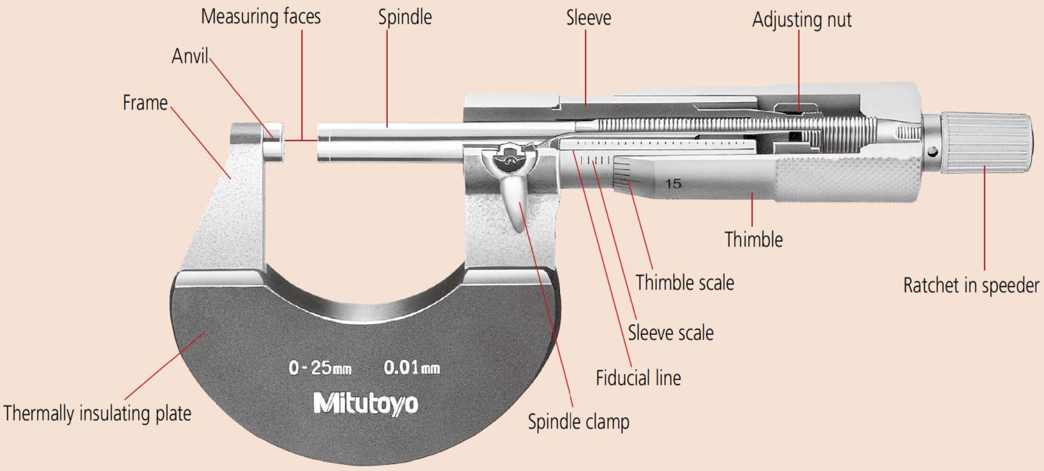
Quick Guide to Precision Measuring Instruments

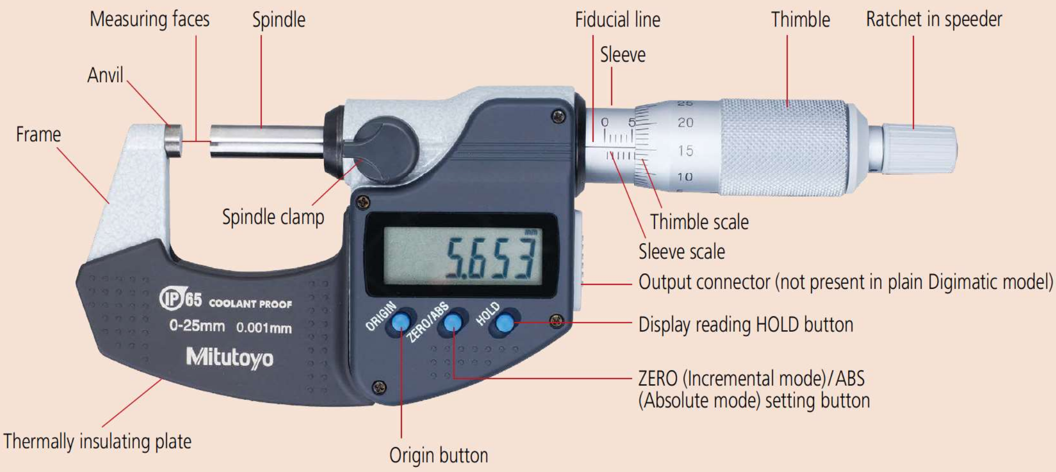
Micrometers

Nomenclature

Standard Analog Outside Micrometer

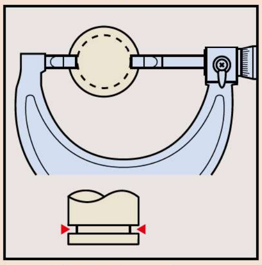


Digimatic Outside Micrometer



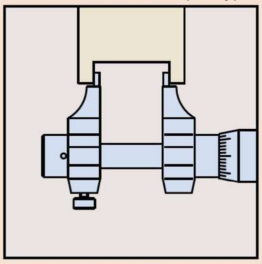
Special Purpose Micrometer Applications

Blade micrometer



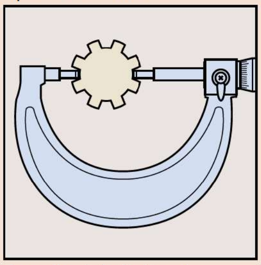
For inside diameter and narrow groove measurement

Inside micrometer, caliper type



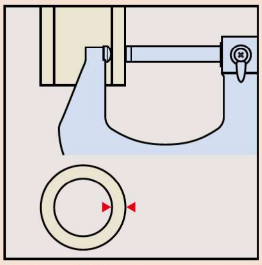
For small internal diameter and groove width measurement

Spline micrometer



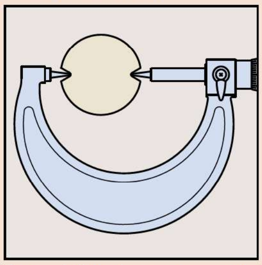
For splined shaft diameter measurement

Tube micrometer



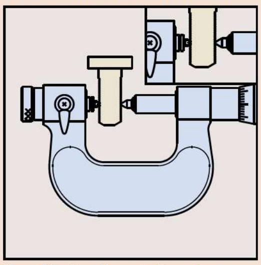
For pipe thickness measurement

Point micrometer



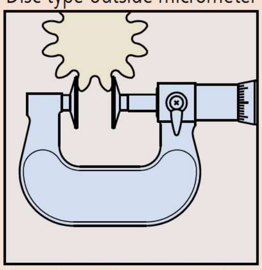
For root diameter measurement

Screw thread micrometer



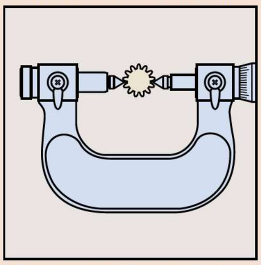
For effective thread diameter measurement

Disc type outside micrometer



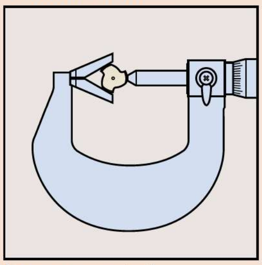
For root tangent measurement on spur gears and helical gears.

Ball tooth thickness micrometer



Measurement of gear over-pin diameter

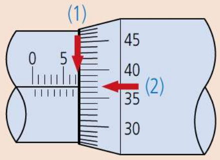
V-anvil micrometer



For measurement of 3- or 5-flute cutting tools

How to Read the Scale

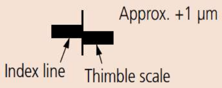
Micrometer with standard scale (graduation: 0.01 mm)

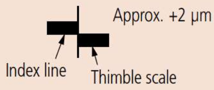


(1)	Sleeve scale reading	7. mm
(2)	Thimble scale reading	+0.37 mm
	Micrometer reading	7.37 mm

Note: 0.37 mm (2) is read at the position where the sleeve fiducial line is aligned to the thimble graduations.

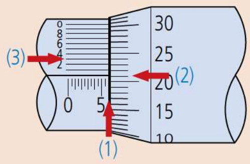
The thimble scale can be read directly to 0.01 mm, as shown above, but may also be estimated to 0.001 mm when the lines are nearly coincident because the line thickness is 1/5 of the spacing between them.





Micrometer with vernier scale (graduation: 0.001 mm)

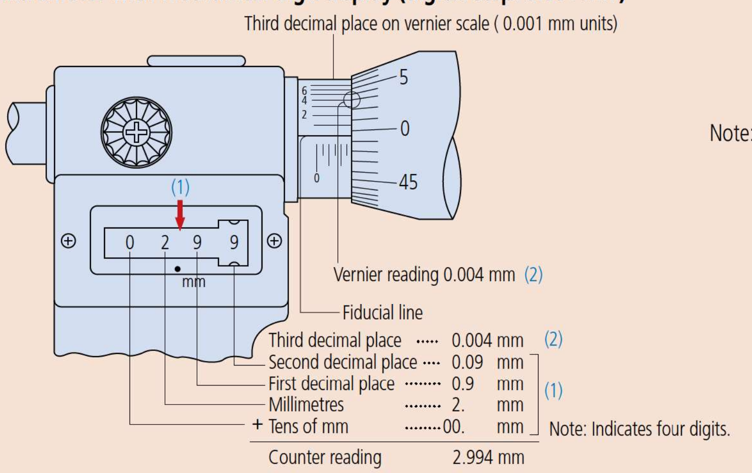
The vernier scale provided above the sleeve index line enables direct readings to be made to within 0.001 mm.



(1)	Sleeve scale reading	6. mm
(2)	Thimble scale reading	0.21 mm
(3)	Reading from the vernier scale marking and thimble graduation line	+0.003 mm
	Micrometer reading	6.213 mm

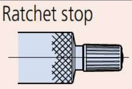
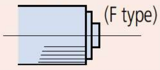
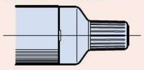
Note: 0.21 mm (2) is read at the position where the index line is between two graduations (21 and 22 in this case). 0.003 mm (3) is read at the position where one of the vernier graduations aligns with one of the thimble graduations.

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

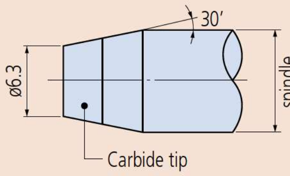


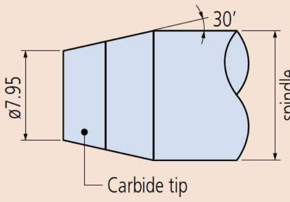
Note: 0.004 mm (2) is read at the position where a vernier graduation line corresponds with one of the thimble graduation lines.

Measuring Force Limiting Device

	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 	Yes	Suitable	Audible operation provides confirmation of constant measuring force

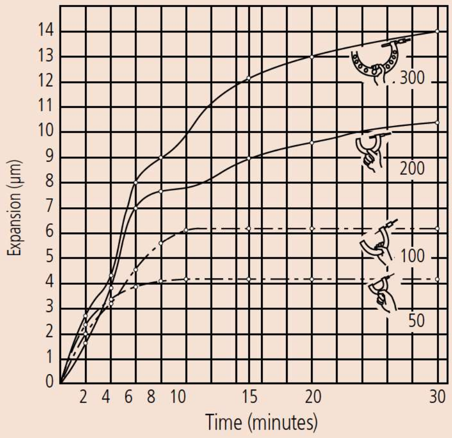
Measuring Face Detail





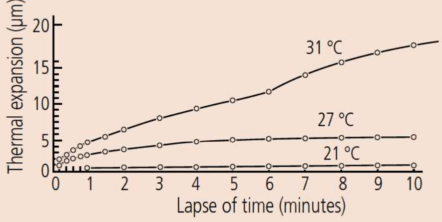
Note: The drawings above are for illustration only and are not to scale

Micrometer Expansion due to Holding Frame with the Bare Hand



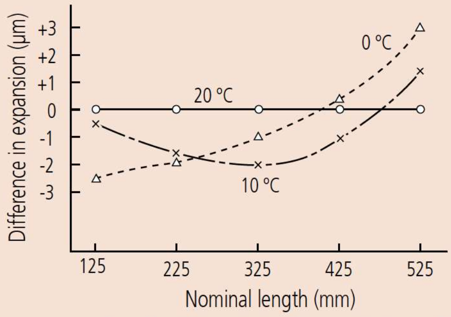
The above graph shows micrometer frame expansion due to heat transfer from hand to frame when the frame is held in the bare hand which, as can be seen, may result in a significant measurement error due to temperature-induced expansion. If the micrometer must be held by hand during measurement then try 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 are not guaranteed values but experimental values.)

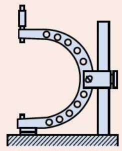
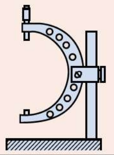
Difference in Thermal Expansion between Micrometer and Length Standard

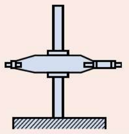
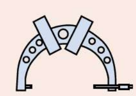


In the above experiment, after the micrometer and its standard were left at a room temperature of 20 °C for about 24 hours for temperature stabilization, the start point was adjusted using the micrometer standard. Then, the micrometer with its standard were left at the temperatures of 0 °C and 10 °C 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.)

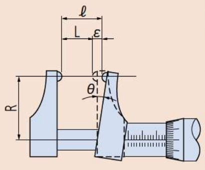
Effect of Changing Support Method and Orientation (Unit: μm)

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 center' case. These actual results show that it is best to set and measure using the same orientation and support method.

Supporting method	Supported at the bottom and center	Supported only at the center
Attitude / Maximum measuring length (mm)		
325	0	−5.5
425	0	−2.5
525	0	−5.5
625	0	−11.0
725	0	−9.5
825	0	−18.0
925	0	−22.5
1025	0	−26.0

Supporting method	Supported at the center in a lateral orientation.	Supported by hand downward.
Attitude / Maximum measuring length (mm)		
325	+1.5	−4.5
425	+2.0	−10.5
525	−4.5	−10.0
625	0	−5.5
725	−9.5	−19.0
825	−5.0	−35.0
925	−14.0	−27.0
1025	−5.0	−40.0

Abbe's Principle



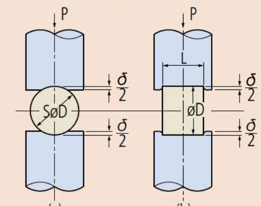
Abbe's principle states that "maximum accuracy is obtained when the scale and the measurement axes are common".
This is because any variation in the relative angle (θ) of the moving measuring jaw on an instrument, such as a caliper jaw micrometer, causes displacement that is not measured on the instrument's scale and this is an Abbe error ($\varepsilon = \ell - L$ 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.

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.

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
$\delta_2 = 0.82\sqrt[3]{P^2/D}$
b) Apparent reduction in diameter of cylinder
$\delta_1 = 0.094 \cdot P/L \sqrt[3]{1/D}$

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 error of a half angle is 15 minutes	1. Measure the angle error and correct the micrometer. 2. Adjust the micrometer using the same thread gage as the workpiece.	±3 µm expected measurement error of half angle
Misaligned contact points	+10 µm		+3 µm
Influence of measuring force	±10 µm	1. Use a micrometer with a low measuring force if possible. 2. Always use the ratchet stop. 3. Adjust the micrometer using a thread gage with the same pitch.	+3 µm
Angle error of thread gage	±10 µm	1. Perform correction calculation (angle). 2. Correct the length error. 3. Adjust the micrometer using the same thread gage as the workpiece.	+3 µm
Length error of thread gage	$\pm\left(3+\frac{L}{25}\right)$ µm	1. Perform correction calculation. 2. Adjust the micrometer using the same thread gage as the workpiece.	±1 µm
Workpiece thread angle error	JIS 2 grade error of half angle ±229 minutes −91 µm +71 µm	1. Minimize the angle error as much as possible. 2. Measure the angle error and perform correction calculation. 3. Use the three-wire method for a large angle error.	±8 µm assuming the error of half angle is ±23 minutes
Cumulative error	(±117+40) µm		+26 µm −12 µm

Screw Pitch Diameter Measurement

• Three-wire method

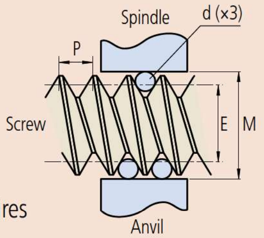
The screw pitch diameter can be measured with the three-wire method as shown in the figure.
Calculate the pitch diameter (E) with equations (1) and (2).

Metric thread or unified screw (60°)

$E=M-3d+0.866025P$ ....(1)

Whitworth thread (55°)

$E=M-3.16568d+0.960491P$ ....(2)



d = Wire diameter
E = Screw pitch diameter
M = Micrometer reading including three wires
P = Screw pitch
(Convert inches to millimeters for unified screws.)

Thread type	Optimal wire size at D
Metric thread or unified screw (60°)	0.577P
Whitworth thread (55°)	0.564P

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 ($\delta p = \delta E$) 2. Measure several points and adopt their average. 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 the optimal wire diameter. 2. No correction is needed.	±0.3 µm	±0.3 µm
Due to anvil difference	1. Use the optimal wire diameter. 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. 2. Use the predetermined width of measurement edge. 3. Use a stable measuring force.	−3 µm	−1 µm
Cumulative error		In the worst case +20 µm −35 µm	When measured carefully +3 µm −5 µm

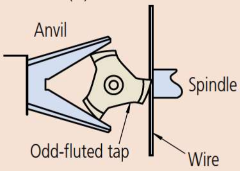
• One-wire method

The pitch diameter of odd-fluted tap can be measured using the V-anvil micrometer with the one-wire method. Obtain the measured value (M_1) and calculate M with equation (3) or (4).

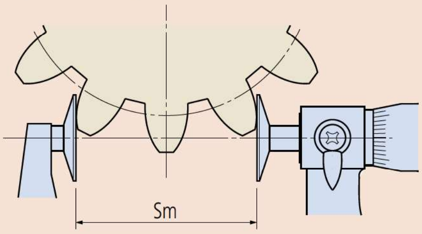
M_1 = Micrometer reading during one-wire measurement
D = Odd-fluted tap diameter

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

Then, assign the calculated M to equation (1) or (2) to calculate the pitch diameter (E).



Root Tangent Length



Formula for calculating a root tangent length (Sm):

$$Sm = m\cos\alpha_0\{\pi(Zm-0.5)+Z\,\mathrm{inv}\,\alpha_0\}+2Xm\sin\alpha_0$$

Formula for calculating the number of teeth within the root tangent length (Zm):

$$Zm' = Z\cdot K(f)+0.5 \quad (\text{Zm is the integer closest to Zm'.})$$

where, $K(f)=\frac{1}{\pi}\left\{\sec\alpha_0\sqrt{(1+2f)^2-\cos^2\alpha_0}-\mathrm{inv}\,\alpha_0-2f\tan\alpha_0\right\}$

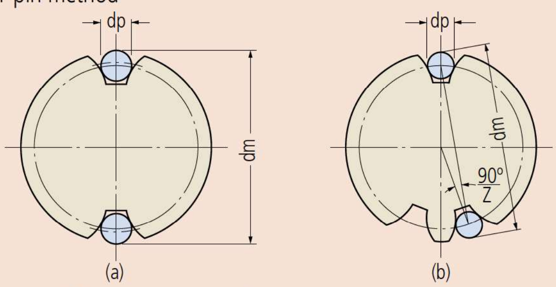
and, $f=\frac{X}{Z}$

inv 20° ≒ 0.014904
inv 14.5° ≒ 0.0055448

m: Module
α_0: Pressure angle
Z: Number of teeth
X: Addendum modification coefficient
Sm: Root tangent length
Zm: Number of teeth within the root tangent length

Gear Measurement

Over-pin method



(a) (b)

For a gear with an even number of teeth:

$$dm = dp+\frac{dg}{\cos\phi}=dp+\frac{z\cdot m\cdot\cos\alpha_0}{\cos\phi}$$

For a gear with an odd number of teeth:

$$dm = dp+\frac{dg}{\cos\phi}\cdot\cos\left(\frac{90°}{z}\right)=dp+\frac{z\cdot m\cdot\cos\alpha_0}{\cos\phi}\cdot\cos\left(\frac{90°}{z}\right)$$

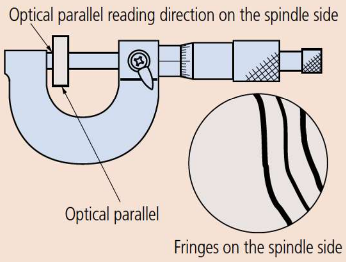
however,

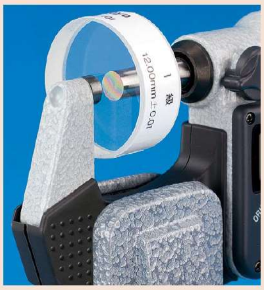
$$\mathrm{inv}\phi=\frac{dp}{dg}-\frac{X}{2}=\frac{dp}{z\cdot m\cdot\cos\alpha_0}-\left(\frac{\pi}{2z}-\mathrm{inv}\alpha_0\right)+\frac{2\tan\alpha_0}{z}\cdot X$$

Obtain ø (invø) from the involute function table.

z : Number of teeth
α_0 : Pressure angle teeth
m : Module
X : Addendum modification coefficient

Testing Parallelism of Micrometer Measuring Faces

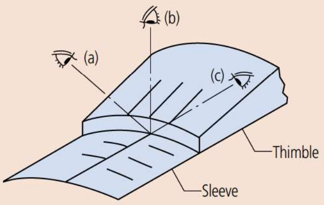




Parallelism can be estimated using an optical parallel held between the faces. First, wring the parallel to the anvil measuring face. Then close the spindle on the parallel using normal measuring force and count the number of red interference fringes seen on the measuring face of the spindle in white 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×3=0.96 μm.

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 fiducial line when taking a reading against the thimble graduations. If the graduation lines are viewed from an angle, the correct alignment position of the lines cannot be read due to parallax error.

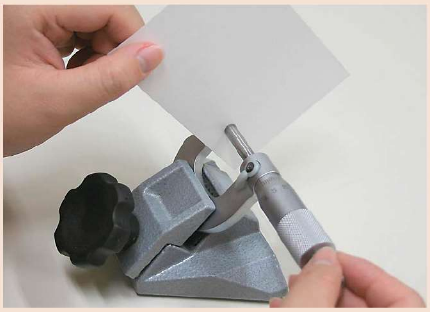


(a) From above the index line

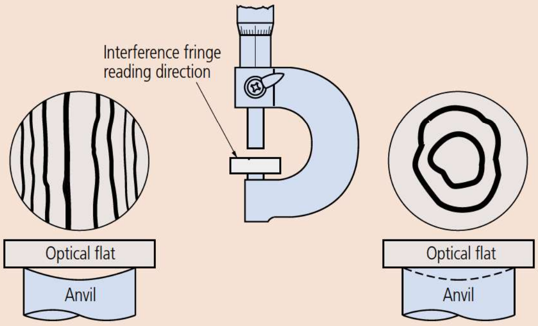
(b) Looking directly at the index line

(c) From below the index line

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



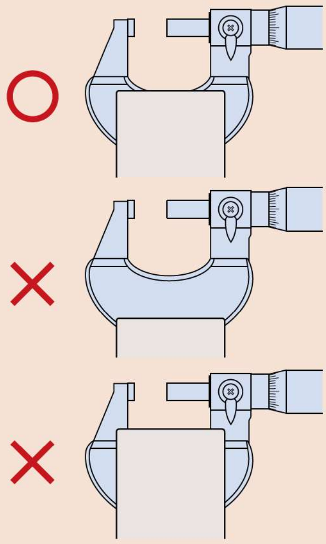
Testing Flatness of Micrometer Measuring Faces



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

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

5. Wipe away any dust, chips and other debris from the circumference and measuring face of the spindle as part of daily maintenance. In addition, sufficiently wipe off any stains and fingerprints on each part with dry cloth.
6. Use the constant-force device correctly so that measurements are performed with the correct measuring force.
7. When attaching the micrometer onto a micrometer stand, the stand should clamp the center 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.
   - When storing the micrometer, always leave a gap of 0.1 to 1 mm between the measuring faces.
   - Do not store the micrometer in a clamped state.

Micrometer Performance Evaluation Method

JIS B 7502 was revised and issued in 2016 as the Japanese Industrial Standards of the micrometer, and the "Instrumental error" indicating the indication error of the micrometer has been changed to "Maximum Permissible Error (MPE) of indication".
The "Instrumental error" of the conventional JIS adopts acceptance criteria that the specification range (precision specification) equals acceptance range, and the OK/NG judgment does not include measurement uncertainty (**Fig. 1**).
The "Maximum Permissible Error (MPE) of indication" of the new JIS employs the basic concept of the OK/NG judgment taking into account the uncertainty adopted in the ISO standard (ISO 14253-1).
The verification of conformity and nonconformity to the specifications is clearly stipulated to use the internationally recognized acceptance criteria (simple acceptance) when the specification range equals the acceptance range, and it is accepted that the specification range equals the acceptance range if a given condition considering uncertainty is met.
The above said internationally recognized acceptance criterion is ISO/TR 14253-6: 2012 (**Fig. 2**).
The following describes the standard inspection method including the revised content of JIS 2016.

Fig. 1 **Conventional JIS** Instrumental error
JIS B 7502-1994

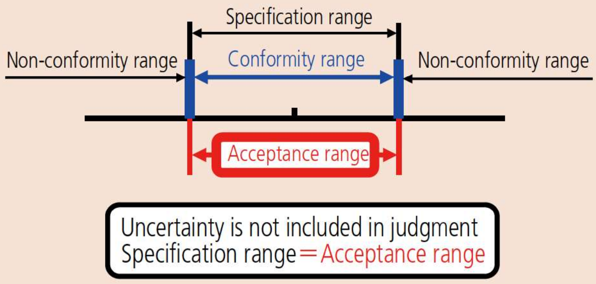
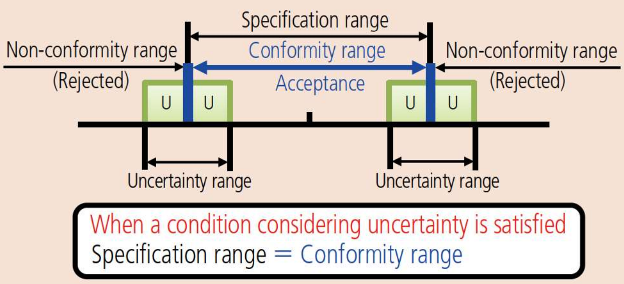


Fig. 2 **New JIS** Maximum Permissible Error (MPE)
JIS B 7502: 2016 (ISO/TR 14253- 6: 2012)



Maximum Permissible Error of Full Surface Contact Error J_{MPE} [JIS B 7502: 2016]

The full surface contact error of the outside micrometer is an indication error measured by contacting the entire measuring surface with the object to be measured at an arbitrary point in the measuring range.
The value can be obtained by adjusting the reference point using a constant pressure device with the minimum measuring length of the micrometer, inserting a grade 0 or 1 gauge block prescribed in JIS B 7506 or an equivalent or higher gage between the measuring surfaces (**Fig. 3**), and then subtracting the dimensions of the gauge block from the indication value of the micrometer using a constant pressure device.

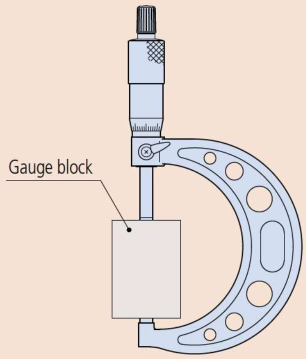


Fig. 3: Measurement of full surface contact error