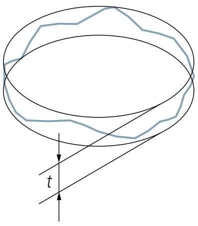
## ▱ Flatness

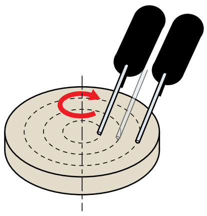
The surface must be contained within the tolerance zone formed between two parallel planes a distance *t* apart.

> Notation example.




> Tolerance zone.



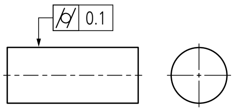



> Verification example using a roundness tester.

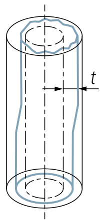
## ⌭ Cylindricity

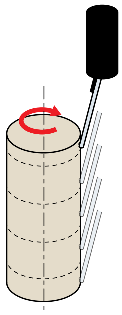
The surface must be contained within the tolerance zone formed between two coaxial cylinders with a difference in radii of *t*.

> Notation example.




> Tolerance zone.



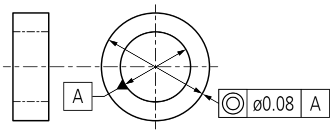



> Verification example using a roundness tester.

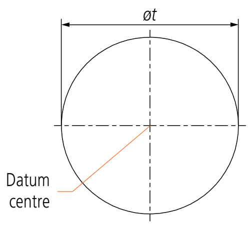
## ◎ Concentricity

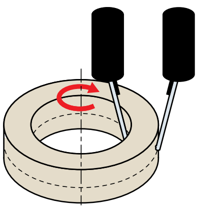
The centre point must be contained within the tolerance zone formed by a circle of diameter *t* concentric with the datum.

> Notation example.




> Tolerance zone.



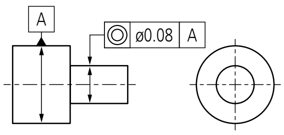



> Verification example using a roundness tester.

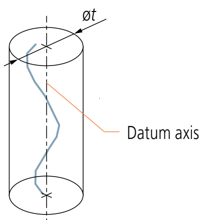
## ◎ Coaxiality

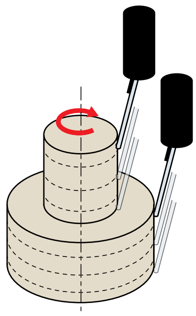
The axial line must be contained within the tolerance zone formed by a cylinder of diameter *t* concentric with the datum.

> Notation example.




> Tolerance zone.



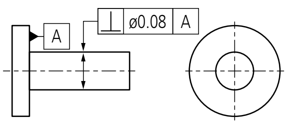



> Verification example using a roundness tester.

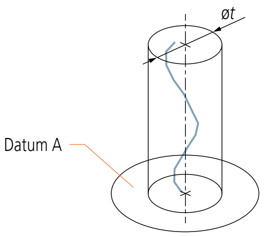
## ⊥ Perpendicularity

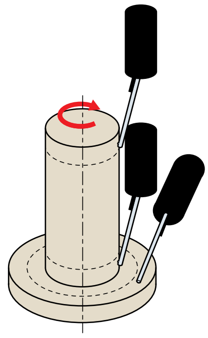
The line or surface must be contained within the tolerance zone formed by a cylinder of diameter *t* perpendicular to the datum or between two planes a distance *t* apart perpendicular to the datum.

> Notation example: Axis-to-Plane.



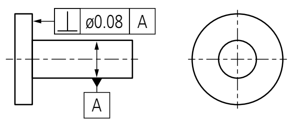

> Tolerance zone.



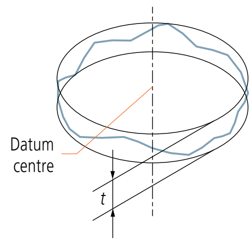



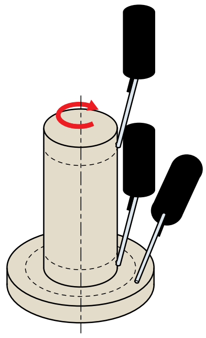
> Verification example using a roundness tester.

> Notation example: Plane-to-Axis.




> Tolerance zone.



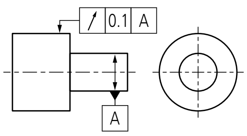



> Verification example using a roundness tester.

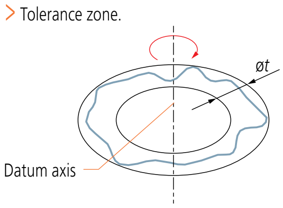
## ↗ Circular runout

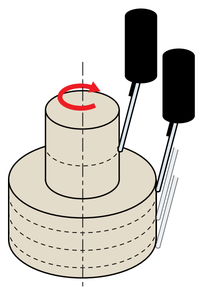
The line must be contained within the tolerance zone formed between two coplanar and/or concentric circles a distance *t* apart concentric with the datum.

> Notation example: Radial.



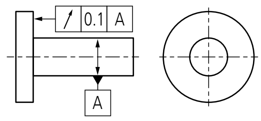

> Tolerance zone.



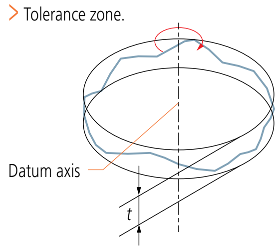



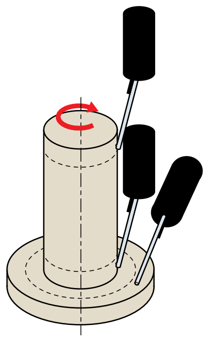
> Verification example using a roundness tester.

> Notation example: Axial.




> Tolerance zone.



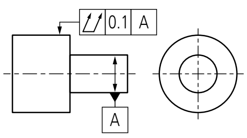



> Verification example using a roundness tester.

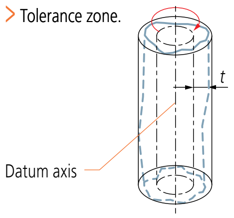
## ⌰ Total runout

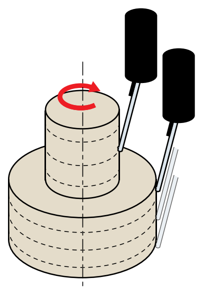
The surface must be contained within the tolerance zone formed between two coaxial cylinders with a difference in radii of *t*, or planes a distance *t* apart, concentric with or perpendicular to the datum.

> Notation example: Radial.



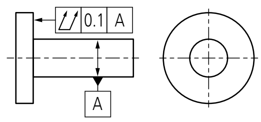

> Tolerance zone.



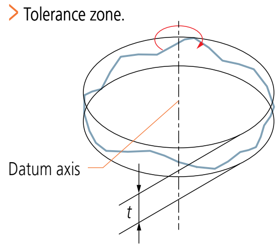



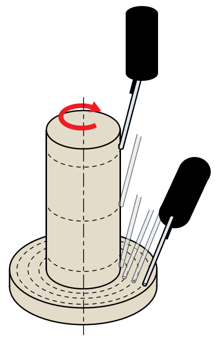
> Verification example using a roundness tester.

> Notation example: Axial.




> Tolerance zone.



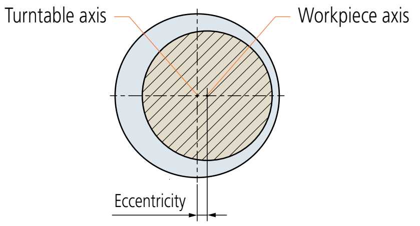
> Verification example using a roundness tester.

# Roundform measurement

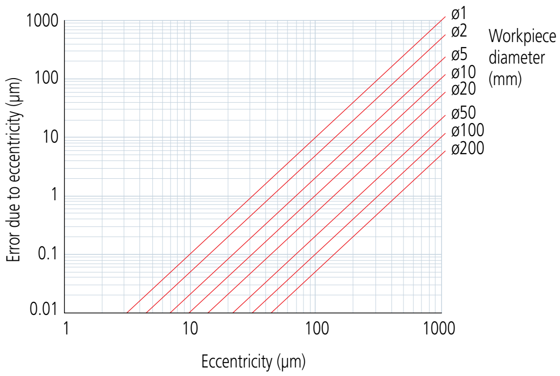
## Adjustment prior to measurement

### Centering

A displacement offset (eccentricity) between the turntable axis of a roundness tester and that of the workpiece results in distortion of the measured form (limaçon error) and consequentially produces an error in the calculated roundness value. The larger the eccentricity, the larger is the error in calculated roundness. Therefore the workpiece should be centered (axes made coincident) before measurement. Some roundness testers support accurate measurement with a limaçon error correction function. The effectiveness of this function can be seen in the graph below.

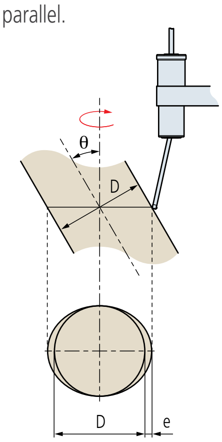



> Effect of eccentricity compensation function

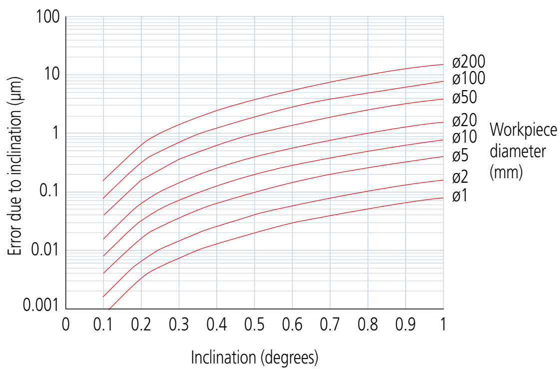



### Levelling

Any inclination (θ) of the axis of a workpiece with respect to the rotational axis of the measuring instrument will cause an elliptic error (e) in the roundness value. Levelling must be performed so that these axes are sufficiently parallel.



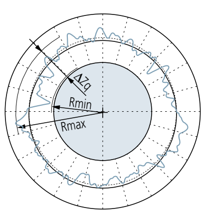

> Inclination versus elliptic error




## Evaluating the measured profile roundness

Roundness (*RON*t) testers use the measurement data to generate reference circles whose dimensions define the roundness value. There are four methods of generating these circles, as shown below, and as each method has individual characteristics the method that best matches the function of the workpiece should be chosen.

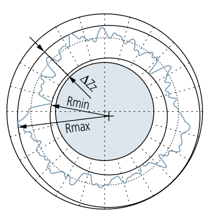
> Least squares circle method (LSCI)




*RON*t = Rmax - Rmin

A circle is fitted to the measured profile such that the sum of the squares of the departure of the profile data from this circle is a minimum. The roundness figure is then defined as the difference between the maximum departures of the profile from this circle (highest peak to the lowest valley).

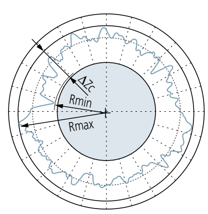
> Minimum zone circles method (MZCI)




*RON*t = Rmax - Rmin

Two concentric circles are positioned to enclose the measured profile such that their radial difference is a minimum. The roundness figure is then defined as the radial separation of these two circles.

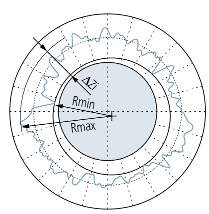
> Minimum circumscribed circle method (MCCI)




*RON*t = Rmax - Rmin

The smallest circle that can enclose the measured profile is created. The roundness figure is then defined as the maximum departure of the profile from this circle. This circle is sometimes referred to as the *ring gauge* circle.

> Maximum inscribed circle method (MICI)



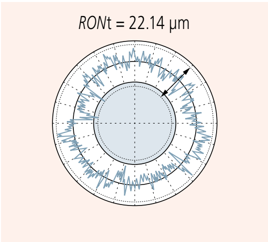

*RON*t = Rmax - Rmin

The largest circle that can be enclosed by the profile data is created. The roundness figure is then defined as the maximum departure of the profile from this circle. This circle is sometimes referred to as the *plug gauge* circle.

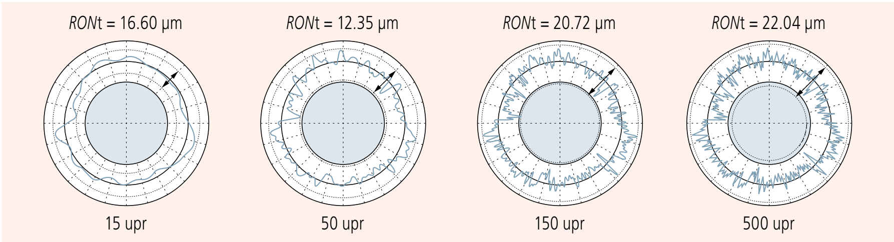
## Effect of filter settings on the measured profile

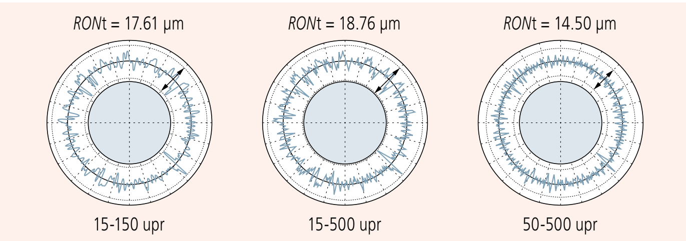
Roundness (*RON*t) values as measured are greatly affected by variation of filter cutoff value. It is necessary to set the filter appropriately for the evaluation required.

> No filtering




> Low-pass filtering

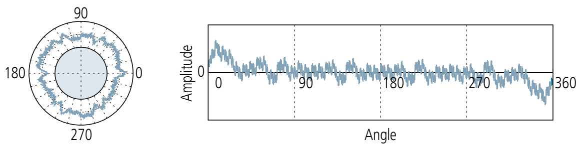


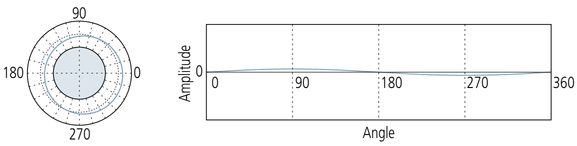

> Band-pass filtering

## Interpreting waviness in the measured profile

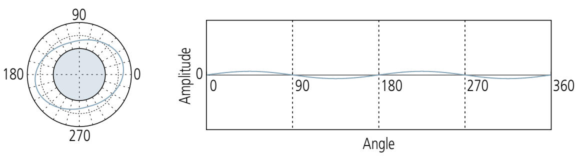
> **Unfiltered measurement result**



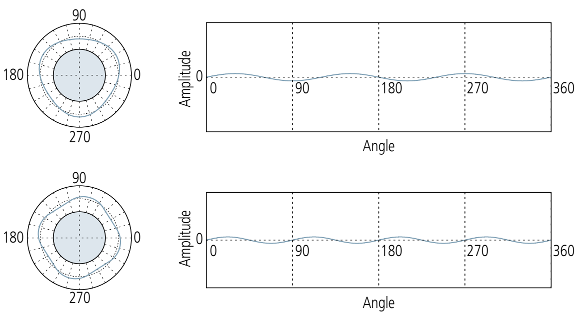

A 1 UPR condition indicates eccentricity of the workpiece relative to the rotational axis of the measuring instrument. The amplitude of undulation components depends on the levelling adjustment



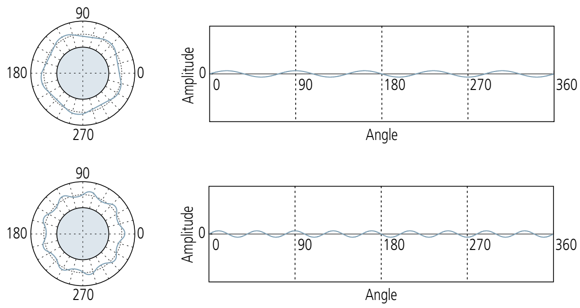

A 2 UPR condition may indicate: (1) insufficient levelling adjustment on the measuring instrument; (2) circular runout due to incorrect mounting of the workpiece on the machine tool that created its shape; (3) the form of the workpiece is elliptical by design as in, for example, an IC-engine piston.



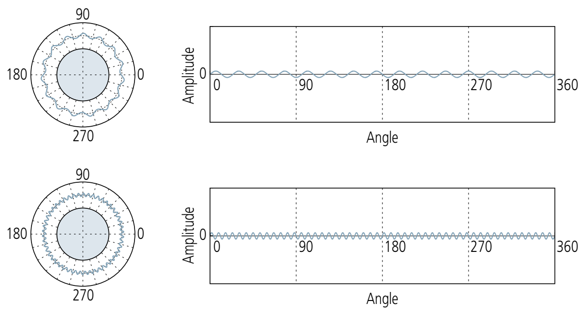

A 3 to 4 UPR condition may indicate: (1) Deformation due to over-tightening of the holding chuck on the measuring instrument; (2) Relaxation deformation due to stress release after unloading from the holding chuck on the machine tool that created its shape.




A 5 to 14 UPR condition often indicates unbalance factors in the machining method or processes used to produce the workpiece.




A 15 (or more) UPR condition is usually caused by tool chatter, machine vibration, coolant delivery effects, material non-homogeneity, etc., and is generally more important to the function than to the fit of a workpiece.



# Hardness testing

## Hardness test methods and guidelines for selection of a hardness testing machine

| | Factors to consider | Test method: Micro hardness (Micro-Vickers) | Micro surface material characteristics | Vickers | Rockwell | Rockwell Superficial | Brinell | Shore | For sponge, rubber, and plastic | Rebound type portable |
|---|---|---|---|---|---|---|---|---|---|---|
| Material | IC wafer | ● | ● | | | | | | | |
| | Carbide, ceramics (cutting tool) | | ▲ | ● | ● | | | | | |
| | Steel (heat-treated material, raw material) | ● | ▲ | ● | ● | ● | | ● | | ● |
| | Non-ferrous metal | ● | ▲ | ● | ● | ● | | | | ● |
| | Plastic | | ▲ | | ● | | | | ● | |
| | Grinding stone | | | | ● | | | | | |
| | Casting | | | | | | ● | | | |
| | Sponge, rubber | | | | | | | | ● | |
| Form | Thin metal sheet (safety razor, metal foil) | ● | ● | ● | | ● | | | | |
| | Thin film, plating, painting, surface layer (nitrided layer) | ● | ● | | | | | | | |
| | Small parts, acicular parts (clock hand, sewing-machine needle) | ● | ▲ | | | | | | | |
| | Large specimen (structure) | | | | | | ● | ● | | ● |
| | Metallic material configuration (hardness for each phase of multi-layer alloy) | ● | ● | | | | | | | |
| | Plastic plate | ▲ | ▲ | | ● | | | | ● | |
| | Sponge, rubber plate | | | | | | | | ● | |
| Application | Strength or physical property of materials | ● | ● | ● | ● | ● | ● | ● | ● | ▲ |
| | Heat treatment process | ● | | ● | ● | ● | | ▲ | | ▲ |
| | Carburized case depth | ● | | ● | | | | | | |
| | Decarburized layer depth | ● | | ● | | ● | | | | |
| | Flame or high-frequency hardening layer depth | ● | | ● | ● | | | | | |
| | Hardenability test | | | ● | ● | | | | | |
| | Maximum hardness of a welded spot | | | ● | | | | | | |
| | Weld hardness | | | ● | ● | | | | | |
| | High-temperature hardness (high-temperature characteristics, hot-workability) | | | ● | | | | | | |
| | Fracture toughness (ceramics) | ● | | ● | | | | | | |

Key: ● = Very suitable, ▲ = Suitable

## Methods of hardness measurement

### 1) Vickers

Vickers hardness is a test method that has the widest application range, allowing hardness inspection with an arbitrary test force. This test has an extremely large number of application fields particularly for hardness tests conducted with a test force less than 9.807N (1 kgf). As shown in the following formula, Vickers hardness is a value determined by dividing test force F (N) by contact area S ($mm^2$) between a specimen and an indenter, which is calculated from diagonal length *d* (mm, mean of two directional lengths) of an indentation formed by the indenter (a square pyramidal diamond, opposing face angle $\theta = 136°$) in the specimen using a test force F (N). *k* is a constant (1/g = 1/9.80665).

$$HV = k\frac{F}{S} = 0.102\frac{F}{S} = 0.102\frac{2F\sin\frac{\theta}{2}}{d^2} = 0.1891\frac{F}{d^2}$$

F : N
d : mm

The error in the calculated Vickers hardness is given by the following formula. Here, $\Delta d1$, $\Delta d2$, and *a* represent the measurement error that is due to the microscope, an error in reading an indentation, and the length of an edge line generated by opposing faces of an indenter tip, respectively. The unit of $\Delta\theta$ is degrees.

$$\frac{\Delta HV}{HV} \cong \frac{\Delta F}{F} - 2\left(\frac{\Delta d1 + \Delta d2}{d}\right) - \frac{a^2}{d^2}\, 3.5 \times 10^{-3}\Delta\theta$$

### 2) Knoop

As shown in the following formula, Knoop hardness is a value obtained by dividing test force by the projected area A ($mm^2$) of an indentation, which is calculated from the longer diagonal length *d* (mm) of the indentation formed by pressing a rhomboidal diamond indenter (opposing edge angles of 172°30' and 130°) into a specimen with test force F applied. Knoop hardness can also be measured by replacing the Vickers indenter of a micro hardness testing machine with a Knoop indenter.

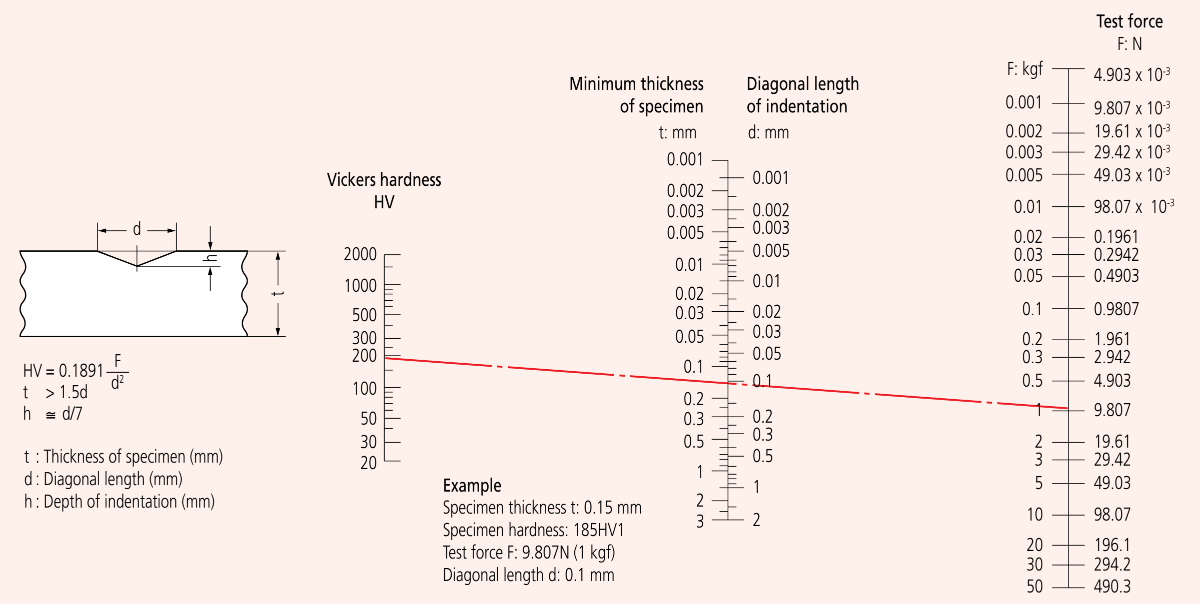
$$HK = k\frac{F}{A} = 0.102\frac{F}{A} = 0.102\frac{F}{cd^2} = 1.451\frac{F}{d^2}$$

F : N
d : mm
c : constant

### 3) Rockwell and Rockwell Superficial

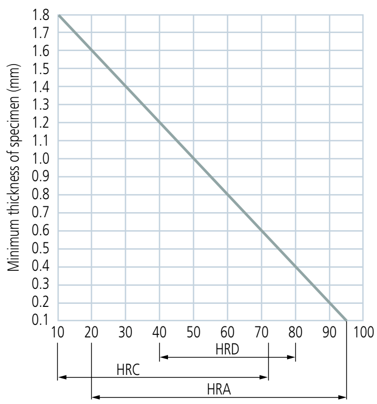
To measure Rockwell or Rockwell Superficial hardness, first apply a preload force and then the test force to a specimen and return to the preload force using a diamond indenter (tip cone angle: 120°, tip radius: 0.2 mm) or a sphere indenter (steel ball or carbide ball). This hardness value is obtained from the hardness formula expressed by the difference in indentation depth *h* (µm) between the preload and test forces. Rockwell uses a preload force of 98.07N, and Rockwell Superficial 29.42N. A specific symbol provided in combination with a type of indenter, test force, and hardness formula is known as a scale. International standards define various scales of related hardness.

## Relationship between Vickers hardness and the minimum recommended thickness of a specimen

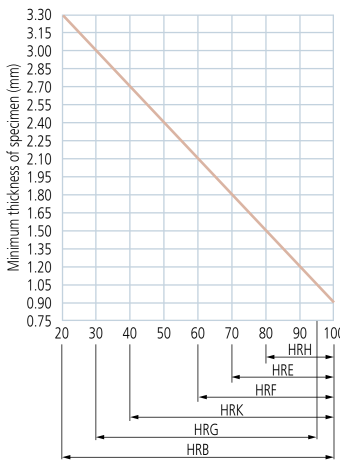



## Relationship between Rockwell / Rockwell Superficial hardness and the minimum recommended thickness of a specimen

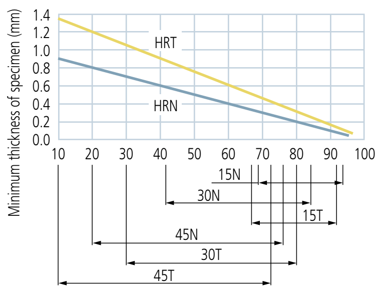
> Rockwell hardness




> Rockwell hardness




> Rockwell Superficial hardness




## Rockwell hardness scales

| Scale | Indenter | Test force (N) | Application |
|---|---|---|---|
| A | Diamond | 588.4 | Carbide, thin steel sheet |
| D | | 980.7 | Case-hardening steel |
| C | | 1471 | Steel (greater than 100HRB or less than 70HRC) |
| F | Ball with a diameter of 1.5875 mm | 588.4 | Bearing metal, annealed copper |
| B | | 980.7 | Brass |
| G | | 1471 | Hard aluminium alloy, beryllium copper, phosphor bronze |
| H | Ball with a diameter of 3.175 mm | 588.4 | Bearing metal, grinding stone |
| E | | 980.7 | Bearing metal |
| K | | 1471 | |
| L | Ball with a diameter of 6.35 mm | 588.4 | Plastic, lead |
| M | | 980.7 | |
| P | | 1471 | |
| R | Ball with a diameter of 12.7 mm | 588.4 | Plastic |
| S | | 980.7 | |
| V | | 1471 | |

## Rockwell Superficial hardness scales

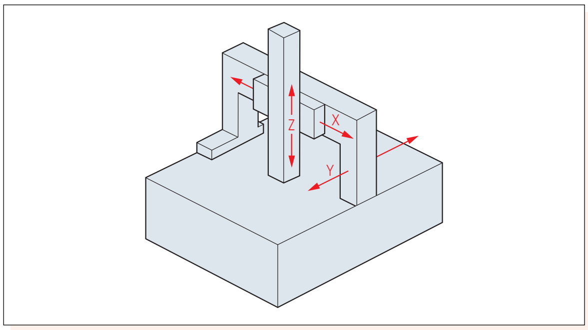
| Scale | Indenter | Test force (N) | Application |
|---|---|---|---|
| 15N | Diamond | 147.1 | Thin, hard layer on steel such as a carburized or nitrided layer |
| 30N | | 294.2 | |
| 45N | | 441.3 | |
| 15T | Ball with a diameter of 1.5875 mm | 147.1 | Thin metal sheet of soft steel, brass, bronze, etc. |
| 30T | | 294.2 | |
| 45T | | 441.3 | |
| 15W | Ball with a diameter of 3.175 mm | 147.1 | Plastic, zinc, bearing alloy |
| 30W | | 294.2 | |
| 45W | | 441.3 | |
| 15X | Ball with a diameter of 6.35 mm | 147.1 | Plastic, zinc, bearing alloy |
| 30X | | 294.2 | |
| 45X | | 441.3 | |
| 15Y | Ball with a diameter of 12.7 mm | 147.1 | Plastic, zinc, bearing alloy |
| 30Y | | 294.2 | |
| 45Y | | 441.3 | |

# Coordinate measuring machines

Coordinate measuring machines for general measurement applications are available in many configurations, but the three types described below are among the most popular. Points of comparison include stability, measuring volume versus total volume ratio, workpiece clamping convenience and initial cost, among others. The fixed bridge type is favoured for machines in the highest accuracy class.

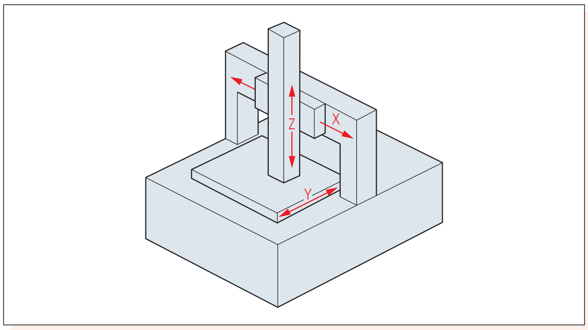
## Moving bridge CMM

This type comprises a vertically moving ram (the Z axis) attached to a carriage that moves horizontally (the X axis) on a bridge structure supported by a base, on which it moves horizontally (the Y axis). The workpiece is mounted on the base.




## Fixed bridge CMM

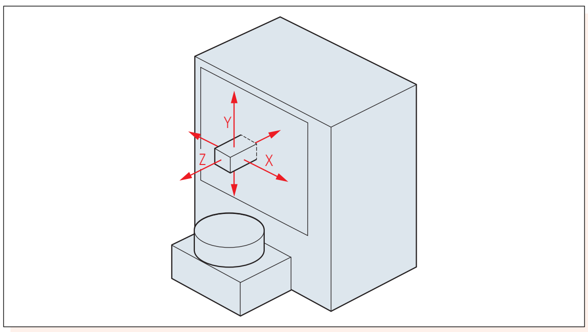
This type comprises a vertically moving ram (the Z axis) attached to a carriage that moves horizontally (the X axis) on a bridge structure rigidly attached to a base, on which a table moves horizontally (the Y axis). The workpiece is mounted on the moving table.



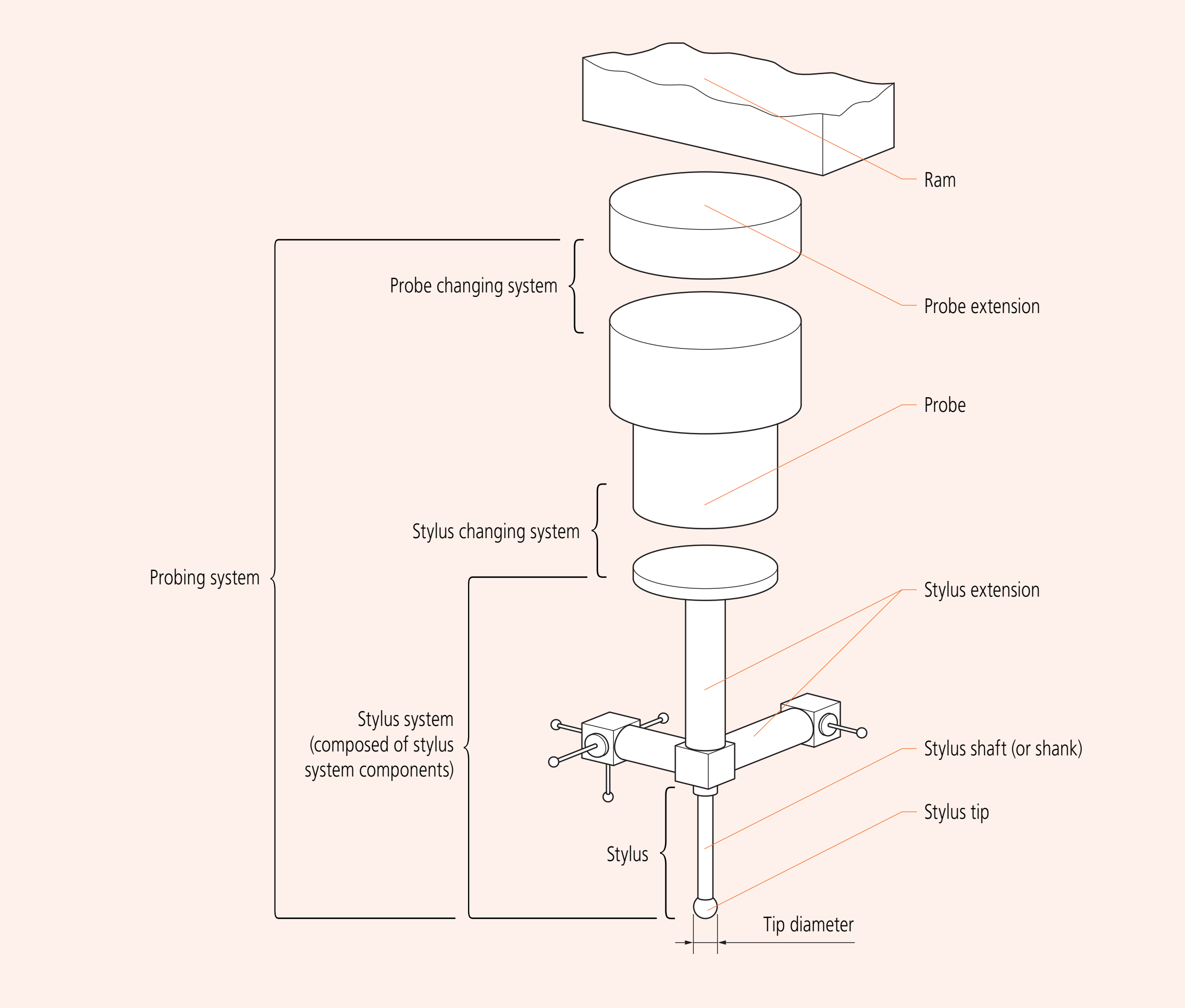


## Horizontal arm CMM

This type comprises a horizontally moving ram (the Z axis) attached to a carriage that moves vertically (the Y axis) on a column supported by a base, on which it moves horizontally (the X axis). The workpiece is mounted on the base.




## The probe system




# Coordinate measuring machines

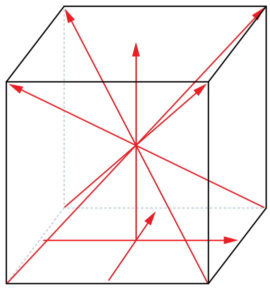
The procedure for assessing the performance of CMMs is defined in the multi-part international standard ISO 10360. This page gives you an overview of the CMM-specific parameters defined in this standard that may be referenced in Mitutoyo catalogues and product brochures.



## Maximum permissible measuring error (MPE) of length measurement $E_{0,MPE}$ (ISO 10360-2:2001)

This part of ISO 10360 defines acceptance and reverification tests for coordinate measuring machines. The test procedure is that a coordinate measuring machine (CMM) is made to perform a series of measurements on five different test lengths in each of seven directions, as shown in *Figure 1*, to produce a set of 35 measurements. This sequence is then repeated twice to produce 105 measurements in all. If these results, including allowances for the uncertainty of measurement, are equal to or less than the values specified by the manufacturer then the performance of the CMM has been proved to meet its specification.

The standard allows up to five measurements to exceed the specified value (two NG results among 3-time measurements in the same position are not allowed). If this is the case, additional 10-times measurements for the relevant position are performed. If all the 10 results, including the uncertainty allowance, are within the specified value, the CMM is assumed to pass the test. The uncertainties to be considered in determining the maximum permissible measuring error are those concerning calibration and alignment methods used with the particular material standards of length involved with the test. (The values obtained by adding an extended uncertainty combining the above two uncertainties to all test results must be less than the specified value.) The result of the test may be expressed in any of the following three forms (unit: µm).



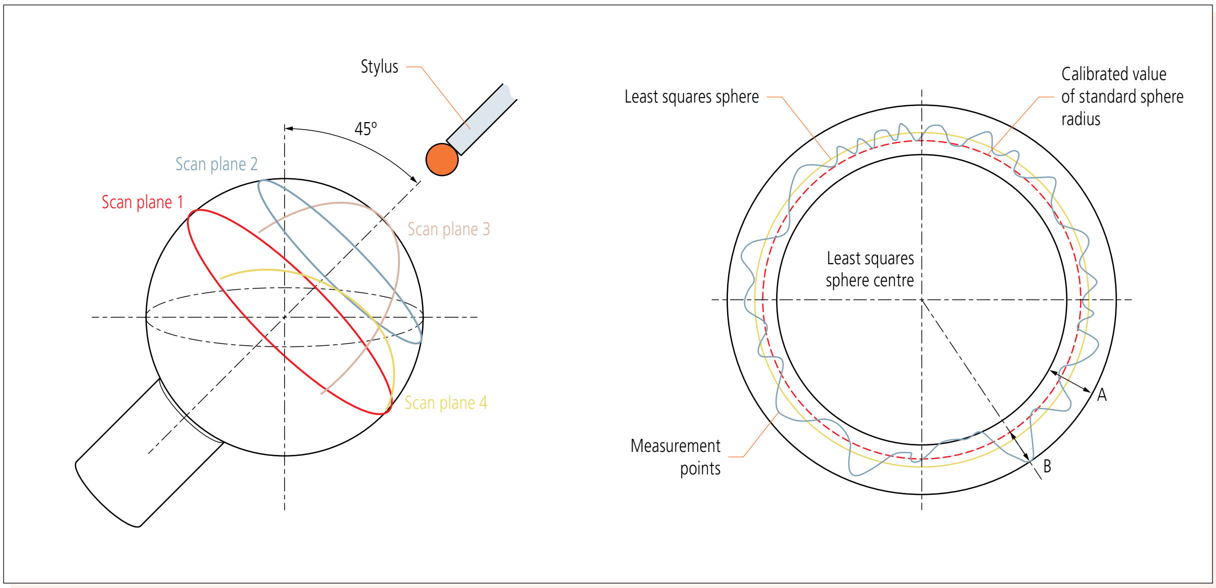
> *Figure 1*
Typical test measurement directions within the CMM measuring volume.

$$E_{0,MPE} = A + L/K \leq B$$
$$E_{0,MPE} = A + L/K$$
$$E_{0,MPE} = B$$

- A: Constant (µm) specified by the manufacturer
- K: Dimensionless constant specified by the manufacturer
- L: Measured length (mm)
- B: Upper limit value (µm) specified by the manufacturer

## Maximum permissible scanning probing error $MPE_{THP}$ (ISO 10360-4:2000)

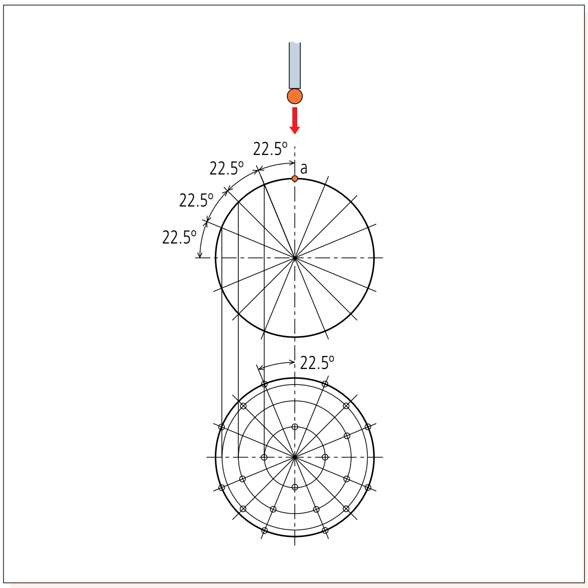
This part of ISO 10360 defines the accuracy of a CMM equipped with a scanning probe. The test procedure is to perform a scanning measurement of 4 planes on the standard sphere and then, for the least squares sphere centre calculated using all the measurement points, calculate the range (dimension *A* in *Figure 2*) in which all measurement points exist. Based on the least squares sphere centre calculated above, calculate the distance between the calibrated standard sphere radius and the maximum measurement point or minimum measurement point, and take the larger distance (dimension *B* in *Figure 2*). Add an extended uncertainty that combines the uncertainty of the stylus tip shape and the uncertainty of the standard test sphere shape to each *A* and *B* dimension. If both calculated values are less than the specified values, this scanning probe test is passed.




> *Figure 2*
Target measurement planes for the maximum permissible scanning probing error and its evaluation concept.

## Maximum permissible single stylus form error $P_{FTU,MPE}$ (ISO 10360-5:2010)

This part of ISO 10360 defines the accuracy of a CMM using stylus contacting probing systems. The test procedure is that a probe is used to measure defined target points on a standard sphere (25 points, as in *Figure 3*) and the result used to calculate the position of the sphere centre by a least squares method. Then the distance *R* from the sphere centre for each of the 25 measurement points is calculated, and the radius difference *Rmax - Rmin* is computed. An extended uncertainty that combines the uncertainty of the stylus tip shape and that of the standard test sphere is added to the radius difference. If this final calculated value is equal to or less than the specified value, the probe has passed the test.




> *Figure 2*
Target points on standard sphere for determining the *maximum permissible probing error.*

**Mitutoyo Europe GmbH**

Borsigstr. 8 -10
41469 Neuss

T +49 (0) 2137 -102-0
F +49 (0) 2137 -102-351

info@mitutoyo.eu
www.mitutoyo.eu