TEXTBOOK No. 7007

Micrometer

TEXTBOOK

Mitutoyo

CONTENTS

1. INTRODUCTION

1.1 History of the Micrometer

<James Watt's Micrometer>

An instrument for measuring lengths with a screw was invented by James Watt around 1772. As shown in **Fig. 1.1**, this prototype micrometer is based on the relation of a screw's rotational movement to its axial movement, which satisfies the definition of modern micrometers. The main difference is that Watt's micrometer has two graduated dials for reading measurements in place of the sleeve and thimble that are used in today's micrometers. As shown in **Fig. 1.2**, the first dial, fixed to the spindle, provides fine readings, and the second dial, which turns with the spindle's movement via a reducing worm gear, provides coarse readings. The anvil with a convex measuring face*1 is fixed*2 to one end of a U-shaped brass frame. The measuring face of the sliding block*3 is on the other end of the frame. The sliding block is fed by a screw that has 18 threads per inch. The measuring range is one inch (25.4 mm). The first dial reads to one hundredth of a revolution of the screw (thereby providing a discrimination of 1/1800 inch). The second dial, which is fixed to a worm gear that is engaged with the drive screw, indicates the number of revolutions of the screw, where each revolution of the screw corresponds to a displacement of the sliding block of 1/18 inch.

[Notes]

*1: It is not necessary to adjust the parallelism between the measuring faces because of the convex measuring face of the anvil.

*2: The anvil can be adjusted and replaced.

*3: The sliding block moves in the direction of the screw axis, guided by the frame and the guide plate which is attached to the frame.

It is believed that James Watt, who also invented the steam engine, was motivated to fabricate the prototype micrometer in order to obtain a uniform and close clearance between the piston and cylinder of his steam engine. Before that, the clearance was as large as a sixpence coin and he used rags or leather sheets to prevent steam leakage, but in vain.

Watt's micrometer is now exhibited at the Science Museum in London.

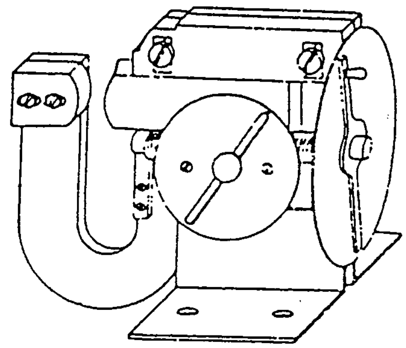


Fig. 1.1 Watt's micrometer

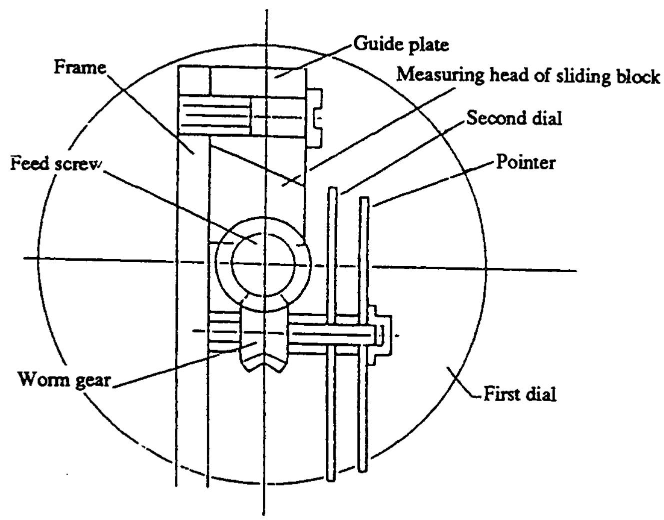


Fig. 1.2 Cross-sectional view of Watt's micrometer

In early 1800s, an Englishman named Henry Maudslay developed a micrometer which was called the "Lord Chancellor." This micrometer has a large measuring range. The feed screw has a thread pitch of 0.1 inch and the dial has a discrimination of 0.001 inch.

<Spread of micrometers in the U.S.A.>

A micrometer having the same design as those used today was first made by Jean Palmer, a Frenchman, in 1848. Two Americans, Joseph R. Brown and Lucian Sharpe, saw this device at the Parisian Exposition in 1867 and obtained the patent right. In 1877, Brown and Sharpe started production of micrometers and marketed them as a "pocket sheet metal gage," which was the first production of micrometers in the United States.

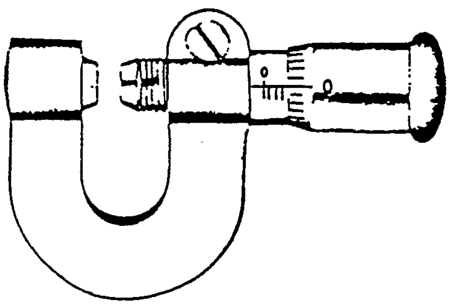


Fig. 1.3 Systeme Palmer micrometer

Following that, various improvements were made to the micrometer design - the feed screw was housed inside the sleeve - while the micrometer became more and more popular. In 1882, the U.S. Railroad Authority decided to use micrometers as the standard gage for measuring wire diameters, replacing the conventional fixed wire gage. The micrometer was designated as a standard of measurement in business transactions in 1885.

<Improvements of the micrometer>

Advances in manufacturing technology brought about further improvements to the design and application of the micrometer as well as to the readout mechanism. Since around 1950, micrometer spindles have been ground after hardening, replacing the previous lathe turning method. At the same time, carbide was used for the measuring face. With the rapid developments in IC and LCD technologies, electronic and digital micrometers entered the market in the 1970s.

<Situation in Japan>

Japan entirely depended on imports to meet its demands for micrometers until the 1930s. Later, domestic production was started by several manufacturers. The production rapidly expanded after 1950, not only for the domestic market but also for overseas sales.

1.2 Principle of the Micrometer

The micrometer is a device that measures the displacement of the spindle when it is moved by the rotation of a screw, by converting the rotational movement of the thimble into the spindle's linear movement. The spindle's displacement is amplified through the screw rotation and the diameter of the thimble. The graduations around the circumference of the thimble allow a minute change in the spindle's position to be read. (See **Fig. 1.4.**)

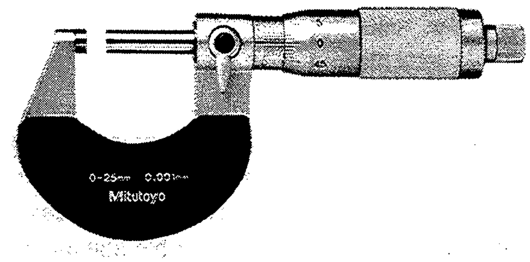


Fig. 1.4 Standard outside micrometer

In **Fig. 1.5**, suppose that the spindle is displaced by distance, x, from points a to b when the screw is rotated by angle, α. Here, letting the thimble radius be r, any point on the thimble's circumference moves by the distance, $r \cdot \alpha$ [radius × angle (in radians) of rotation]. When the spindle is displaced by a distance that is equal to one pitch of the screw threads, p, the graduations on the thimble make one complete revolution. These relationships are expressed by the following formulas:

$$\frac{\text{Displacement of spindle}}{\text{Angular displacement of graduated face}} = \frac{p}{2\pi r} = \frac{x}{r\alpha}$$

Therefore,

$$x = \frac{p\alpha}{2\pi} \text{------} (1)$$

where,

x: Displacement of spindle (mm)
p: Screw thread pitch (mm)
α: Rotational angle of screw (radian)
r: Thimble radius (mm)

Standard micrometers have a 0.5 mm screw thread pitch and their thimble is graduated into 50 equal divisions around its circumference.

Substituting 0.5mm for p, and 1/50 for $\alpha/2\pi$ in formula (1), we obtain the discrimination, or the value of one graduation of the micrometer, as follows:

$$\text{Discrimination } (x) = 0.5 \times \frac{1}{50} = 0.01 \text{ (mm)}$$

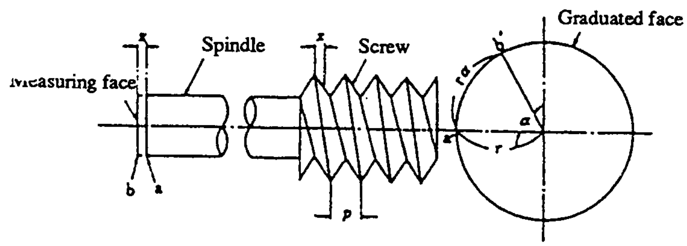


Fig. 1.5 Principle of micrometer

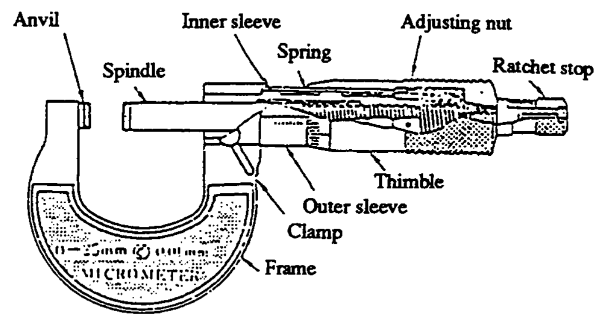


Fig. 1.6 Cutaway view of outside micrometer

1.3 Construction of the Micrometer

As shown in **Figs. 1.6** and **1.7**, the main parts of an outside micrometer are a frame, spindle, anvil, inner and outer sleeves, thimble, ratchet stop, and clamp.
The frame holds all the micrometer parts together. The inner sleeve, which has the guide threads of the feed mechanism, is fixed to one end of the frame. The anvil, which serves as a fixed measuring face, is attached to the other end of the frame.
The spindle has a measuring face on one side and external threads on the other side. It is fitted in the inner sleeve which ensures the linearity of the spindle motion in the axial direction. The spindle's threads engage with the internal threads of the inner sleeve.
The measuring face of the spindle serves as a contact point for measuring a workpiece. Measurement is performed by feeding the spindle so that the measuring faces of the spindle and the anvil touch the workpiece.
The outer sleeve is fitted over the inner sleeve. It has graduations that correspond to spindle's thread pitch, and an index line for reading the graduations on the thimble. If it becomes out of adjustment, the sleeve can be rotated around the inner sleeve with a certain torque to re-align the index line with the thimble zero line.
The thimble is fixed to the spindle and turns together with the spindle. One side of the thimble is knurled for easy operation, and the other side has graduations for reading measurements.
The ratchet stop, usually provided at one end of the spindle, applies a constant pressure to the workpiece being measured. It normally consists of a leaf spring and a ratchet.
The clamp, fixed to the spindle guide section of the frame, locks the spindle against the inner sleeve.

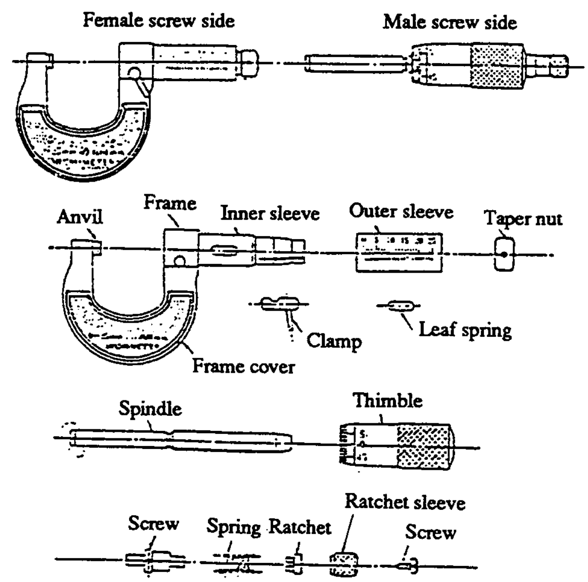
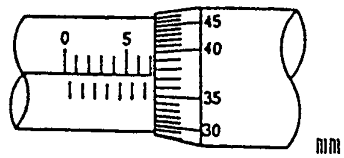


Fig. 1.7 Construction of outside micrometer

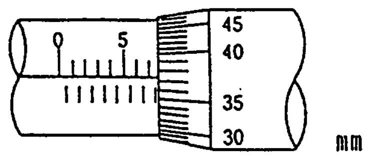
1.4 Reading the Micrometer

1.4.1 Standard micrometer (0.01 mm discrimination)

Perform measurement with a standard outside micrometer, as follows (see **Figs. 1.8** and **1.9**):
First read the sleeve graduations, then read the thimble graduations. Add the two readings to obtain the total reading. Be careful not to misread the smallest graduation on the sleeve (this will result in an error of 0.5 mm on standard metric micrometers). **Fig. 1.9** shows a method of reading measurements down to 0.001 mm. This method uses the fact that the width of a thimble graduation line equals one-fifth of a thimble division.



Sleeve reading 7.
Thimble reading .373 (+
Total reading 7.373 mm



Sleeve reading 7.5
Thimble reading .373 (+
Total reading 7.873 mm

Fig. 1.8 Reading a standard micrometer

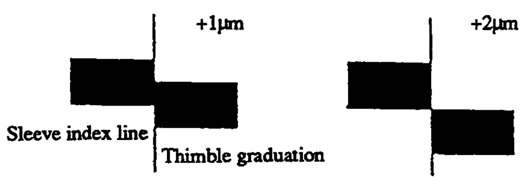


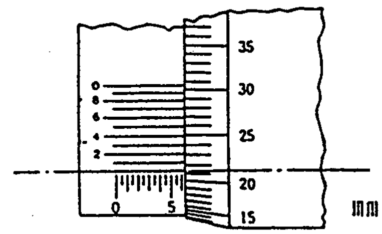
Fig. 1.9 Reading down to 0.001 mm

1.4.2 Micrometers with a 0.001 mm discrimination

Some micrometers have a special device (such as an auxiliary scale or a vernier on the sleeve) and provide a discrimination of 0.001 mm.

- Outside micrometer with vernier

This type of micrometer has the same construction as a standard outside micrometer but has a vernier above the index line in order to provide a discrimination of 0.001 mm. Readings on the vernier are taken by finding the vernier graduation that is aligned with the graduation on the thimble.



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

Fig. 1.10 Reading a micrometer with vernier

2. OUTSIDE MICROMETERS

2.1 Standard Outside Micrometers

2.1.1 Parts of the standard outside micrometer

The standard outside micrometer consists of a frame, spindle, anvil, inner and outer sleeves, thimble, ratchet stop, and clamp.

2.1.2 Description of micrometer parts

(1) Frame

A wide variety of designs, sizes, and materials are available for the frames of a standard outside micrometer. The materials for the micrometer frames include cast iron, forged iron, cast light alloys, steel, etc. Frames are generally constructed from solid metal, but large micrometers may have tubular frames. Some standard outside micrometers have a thermal insulation cover against heat from operator's hands. The surface of many frames is chromium-plated or painted. From a functional point of view, micrometer frames should meet the following requirements:

- Long-term stability
- High rigidity
- Light weight (especially for large-sized micrometers)

High rigidity is required in order to minimize measurement errors arising from frame deformation due to the supporting posture and the measuring force of the micrometer.

The weight factor concerns operability. If a micrometer is too heavy, the measurement accuracy will also be affected; the measured data may be different for different measuring postures, and also may be influenced by the weight of the micrometer itself.

(2) Measuring face

The diameter of measuring faces is typically 6.5 mm in micrometers of up to 300 mm in size, and 8 mm in larger ones. Carbide is the most commonly used material for measuring faces. Hardened tool steel is used for non-flat measuring faces. The surface of measuring faces is finished to a closer tolerance because the surface roughness and form errors of the measuring faces significantly affect the measuring accuracy.

(3) Fit of screw threads

The fit of the screw threads in a micrometer is one of the most important factors to determine the measuring accuracy. The basic requirements for the appropriate fit are as follows:

- Accurate thread pitch and uniform pitch diameters
- High concentricity between the non-threaded and threaded potions
- Appropriate play between threads in both axial and radial directions to ensure smooth movement
- Resistance to wear

In order to ensure the appropriate fit of the threads over the entire stroke, the pitch diameter of the internal threads must be adjustable. Also the condition of fit should not go out of adjustment even though the threads are worn during long periods of use.

The following methods are used for adjusting internal threads:

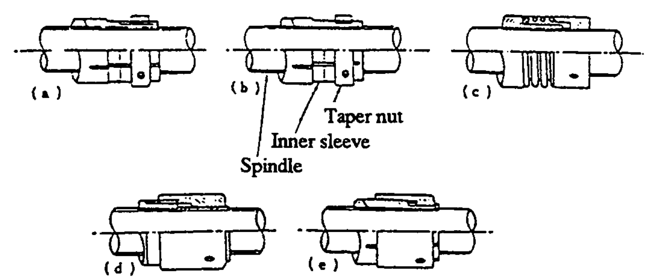


Fig. 2.1 Adjusting methods for internal threads

(a) The female screw has three slots that are evenly spaced around the circumference and extend halfway from the end of the screw. A taper nut is used to adjust the pitch diameter of the slotted portion.

(b) This construction is similar to (a), but the slots are located on the middle portion. The pitch diameter of the internal threads is smaller at the middle than at the ends.

(c) The female screw is divided into two sections; one is fixed and the other is spring-loaded and can move in the axial direction. This construction keeps the male and female screw threads in contact on one flank.

(d) Instead of using slots, the wall of the female screw is thin. A taper nut is used to adjust the pitch diameter.

(e) This construction is similar to (b), but the female screw is tightened at one end without using a taper nut.

Fig. 2.2 illustrates the condition of the screw thread engagement at an enlarged scale. (A) shows cases (a) and (d) described above; (B) shows cases (b) and (e); (C) shows case (c).

In (A) and (B), a portion of the female screw is tightened in order to adjust the clearance between the screw threads. Because of this, only part of the female screw threads make contact with their counterparts and the contacting surfaces vary from thread to thread. In (C), the flanks of the screw threads make a uniform contact over the entire length, minimizing the feed error that could arise from screw thread pitch error.

The fit of screw threads in micrometers is adjusted by the manufacturer so that the threads make a uniform contact. Re-adjustment is necessary whenever the fit goes out of adjustment, before the wear of the threads becomes too large.

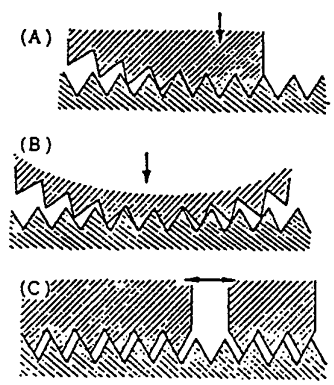


Fig. 2.2 Screw thread engagement

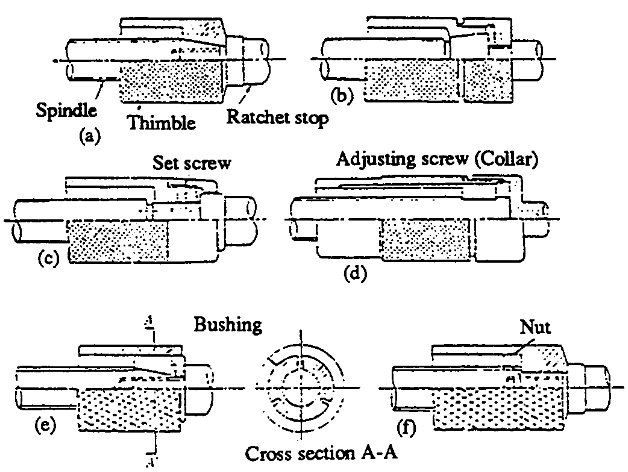


Fig. 2.3 Thimble attachment methods

(4) Thimble attachment

Fig. 2.3 shows methods of attaching a thimble. In methods (a) and (b), the thimble is fixed to the spindle using a taper. The direction of the taper is opposite between methods (a) and (b). Methods (c) through (f) allow adjustment of the thimble position. Of the above methods, method (a) is most commonly used.

(5) Sleeve attachment

The sleeve is fitted over the inner sleeve. Recent micrometers have adjustable sleeves for setting the zero point (i.e. aligning the index line on the sleeve with the zero line on the thimble). In this type, the sleeves have a notch and can be rotated with a key spanner.

(6) Constant-force device

In order to minimize the variation of the readings, measurement should be performed under the same force as was used for setting the zero point. To facilitate this, a costant-force device called the ratchet stop is used in many micrometers. **Fig. 2.4** shows three types of ratchet stops. The mechanism of ratchet stop type (b), which is the most commonly used, is explained below:

Two ratchets are opposed to each other and their toothed faces are pressed together by the force of a spring. The ratchet teeth are somewhat wedge shaped. One flank has a low slope and the other has an acute slope. When the knob of the ratchet stop is rotated clockwise, both ratchets turn together until the measuring force is above a certain limit. When the measuring force exceeds this limit, the ratchet in the knob spins idly and clicks. When the knob is rotated counterclockwise, there is no idling between the ratchets because the ratchets engage on the acutely angled flanks.

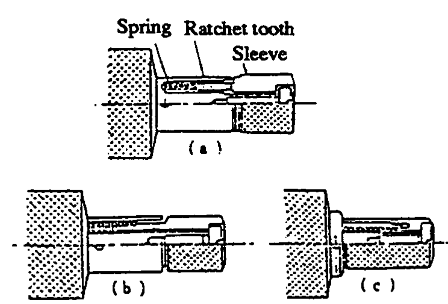


Fig. 2.4 Ratchet stops

Another type of costant-force device is called the friction thimble (Fig. 2.5).

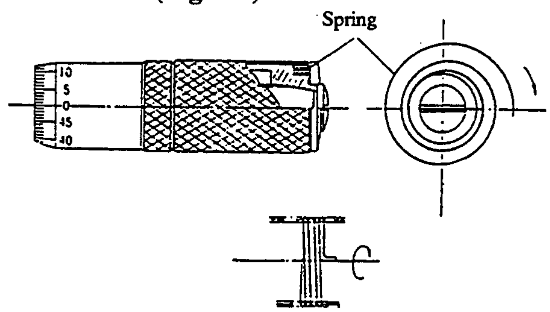


Fig. 2.5 Friction thimble

(7) Clamping device

A clamping device locks the spindle to the inner sleeve. It is used for setting the zero point or when a reading cannot be taken with the workpiece held between the anvil and the spindle. In the latter case, lock the spindle and gently remove the workpiece, then take the reading.

Clamping devices can be roughly classified into two types; the lever type and the ring type. In the lever type, the spindle is clamped directly by a screw or indirectlyvia a cam (Mitutoyo micrometers use screw clamping). In the ring type, the spindle is clamped around its circumference by the ring.

Fig. 2.6 shows various types of clamping devices.

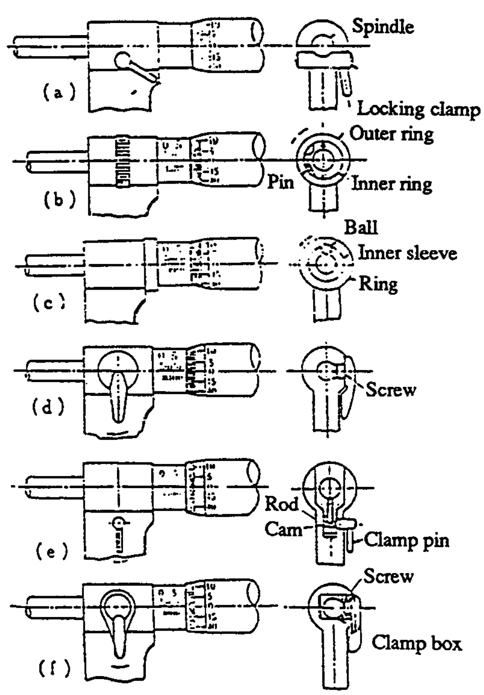


Fig. 2.6 Clamping devices

2.2 Screw-thread Micrometers

The micrometer for measuring the pitch diameter of a screw thread is called the screw-thread micrometer. This micrometer is mainly used for measuring pitch diameters of triangular threads. There are special-purpose screw-thread micrometers for measuring pitch diameters of square threads, trapezoidal threads, and ball screw threads.

The most important requirement to ensure interchangeability between screws is the fit of mating external and internal threads. For any two mating screws to properly function, the internal and external threads must be engaged so that power is transmitted by the flanks of the threads. Five dimensional variables determine the fit of screw threads and the displacement accuracy of the screws; they are the major diameter, minor diameter, pitch diameter, thread angle, and pitch. These factors are interrelated with each other and their measurements are essential for quality control of screws. Generally, dimensional and fixturing controls of cutting tools are responsible for errors of thread angles, and feed accuracy of machine tools for the pitch errors.

2.2.1 Pitch diameter

The pitch diameter of threads is defined as the diameter of an imaginary cylinder, coaxial with the screw, that intersects with the threads in such a way that, in a cross-sectional view, the intersecting line segment included in each crest equals that included in each root (see **Fig. 2.7**).

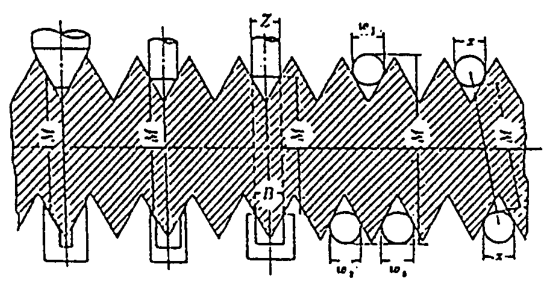


Fig. 2.7 Pitch diameter

2.2.2 Construction of the screw-thread micrometer

The screw-thread micrometer has a V-grooved anvil and a cone-pointed spindle. Unlike the three-wire method (see **Section 2.2.5**), the screw-thread micrometer provides direct readings of the pitch diameters of threads. Different anvils and spindles are used to measure screw threads of different pitches and thread angles. **Fig. 2.8** shows a standard screw-thread micrometer (dedicated type) and **Fig. 2.9** shows a screw-thread micrometer with interchangeable anvils and spindle tips.

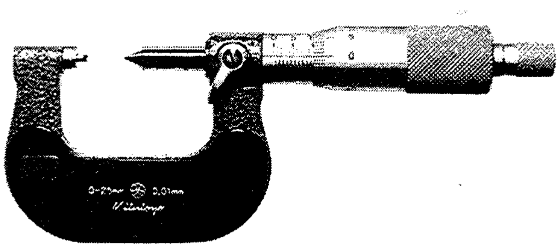


Fig. 2.8 Screw-thread micrometer

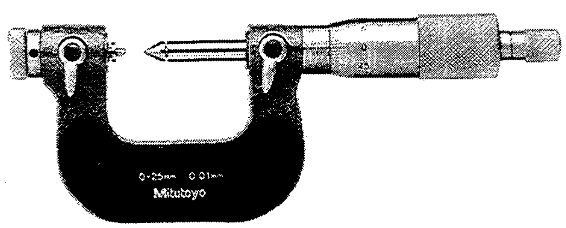


Fig. 2.9 Screw-thread micrometer with interchangeable anvils and spindle tips

2.2.3 Reference gage for screw-thread micrometers

For screw-thread micrometers with a measuring range of 0 - 25 mm, the zero point setting can be checked by simply bringing the cone point of the spindle into contact with the V-anvil. For larger micrometers whose maximum measuring length is greater than 25 mm, special reference gages are required for checking the zero point. Reference gages are of a conical, plate, thread, or hybrid type, as shown in **Fig. 2.10**. Thread gages can also be used as a reference gage.

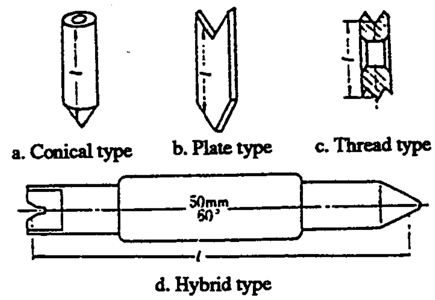


Fig. 2.10 Reference gages for screw-thread micrometers

2.2.4 Error factors involved in measurement with a screw-thread micrometer

The following error factors are involved in measurement with a screw-thread micrometer:

- Feed error of the micrometer
- Difference between the anvil and spindle tip angles and the thread angle
- Misalignment between the anvil and spindle tip
- Variation in the measuring force
- Reference gage length error
- Reference gage angle error
- Thread angle error
- Thread lead angle error
- Thread pitch error

Table 2.1 lists the measurement errors caused by these factors and the methods of minimizing the errors. Theoretically, the cumulative error can be very large. In practice, however, some error factors cancel out others, resulting in a smaller measurement error than the maximum possible error.
In general, the pitch diameters measured using a screw-thread micrometer tend to be larger than the actual pitch diameters.
As shown in the table, the errors of the threads being measured lead to measurement errors. This means that the higher the precision of the threads, the smaller the measurement errors. To examine this, the pitch diameter of a thread gage was measured using a screw-thread micrometer and the result was compared with a reference value obtained by the three-wire method. The micrometer measurement was larger than the reference value by only a few microns.

Table 2.1 Errors involved in measurement with a screw-thread micrometer

Error factor	Maximum possible error	Method of minimizing error	Error after taking countermeasures
Feed error of micrometer	±2μm	1. Compensate for the feed error.	±1μm
Angle error of anvil and spindle tip	±5μm (when half-angle error is 15 minutes)	1. Measure the angle error and compensate for the error. 2. Adjust using a thread gage that has the same thread angle as the workpiece.	±3μm (including error involved in angle error measurement)
Misalignment between anvil and spindle tip	±10μm	1. Use a micrometer that has minimum misalignment. 2. Measure the misalignment and compensate for the error.	±3μm
Variation in measuring force	±10μm	1. Use a micrometer that requires a small measuring force. 2. Use a costant-force device. 3. Adjust using a thread gage that has the same pitch as the workpiece.	±3μm
Reference gage angle error	±10μm	1. Compensate for the angle error. 2. Adjust using a thread gage that has the same thread angle as the workpiece.	±3μm
Reference gage length error	±(2 + L/50)μm	1. Compensate for the length error. 2. Adjust using a thread gage that has the same length as the pitch diameter of the workpiece.	±1μm
Thread angle error	-91μm to +71μm (when half-angle error is ±229 minutes — JIS Grade 2)	1. Fabricate screws with minimum thread angle error. 2. Measure the thread angle error and compensate for the error.	±3μm (when half-angle error is 23 minutes)
Thread lead angle error	±2μm	1. Compensate for the lead angle error 2. Use a spindle and anvil having angles slightly smaller than the thread angle. 3. Set the zero point using a thread gage.	±1μm
Thread pitch error	±18μm (when pitch error is 20μm)	1. Compensate for the error (1.5 to 2.0 times the pitch error corresponding to the pitch diameter)	±3μm
Cumulative error	(±117 + 40)μm		+26μm −12μm

2.2.5 Thread measurement by the three-wire method

The pitch diameter of threads can be measured very accurately by the three-wire method. However, this method is more complicated and takes more time than screw-thread micrometer measurement. Special attachments, such as Three-wire Units (Fig. 2.11), are available to facilitate measuring operation.

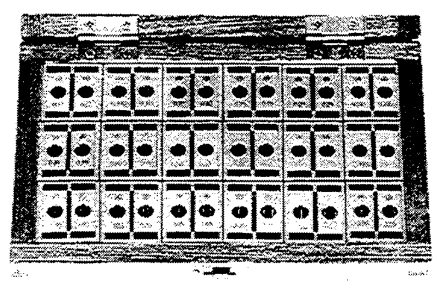


Fig. 2.11 Three-wire units

(1) Principle of the three-wire method

As shown in **Fig. 2.12**, three wires or pins of the same diameter are placed in contact with the flanks of a screw thread. Two wires are placed in contact with the thread on one side and a third wire on the opposite side. If the thread angle is 60°, the pitch diameter of the thread is given by the following formula:

$$E = M - 3d + 0.866025p$$

where,

M: measured value

d: wire diameter

p: thread pitch

Refer to **App. 2.1** for the general formula.

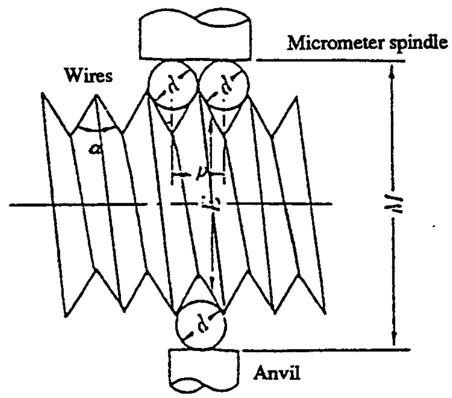


Fig. 2.12 Measuring pitch diameter by three-wire method

(2) Error factors involved in the three-wire method

Table 2.3 lists various error factors that may be introduced when measuring pitch diameters using the three-wire method.

(a) Wire angle relative to thread lead angle

The above formula assumes that the thread has no lead angle. Actually, the wires are in contact with the thread at certain angles with the axis of the thread because of the lead angle of the thread. To obtain more accurate pitch diameter, use the formula shown in **App. 2.2**.

(b) Effect of measuring force

When a measuring force is applied, both the wires and the flanks of the thread will be deformed. If the measuring force is too small, a great variation in measurements will result. Also, the wires may not be parallel with the grooves between the flanks. Because of this, many countries have standardized methods of measuring wire diameters and screw-thread gages.

JIS B 0271 "Three Wires for Screw Thread Measuring" specifies a method of measuring wire diameters as follows:

As shown in **Fig. 2.13**, fix a feeler having a cylindrical portion with a radius of 9.5 to 10.5 mm to the detecting head of an indicator and place the wire to be measured between the feeler and the gauge block that is used as a base. Adjust the inclination of the measuring table until the measured value remains unchanged when the wire is moved to and fro. Replace the wire with a gauge block having a thickness close to the diameter of the wire, then adjust the indicator's reading to zero. Replace the gauge block with the wire and measure the wire. Determine the diameter of the wire by making the necessary corrections according to the measuring force and the material of the feeler.

JIS B 0261 specifies the measuring force and contact length of wires in the three-wire method as shown in **Table 2.2**.

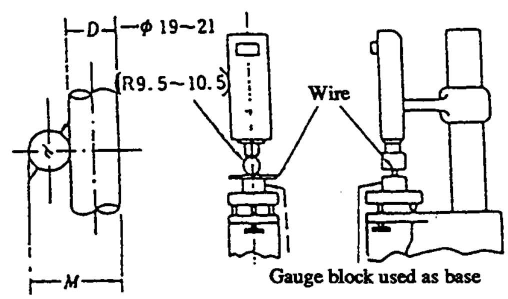


Fig. 2.13 Measuring wire diameter

Table 2.2 Measuring force and contact length of wires on flanks (JIS B 0271)

Pitch (mm)	Threads per inch	Measuring force (gf) {N}	Contact length (mm)
0.2 – 0.5	80 – 48	170 – 230{1.67 – 2.26}	4 – 6
0.6 – 1	44 – 24	450 – 550{4.41 – 5.39}	4 – 6
1.25 – 4	20 – 6	900 – 1100{8.83 – 10.79}	6 – 8
4.5 or more	5 or less	900 – 1100{8.83 – 10.79}	8 – 10

(c) Variation in wire diameters

Variation in wire diameters also affects measuring accuracy. One technique to minimize this effect is to place the two wires having the largest and smallest diameters on one side and the wire having the middle diameter on the other side.

Table 2.3 Errors involved in measurement by three-wire method

Error factor	Method of minimizing error	Maximum possible error	Error after taking countermeasures
Thread pitch error	1. Compensate for the pitch error 2. Measure several portions and use the mean value 3. Fabricate screws with minimum thread pitch error.	±18μm (when pitch error is 0.02mm)	±3μm
Thread angle error	1. Use the wires with the optimum diameter.	±0.3μm	±0.3μm
Wire diameter error	1. Use the wires with the optimum diameter. 2. Place the wire with the middle diameter on one side.	±8μm	±1μm
Wire angle relative to thread lead angle	1. Compensate for the angle if the thread has a large lead angle. 2. Use wires that have a minimal bend. 3. Correctly fit the wires in the thread grooves. (Use a wire holder.)	−3μm	−0.5μm
Variation in measuring force	1. Use the measuring force specified for the thread pitch. 2. Fit the wires so that they touch the flanks over the specified length. 3. Minimize variation in measuring force.	−3μm	−1μm
Cumulative error		+20μm −35μm	+3μm −5μm

2.3 Gear-tooth Micrometers

The gear is one of the most important elements of machines and measurement of gears is often required to ensure the intended performance of a machine. For mating gears to correctly function, their teeth must be properly engaged with each other without changing the distance between the two centers of rotation. At this time, the peripheral speed along the pitch circles must be constant. In order to meet this requirement, the following elements of gears should be inspected:

(1) Addendum circle diameter
(2) Runout of base circle
(3) Root tangent length
(4) Tooth depth
(5) Tooth thickness
(6) Tooth form
(7) Over-pin diameter

The addendum circle in (1) can be measured with a standard outside micrometer. Gear-tooth micrometers are used mainly for measuring (3) root tangent length, (5) tooth thickness, and (6) over-pin diameter. There are different types of gear-tooth micrometers which are classified according to their applications as follows:

For measurement of tooth thickness:
- Disc type tooth thickness micrometer (**Fig. 2.14**)
- Caliper type tooth thickness micrometer (**Fig. 2.15**)
- Slide type tooth thickness micrometer (**Fig. 2.16**)

For measurement of over-pin diameter:
- Ball-tipped gear tooth micrometer (**Fig. 2.17**)

There are two types of tooth thickness micrometer, one for measuring chordal thickness and the other for measuring root tangent length.
Refer to **Appendix 3** for the measuring principles of tooth thickness micrometers and ball-tipped gear tooth micrometer, the measuring method of over-pin diameters, and other detailed information.

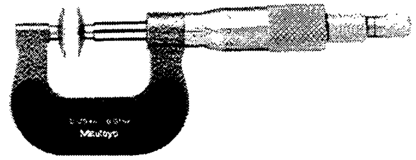


Fig. 2.14 Disk type tooth thickness micrometer

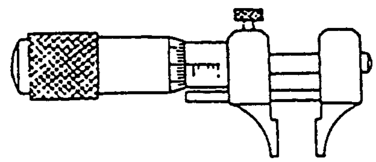


Fig. 2.15 Caliper type tooth thickness micrometer

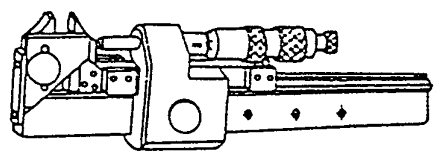


Fig. 2.16 Slide type tooth thickness micrometer

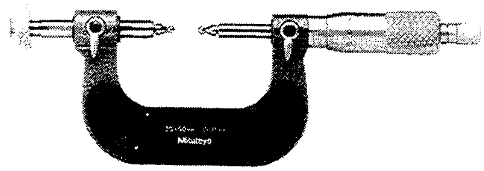


Fig. 2.17 Ball-tipped gear tooth micrometer

2.4 V-anvil Micrometers (for measuring workpieces with odd-numbers of flutes)

The V-anvil micrometer is used for measuring the outside diameter of cutting heads (such as taps, reamers, end mills) with odd-numbers of flutes that standard outside micrometers cannot measure. Measured diameters can be read directly off the micrometer or obtained from a conversion table. It is also possible to measure the pitch diameter of taps by means of the single-wire method.
The following three types are available:

- Three-flute type
- Five-flute type
- Seven-flute type

Each of the above types can measure workpieces having a multiple number of flutes.

2.4.1 Three-flute type V-anvil micrometer

As shown in **Fig. 2.18**, the three-flute V-anvil micrometer has an anvil with a 60° vee angle. Otherwise, the construction is the same as that of a standard outside micrometer.

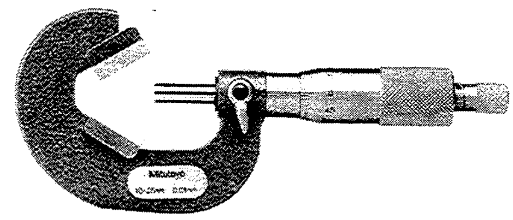


Fig. 2.18 Three-flute V-anvil micrometer

Fig. 2.19 illustrates the measuring principle of three-flute V-anvil micrometers. The relationship between an increment (D - d) of the workpiece diameter and the corresponding displacement, A, of the spindle is as follows:

$$A = 1.5 \times (D-d)$$

Therefore, spindle's thread pitch of the direct reading type is 1.5 times greater (i.e., 0.5 mm × 1.5 = 0.75 mm) than that of a standard outside micrometer. The thimble is graduated into 50 divisions, providing a discrimination of 0.01 mm.

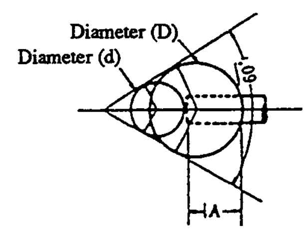


Fig. 2.19 Measuring principle of three-flute V-anvil micrometer

2.4.2 Five-flute type V-anvil micrometer

As shown in **Fig. 2.20**, the five-flute V-anvil micrometer has an anvil with a 108° vee angle. Many micrometers of this type have a spindle thread pitch of 0.5 mm, and measured diameters are obtained using a conversion table or by calculation based on micrometer's readings.
The measuring principle is the same as that of the three-flute type, and the relationship between an increment (D- d) of the workpiece diameter and the corresponding displacement, A, of the spindle is given by the following formula:

$$A = 1.118031 \times (D - d)$$

The five-flute V-anvil micrometers from Mitutoyo have a spindle's thread pitch of 0.559015 mm (0.5 mm × 1.118031) in order to allow direct readout of workpiece diameters. Refer to **Appendix 4** for the measurement of the pitch diameter of taps with a V-anvil micrometer.

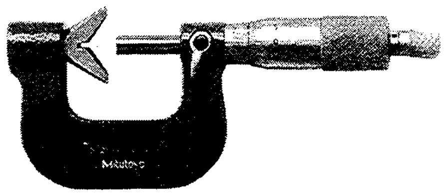


Fig. 2.20 Five-flute V-anvil micrometer

2.5 Sheet Metal Micrometers

This type of micrometer is used for checking the thickness of sheet metal during the rolling process as well as in the final inspection. Because the frame has a deep throat, it can measure thickness at portions deep inside the edge of sheet metal. Some micrometers are provided with a dial for easy reading.

2.5.1 Deep-throat type

Fig. 2.21 shows a deep-throat micrometer. The throat depth ranges from 100 mm to 600 mm. Parts other than the frame are the same as those of a standard outside micrometer.

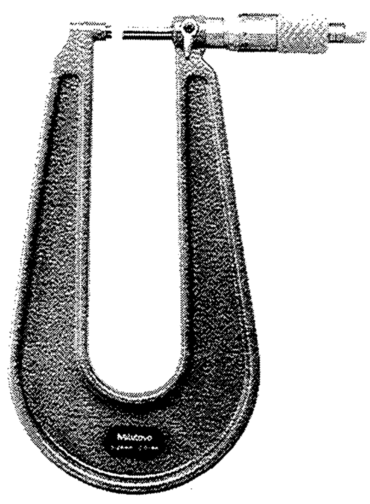


Fig. 2.21 Deep-throat micrometer

2.5.2 Dial type

A dial is attached to the sleeve as shown in **Fig. 2.22.** This design allows readings to be easily taken from above when the sheet metal to be measured is laid flat. The thread pitch of the spindle is 1 mm and the dial is graduated into 100 divisions around the circumference to provide a discrimination of 0.01 mm.

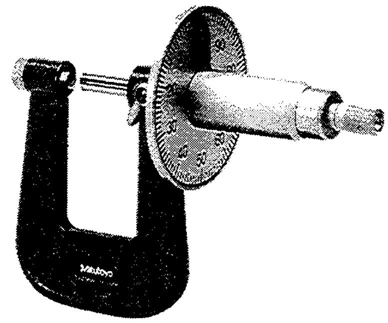


Fig. 2.22 Micrometer with a dial for sheet metal measurement

2.6 Tube Micrometers

This type is designed for measuring wall thickness of tubular parts such as sleeves and collars. It can also be used for measuring from the inside of holes that are too small for the anvil end of a standard micrometer to be inserted. The following types are available:

(1) Spherical anvil type
(2) Spherical anvil and spindle type
(3) Cylindrical anvil type

2.6.1 Spherical anvil type

Fig. 2.23 shows a spherical anvil type micrometer. The spherical anvil measuring face allows measurement of wall thickness of tubes and other parts with cylindrical walls. Measurements are taken by bringing the spherical surface into contact with the inside surface of a tube, and the spindle's flat measuring face into contact with the outside surface.

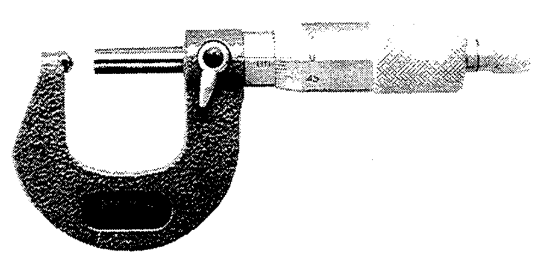


Fig. 2.23 Spherical anvil type for tube wall measurement

2.6.2 Spherical anvil and spindle type

The anvil and spindle measuring faces are both spherical as shown in **Fig. 2.24**. This type is useful for measuring wall thickness of special-shaped tubes with a non-circular outside surface that flat-ended spindles cannot accurately measure.

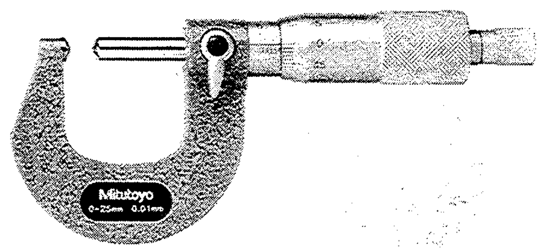


Fig. 2.24 Spherical anvil and spindle type micrometer for tube wall measurement

2.6.3 Cylindrical anvil type

This type is used for measuring wall thickness of tubes with small inside diameters. The shape of the spindle end is either flat or spherical. The cylindrical anvil type requires special care in measurement because the long and thin anvil is subject to bends or deformation when an excessive measuring force is applied. To avoid this problem, the measuring force setting of the ratchet stop is smaller than that of a standard outside micrometer.

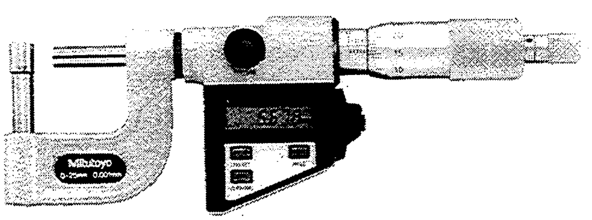


Fig. 2.25 Cylindrical anvil type for tube wall measurement

2.7 Spline Micrometers

In this type, the anvil and spindle have a small diameter in order to measure splined shafts, slots, keyways, etc. that standard outside micrometers cannot measure. The standard size of the measuring portions is 3 mm (dia.) × 10 mm (length). The specifications are basically the same as those of a standard outside micrometer.

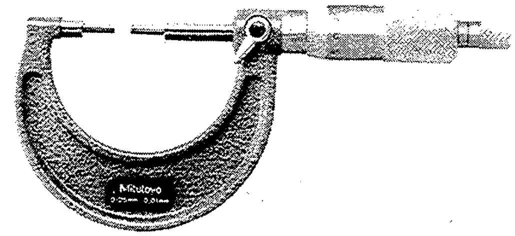


Fig. 2.26 Spline micrometer

2.8 Point Micrometers

As shown in **Fig. 2.27**, point micrometers have a pointed spindle and anvil. This type is used for measuring the web thickness of drills, root circle diameters of external threads, small grooves, and other hard-to-reach portions. The angle of the anvil and the spindle end is 15°, 30°, 45° or 60°. The measuring points normally have a 0.3 mm radius of curvature. Because the two points may not touch at the tips, a gauge block is used for setting the zero point. In order to protect the pointed tips, the measuring force setting of the ratchet stop is smaller than that of a standard outside micrometer.

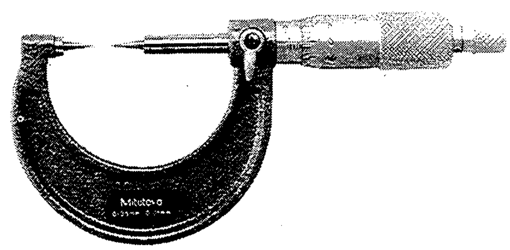


Fig. 2.27 Point micrometer

2.9 Can Seam Micrometers

This micrometer is specially designed for measuring the widths and heights of can seams. As shown in **Fig. 2.28**, the can seam micrometer consists of a micrometer head (which has the same construction as that of a standard outside micrometer) and a measuring head that has a depth bar for measuring seam heights. **Fig. 2.29** shows an example of can seam measurement.

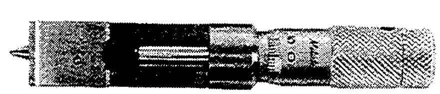


Fig. 2.28 Can seam micrometer

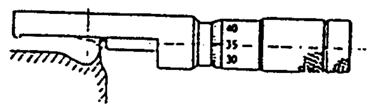


Fig. 2.29 Can seam measurement

2.10 Indicating micrometers

This type of micrometer integrates a dial indicator, as shown in **Fig. 2.30**. The anvil can move a small distance in the axial direction and its displacement is shown on the indicator. This mechanism allows a uniform measuring force to be applied to workpieces, minimizing the variations in measurements that could be caused by variations in the measuring force and the level of expertise of the user.

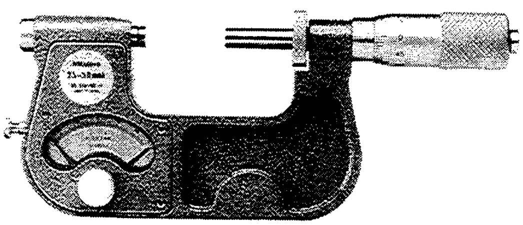


Fig. 2.30 Indicating micrometer

JIS B 7520 specifies the indicating micrometer as follows:
"Micrometers that consist of a micrometer part and an indicator part and have a maximum measuring length of 100 mm or less, where the micrometer part provides 0.01 mm readings and has a measuring stroke of 25 mm, and the indicator part provides 0.002 mm readings and has an indicating range of ±0.02 mm."

2.11 Non-rotating spindle type outside micrometers

In ordinary micrometers, the spindle rotates with the thimble as it is displaced in the axial direction. The non-rotating spindle type outside micrometer does not turn the spindle as it is displaced. **Fig. 2.31** shows its construction. Because the non-rotating spindle does not produce radial torsion on the measuring faces, wear on the measuring faces is greatly reduced. This type is suitable for measuring workpieces with coated surfaces, fragile workpieces, and workpiece features that require a specific angular position of the spindle's measuring face.
Non-rotating spindles are mainly used in the following types of micrometers:

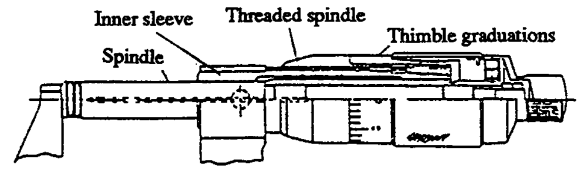


Fig. 2.31 Non-rotating spindle type outside micrometer

(1) Double-thimble micrometer
One of the features of the non-rotating type double-thimble micrometer is that the graduated surface of the thimble is flush with the surface of the sleeve where the index line and the vernier scale are inscribed, which allows parallax-free reading.

(2) Disc type paper thickness micrometer
This type is similar to the disk type tooth thickness micrometer, but it uses a non-rotating spindle in order to eliminate torsion on workpiece surfaces, thus making it suitable for measuring paper and thin workpieces. The disks are used to provide large measuring faces in order to avoid concentrating the measuring force.

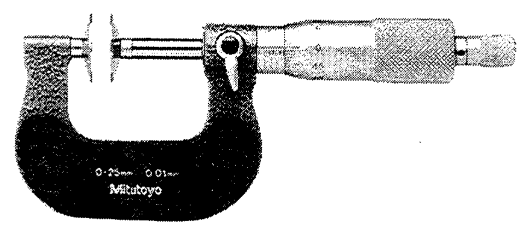


Fig. 2.32 Disc type paper thickness micrometer

(3) Blade micrometer
As shown in **Fig. 2.33**, the anvil and the spindle has a blade so that narrow grooves, keyways, and other hard-to-reach portions can be measured. **Fig. 2.34** shows some types of blades of Mitutoyo blade micrometers.

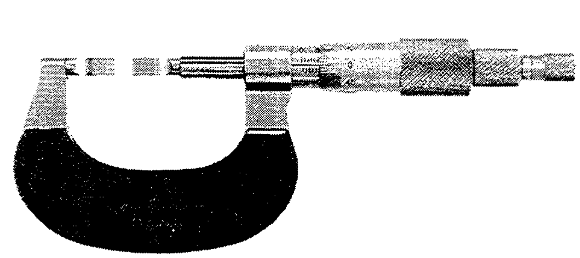


Fig. 2.33 Blade micrometer

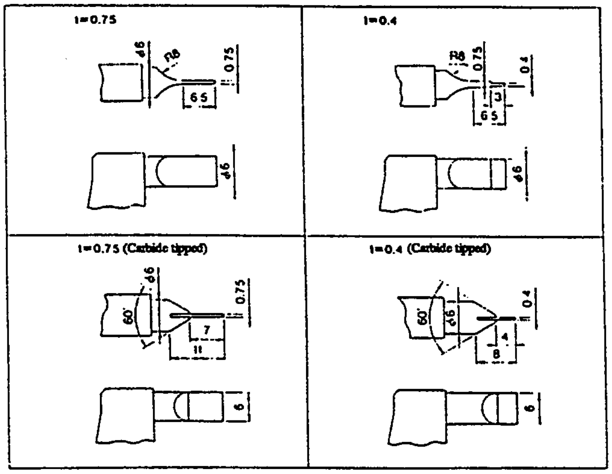


Fig. 2.34 Types of blades

(4) Groove micrometer

This micrometer is used to measure widths and positions of internal grooves (e.g. grooves for O-rings in a hydraulic equipment), as shown in **Fig. 2.35**.

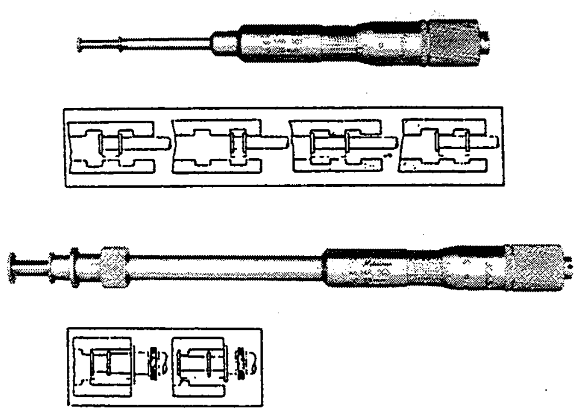


Fig. 2.35 Groove micrometer and examples of use

2.12 Micrometer Heads

The micrometer head consists of a spindle, sleeve, and thimble. Some micrometer heads are provided with a constant-force device such as a ratchet stop. It is seldom used on its own, but is installed on other equipment or used in conjunction with other measuring instruments. In addition to measurement, it is also used as a precision feed device. A wide variety of micrometer heads with measuring ranges from 6.5 mm to 50 mm are available. **Fig. 2.36** shows various types of micrometer heads. The mounting dimensions of popular types of micrometer heads are shown in **Fig. 2.37**.

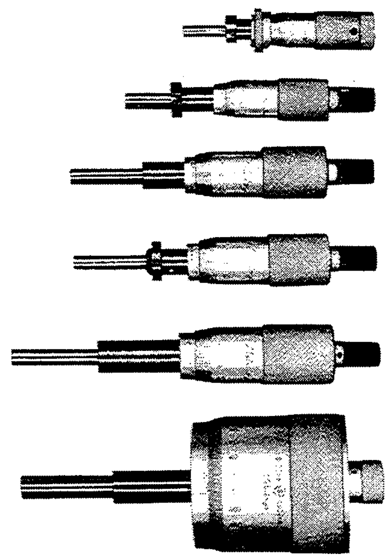


Fig. 2.36 Various types of micrometer heads

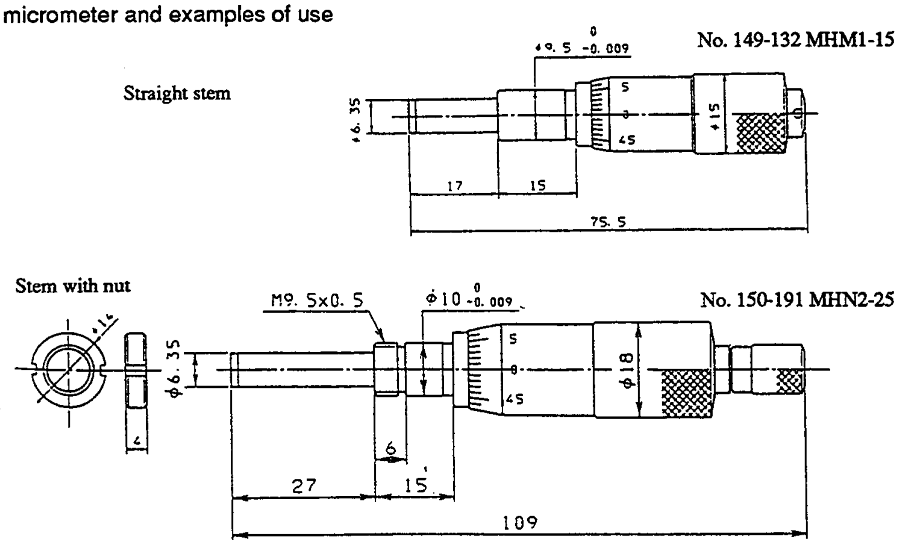


Fig. 2.37 Mounting dimensions of micrometer heads

3. INSIDE MICROMETERS

Like the outside micrometers discussed in the previous chapter, inside micrometers are also diversified into many application-specific types. They are broadly classified as follows:

(1) Tubular inside micrometer
(2) Caliper type inside micrometer
(3) Three-point type inside micrometer

3.1 Tubular Inside Micrometers

Tubular inside micrometers are available in several types, as shown below:

(1) Single rod type
(2) Extension type
(3) Interchangeable rod type
(4) Interchangeable tip type
(5) Internal gear measuring type

3.1.1 Single rod type inside micrometer

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

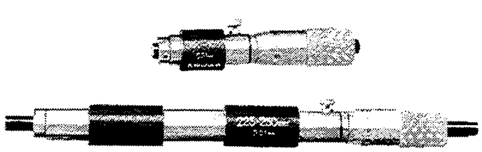


Fig. 3.1 Single rod type inside micrometer

(1) Construction

Fig. 3.2 shows the construction of a single rod type inside micrometer.

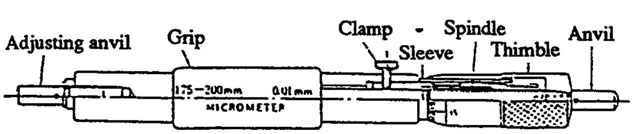


Fig. 3.2 Construction of single rod type inside micrometer

(2) Measuring method

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

Accurate positioning is the key to obtaining accurate measurements of inside diameters. In order to ensure accurate positioning, move the measuring head end to the left and to the right in the lateral direction until the highest point in the plane normal to the axis is determined. Then move it back and forth in the axial direction to determine the shortest distance, as shown in **Fig. 3.3**. This procedure is required even if the micrometer is provided with a constant-force device.

Another measurement technique is to set the micrometer length to the dimension of the lower limit on the drawing, and then while measuring, to make fine adjustments a little at a time until an accurate diameter is obtained.

Tubular inside micrometers take a comparatively long time for making measurements. The longer time of handling increases the effect of heat from the hands on the micrometer, which can substantially increase its length, resulting in a minus error. To minimize the thermal effects, the inspector should always wear gloves and should also try to reduce the measuring time.

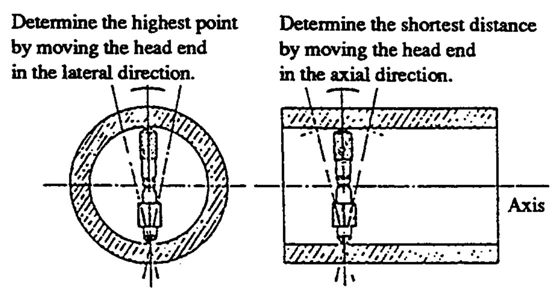


Fig. 3.3 Measuring with an inside micrometer

To measure at a position deep inside a hole, a holder may be used as shown in **Fig. 3.4**. In this case, first set the micrometer length to the approximate dimension, and then make fine adjustments until the micrometer accurately measures the diameter. Bore gauges are more effective for this type of measurement.

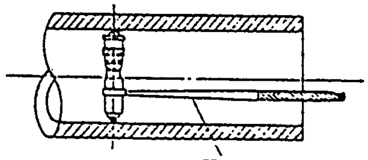


Fig. 3.4 Measuring a diameter deep inside a tube

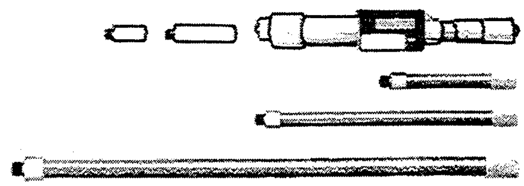


Fig. 3.5 Extension pipe type

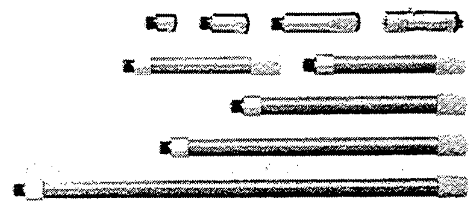


Fig. 3.6 Extension rod type

3.1.2 Extension type inside micrometer

There are two kinds of extension type inside micrometers: the extension pipe type (J-type, **Fig. 3.5**) and the extension rod type (Z-type, **Fig. 3.6**). The maximum measuring length of the extension pipe type ranges from 100 mm to 5000 mm, and that of the extension rod type ranges from 50 mm to 1500 mm. **Table 3.1** shows the comparison between the two types.

Table 3.1 Comparison between the extension tube and extension rod types

Item	Extension pipe type		Extension rod type	
Structure	Pipe	Each extension pipe is finished to a close tolerance on both ends. A specific length is obtained by adding extension pipes.	Rod	The rod is accurately finished to a close tolerance and incorporated in a pipe. A specific length is obtained by adding extension rods.
Weight	Light	Because of the hollow structure	Heavy	Because a solid rod is incorporated in a pipe
Flexure	Small	Because of the light weight	Large	Because of the heavy weight
Thermal effect	Significant	Heat is transmitted from the hands because the pipe is directly held in the hands.	Insignificant	Less subject to thermal effects because the rod that serves as the reference length is inside a pipe, which is held in the hands.
Durability	Less durable	The measuring accuracy is affected because the ends of the pipe are not covered and are subject to contamination and damage.	Durable	Because the rod is incorporated in a pipe, it is not subject to damage. Because connection is made by a flat surface against a spherical surface, the point of contact is relatively free from contamination.
Accuracy		Because the pipe ends are threaded and screwed together, the overall length may change depending on the torque used to tighten them, although the flexure of pipes is small.		The rods are connected by means of a spring, independent of the connection of the external pipes, so the tightening torque does not affect the length. The accuracy is affected by flexure when a long rod is used.
Overall assessment	Light weight and easy to measure with. Special care is required since the end faces are subject to damage and the accuracy is affected by the torque used to connect the pipes. This type is suitable for use in an inspection laboratory where the environment is controlled.		Because of the heavy weight, they are less easy to handle than the pipe type. Because the rod and the connecting pipe are independent, the accuracy is not much affected by dust or careless handling, making it suitable for shop-floor use.	

3.1.3 Interchangeable rod type inside micrometer

This micrometer consists of a micrometer head, interchangeable rods of different lengths, and a handle, as shown in **Fig. 3.7**. One of the interchangeable rods is attached to the micrometer head to obtain the desired measuring range.

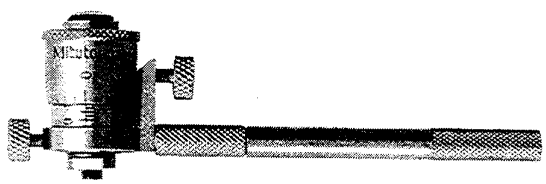


Fig. 3.7 Interchangeable rod type inside micrometer

3.1.4 Interchangeable tip type inside micrometer

This micrometer has the same construction as that of the single rod type inside micrometer, but the measuring heads have a hole for attaching various types of tips, for measuring internal threads, grooves, etc.

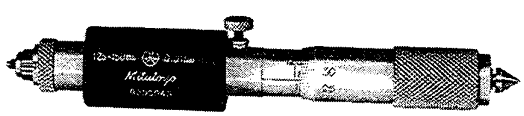


Fig. 3.8 Interchangeable tip type inside micrometer

<Zero point adjustment and calibration>
Zero point adjustment of an outside screw thread micrometer for external threads can be done by bringing the two measuring faces into contact with each other or by using a standard gage. For inside micrometers which measure internal threads, zero point adjustment and calibration must be made against an accurately calibrated screw thread micrometer, as shown in **Fig. 3.9**.

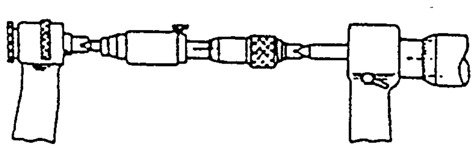


Fig. 3.9 Zero point adjustment of an inside micrometer for measuring internal threads

3.1.5 Internal gear micrometer

This micrometer is used for measuring the diameters of internal gears. It has the same construction as that of the single rod type inside micrometer, but the measuring heads are ball-tipped, as shown in **Fig. 3.10**.

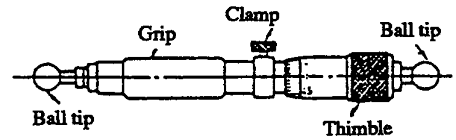


Fig. 3.10 Rod type internal gear micrometer

3.2 Caliper Type Inside Micrometers

3.2.1 Structure of caliper type inside micrometer

Fig. 3.11 shows the external view of a caliper type inside micrometer. The structure of the thimble and sleeve is the same as that of a standard outside micrometer.

Fig. 3.12 shows the internal structure of a caliper type inside micrometer. The spindle goes through a tube to which the fixed jaw (the right side jaw in the figure) is attached. This tube has a keyway in which the key on the inner sleeve is fitted so that the fixed jaw will not turn in the radial direction but can be moved along the sleeve for adjustment. The spindle has two parts, a threaded part which rotates, and a non-rotating part to which the movable jaw (the left side jaw) is clamped by a nut. The thimble is fixed to the rotating part of the spindle. When the thimble is rotated, it displaces the spindle and the movable jaw with respect to the fixed jaw. The distance between the measuring faces of the fixed and movable jaws is read from the graduations on the sleeve and thimble. The graduations are given in the opposite direction of a standard outside micrometer.

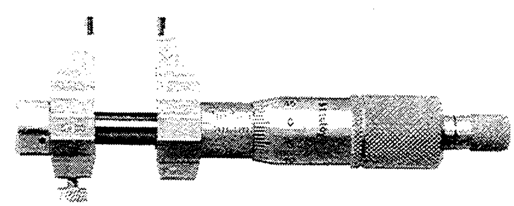


Fig. 3.11 Caliper type inside micrometer

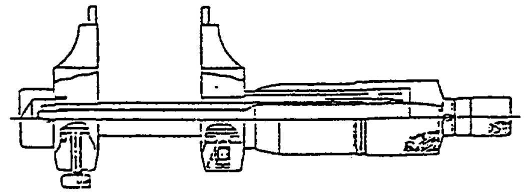


Fig. 3.12 Structure of caliper type inside micrometer

3.2.2 Measuring method

To measure hole diameters with a caliper type inside micrometer, insert the nibs of the jaws in the hole and turn the thimble until the ratchet stop turns idly two or three revolutions. In this case, slightly move one of the jaws back and forth along the circumference of the hole while turning the ratchet stop slowly. This adjustment is required for obtaining the maximum diameter of the hole.

3.2.3 Precautions in using a caliper type inside micrometer

Because the structure of caliper type inside micrometers do not satisfy Abbe's principle (see **6.1.1**), large measurement errors will result when an excessive measuring force is applied. The same measuring force as is used for setting the zero point should be applied when performing measurements.
To set the zero point, use a gauge block with jaws (auxiliary jigs for gauge blocks) attached to both measuring faces of the block, or an accurately calibrated ring gage. A simpler way is to use an outside micrometer and measure the distance between the measuring faces.

3.3 Three-point Type Inside Micrometers

The inside micrometers described above measure inside diameters with only two contact points. This method, however, requires considerable expertise because the micrometer must be accurately aligned with the diametral line of the hole being measured. The three-point type inside micrometer is simpler to use because it aligns itself with the hole axis by means of the three evenly-spaced contact points (anvils). This allows accurate measurements to be made easily without special skill. It uses a tapered part (cone or tapered threads) for converting the spindle's axial displacement to the radial displacements of the contact points.

3.3.1 Three-point type inside micrometers using a cone

Fig. 3.13 shows the external view of a three-point type inside micrometer that uses a cone. (The Mitutoyo three-point type inside micrometer is named the "Holtest.") **Fig. 3.14** shows its internal structure.
When the spindle is displaced forward in the axial direction, the ball contact of the spindle pushes the cone forward. As the cone moves forward, its tapered surface pushes the three contact points outward in radial directions. The measurement is read off the micrometer when the contact points touch the inner surface of the hole with a specific measuring force.
To measure a diameter at a position deep inside a hole, an extension rod may be attached between the measuring head and the micrometer head.

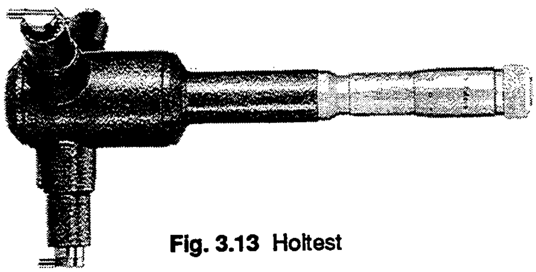


Fig. 3.13 Holtest

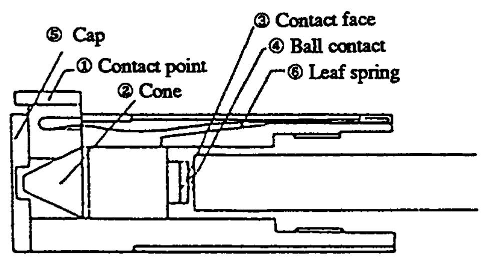


Fig. 3.14 Structure of the Holtest

3.3.2 Three-point type inside micrometers using tapered threads (Imicro manufactured by TESA)

This micrometer has a similar appearance to the Holtest shown in **Fig. 3.13**. Its internal structure is shown in **Fig. 3.15**. The contact points are pressed against the tapered threads by springs. When the spindle is rotated, the tapered threads continuously push the contact points outward in radial directions.
The tapered thread pitch is 1 mm and the micrometer head has a minimum reading of 0.001 mm (0.005 mm or 0.01 mm on large diameter types).
To measure a diameter at a position deep inside a hole, an extension rod may be attached between the measuring head and the micrometer head.

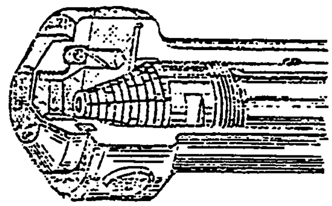


Fig. 3.15 Structure of a three-point type inside micrometer using tapered threads

4. DEPTH MICROMETERS

Depth micrometers are used to measure the depths of holes, slots and steps.
Depth micrometers are classified as follows:
(1) Single rod type
(2) Interchangeable rod type
(3) Sectioned rod type
Of the above three types, the interchangeable rod type is the most widely used.

4.1 Single Rod Type Depth Micrometer

As shown in **Fig. 4.1**, the single rod type depth micrometer consists of a micrometer head, spindle and base. The construction of the sleeve and thimble is the same as that of a standard outside micrometer, but the graduations are given in the reverse direction. The typical measuring range (spindle's stroke) is 25 mm. The end face of the spindle serves as the measuring face. The base is made of hardened steel. Because the bottom face of the base is used as the reference surface, it is precision-lapped to a high degree of flatness. (The bottom face flatness of Mitutoyo depth micrometers is 1.3 μm for the 60 mm base and 2.0 μm for the 100 mm base.)

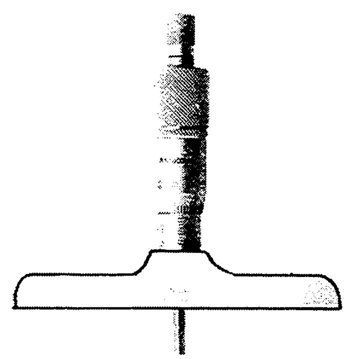


Fig. 4.1 Single rod type depth micrometer

4.2 Interchangeable Rod Type Depth Micrometer

Figs. 4.2 and 4.3 respectively show the external view and the structure of a typical interchangeable rod type depth micrometer.

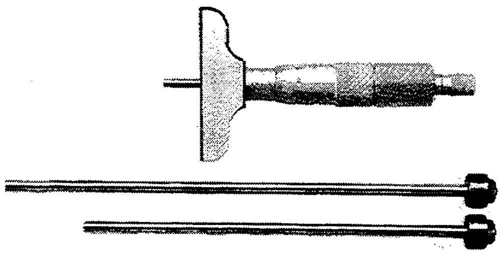


Fig. 4.2 Interchangeable rod type depth micrometer

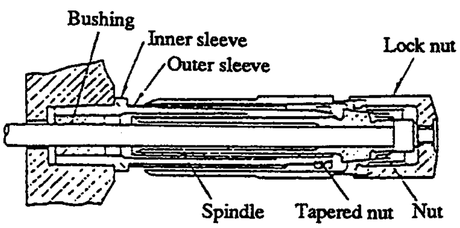


Fig. 4.3 Structure of an interchangeable rod type depth micrometer

This type of micrometer uses a hollow spindle without a measuring face. Instead, an interchangeable rod that goes through the spindle and the base has a precision-lapped measuring face on one end. The other end of the rod is fixed to the spindle. The method of clamping the rod to the spindle depends on the manufacturer (for example, using a rod collar and a set screw, or pressing the rachet stop screw against the rod end).
Interchangeable rods with various lengths are available in 25 mm increments and can easily be replaced according to the desired measuring length.
The sizes and flatness of the base are similar to those of the single rod type depth micrometer. The standard measuring range is 0 to 150 mm, some can measure a depth up to 300 mm.

<Precautions in use>

(1) The reference surface of the base tends to collect dust and cutting chips. Always keep the surface clean to ensure accurate measurements.
(2) Apply sufficient force to the base when taking measurements. If the force is insufficient, the base may be jacked up due to the measuring force applied to the spindle, which results in measurement errors.
(3) When using a long rod, an excessive measuring force can bend the rod. Also, be careful for the ambient temperature, because thermal expansion will be significant on long rods.
(4) Check the zero point each time a rod is replaced.

4.3 Sectioned Rod Type Depth Micrometer

The sectioned rod type depth micrometer is designed to overcome a disadvantage of the single rod type – the measuring range is limited – and that of the interchangeable rod type – various lengths of rods are required and they must be replaced for different measuring lengths. The sectioned rod type allows selection of the effective rod length with one long rod that has V-grooves around its circumference at 25 mm intervals along the axis.
Figs. 4.4 and 4.5 respectively show the external view and the structure of a sectioned rod type depth micrometer. The spindle of this type is hollow which is similar to that of the interchangeable rod type, but it has a dog at one end for clamping the rod at one of the grooves in order to set the effective rod length. The standard measuring range of this type is 0 to 300 mm.

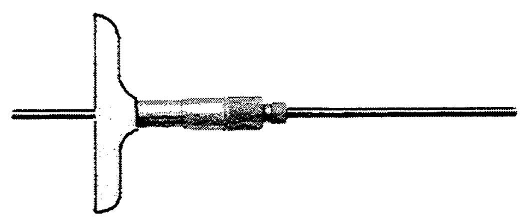


Fig. 4.4 Sectioned rod type depth micrometer

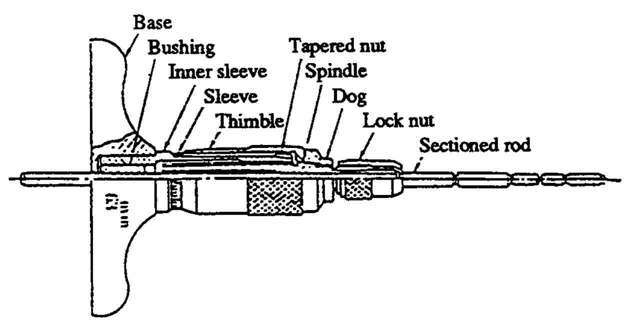


Fig. 4.5 Structure of a sectioned rod type depth micrometer

5. DIGITAL MICROMETERS

5.1 Analog Display vs. Digital Display

When the diameter of a round bar or the thickness of a sheet is measured using a conventional micrometer, the measurement is indicated by an analog scale. If the true value of the dimension could be expressed, it would require an infinite number of decimal digits. While a dimension may be represented by a finite number of digits, say 10.24 mm or 10.25 mm, this number is actually the best estimate that the inspector can read from the scale of his gage. In other words, the inspector has converted the analog value into a digital value based on his judgment.

A measuring instrument that can display digital values dispenses with the need for the inspector's judgment in reading the scale. In order to provide digital readout, a device or mechanism to convert analog data into digital values is necessary. For this purpose, some measuring instruments use mechanical counters while others use electrical A/D converters.

Digital readout micrometers that provide direct readings use either a mechanical or electronic counter, as shown in **Figs. 5.1** and **5.2**. The mechanical counter types usually provide a reading to 0.01 mm. Electronic micrometers detect the spindle's displacement with a rotary encoder and provide a reading to 0.001 mm.

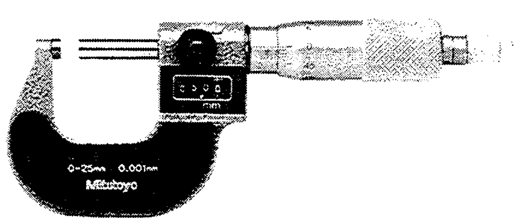


Fig. 5.1 Digital readout micrometer with a mechanical counter

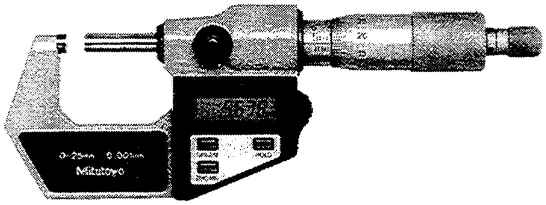


Fig. 5.2 Digital readout micrometer with an electronic counter

5.2 Micrometers with a Mechanical Counter

Mechanical type digital readout micrometers incorporate a counter that counts 1/50th of a revolution of the spindle. This mechanism is employed not only by standard outside micrometers but also by inside micrometers (**Fig. 5.3**), depth micrometers, micrometer heads (**Fig. 5.4**), and other types of special-purpose micrometers.

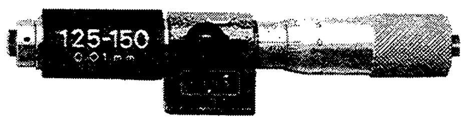


Fig. 5.3 Inside micrometer with a mechanical counter

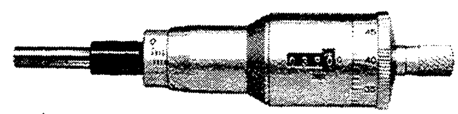


Fig. 5.4 Micrometer head with a mechanical counter

5.2.1 The counter mechanism

Fig. 5.5 shows the counting mechanism of an outside micrometer. Each counter ring has the digits from 0 to 9 inscribed around it. The lowest decimal place indicates a unit of 0.01 mm, therefore one full revolution of the counter ring (ten digits) corresponds to a measured length of 0.1 mm. If the micrometer spindle has a thread pitch of 0.5 mm (meaning that one revolution of the spindle corresponds to 0.5 mm of the spindle's linear displacement), then to indicate a unit of 0.01mm, the counter ring for the lowest digit must rotate five revolutions per revolution of the spindle. To do this, the spindle and this counter ring are linked via a gear train with a ratio of 5 to 1.

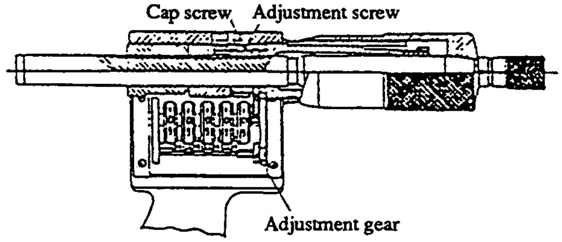
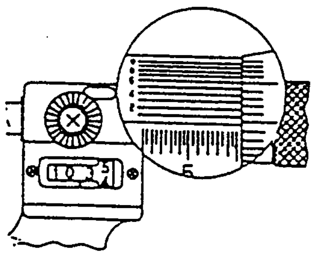


Fig. 5.5 The counter mechanism of an outside micrometer

5.2.2 Reading micrometers with a mechanical counter

Fig. 5.6 shows how to read a micrometer that uses a mechanical counter and a vernier. In the case shown, be careful not to misread the measured value as 10.356. (This error occurs when the smallest digit is incorrectly read.)



Counter reading: 10.3
Thimble reading: 0.04
Vernier reading: 0.006 (+
Total micrometer reading: 10.346

Fig. 5.6 Reading an outside micrometer with a digital counter and a vernier

5.2.3 Advantages of digital-readout micrometers

The obvious advantage of digital-readout micrometers is the ease of reading. There is also another advantage. On conventional analog micrometers, there is a chance to misread the sleeve divisions by 0.5 mm. This problem is eliminated by digital-readout micrometers.
One of the cautions required in reading a micrometer with a mechanical counter is to avoid misreading a digit when the next lower digit is about to change from 0 to 9.
The following report shows an experiment that was conducted to find the difference of the frequencies of occurrence of 0.5 mm reading errors, between an analog micrometer and a digital-readout micrometer.

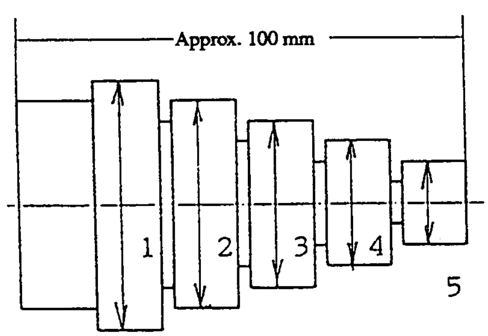


Fig. 5.7 Sample workpiece

Measured portion	1	2	3	4	5
Diameter (mm)	15.850	14.553	11.302	9.955	7.701

Twelve experienced micrometer users and eighteen inexperienced people (who knew how to use a micrometer) participated in the experiment. The diameters of five portions on a sample workpiece (**Fig. 5.7**) were measured using a digital-readout micrometer with a mechanical counter, and using a standard outside micrometer.

- Micrometers used:
  Digital-readout outside micrometer (Mitutoyo micrometer model 193-101)
  Standard outside micrometer (Mitutoyo micrometer model 103-137)
- Measuring positions:
  Diameters of five portions 1, 2, 3, 4 and 5 shown in **Fig. 5.7**
- Discrimination: 0.001 mm

<Results of 0.5 mm reading errors>
Table 5.1 shows the results of the experiment.
Both the experienced and inexperienced users made 0.5 mm reading errors when they used the standard outside micrometer. On the other hand, none of them made 0.5 mm reading errors when they used the digital-readout outside micrometer.

Table 5.1 Results of 0.5 mm reading error experiment

	Number and percentage of reading errors			
Micrometer used	Standard outside micrometer (Mitutoyo 103-137)		Digital-readout outside micrometer (Mitutoyo 193-101)	
Experienced	4	6.7%	0	0%
Inexperienced	14	15.6%	0	0%
Total	18	12.0%	0	0%

5.3 Digimatic Micrometers

Prompted by the rapid progress of IC technologies and the development of display devices such as LCD's, electronic and digital capabilities have been incorporated into micrometers. These advanced features have eliminated human errors in reading and enabled micrometers to be integrated into a data processing system, paving the way to a new field of measurement and inspection.
The Mitutoyo digital readout micrometers with an electronic readout are named the "Digimatic" micrometers. These micrometers incorporate a photoe lectric or capacitance type rotary encoder which de-

tects the spindle rotation and electrically divides the count signals to display down to 0.001 mm. This electronic system is used in various types of Mitutoyo micrometers including standard outside micrometers, interchangeable anvil type outside micrometers, gear-tooth micrometers, depth micrometers, micrometer heads, and bench micrometers, as shown in **Figs. 5.8 - 5.12.**

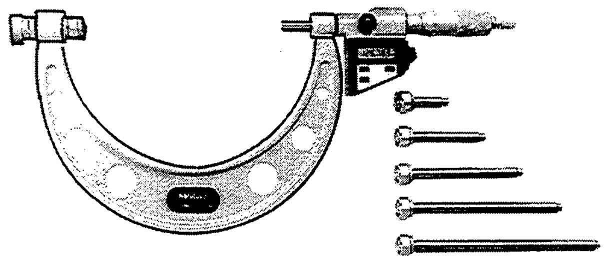


Fig. 5.8 Interchangeable anvil type Digimatic outside micrometer

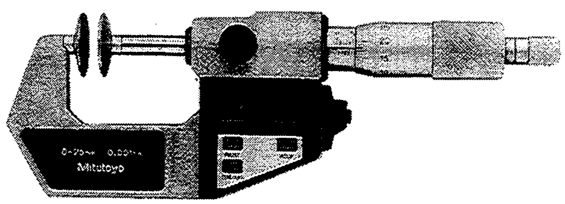


Fig. 5.9 Digimatic gear-tooth micrometer

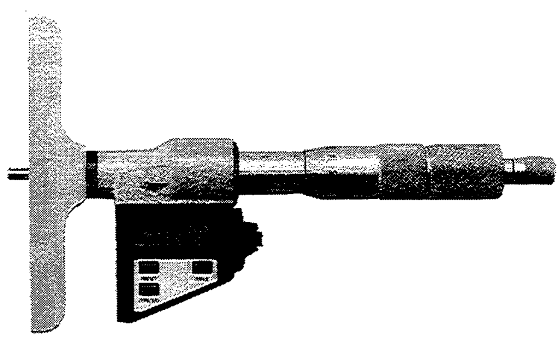


Fig. 5.10 Digimatic depth micrometer

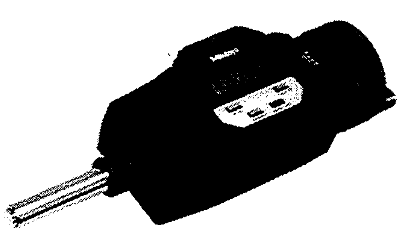


Fig. 5.11 Digimatic micrometer head

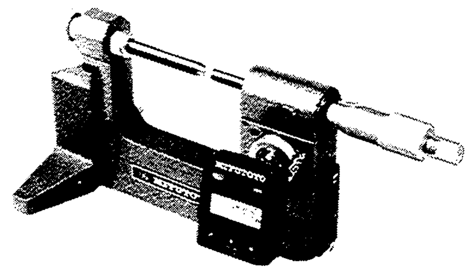


Fig. 5.12 Digimatic bench micrometer

6. ERRORS INVOLVED IN MICROMETER MEASUREMENT

It is important to know the possible causes of errors when measuring with a micrometer or other measuring instruments. Based on this knowledge, the appropriate instrument and measuring method should be used.

The following points must be kept in mind when making measurements with a micrometer:

(1) Abbe's principle
(2) Parallax error
(3) Airy point, Bessel point
(4) Hooke's law
(5) Hertz's deformation
(6) Instrumental errors
(7) Effect of temperature

6.1 Abbe's Principle

Ernst Abbe, a co-founder of Zeiss (Jena) Company, proposed in 1890 that "maximum accuracy may be obtained only when the standard is in line with the axis of the workpiece being measured." This is the so called "Abbe's principle" and explanatory examples are shown in the following.

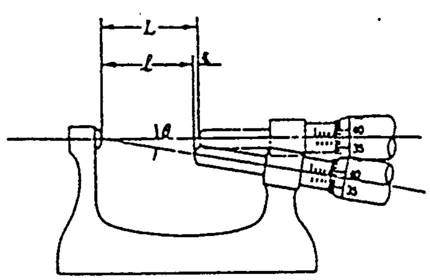


Fig. 6.1 Abbe's error – Example (1)

In **Fig. 6.1**,

$$\varepsilon = L - l = L(1-\cos\theta)$$
$$= L\left[1-\left\{\left(1-\sin^2\frac{\theta}{2}\right)-\sin^2\frac{\theta}{2}\right\}\right]$$
$$= L - L + 2L\sin^2\frac{\theta}{2}$$
$$= 2L\sin^2\frac{\theta}{2}$$
$$= 2L\left(\frac{\theta}{2}\right)^2$$
$$\therefore \varepsilon = \frac{1}{2}L\theta^2$$

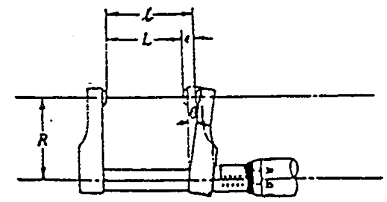


Fig. 6.2 Abbe's error – Example (2)

In **Fig. 6.2**,

$$\varepsilon = l - L = R\tan\theta$$
$$= R\cdot\theta$$

Letting
$\theta = 1/3000$ rad, L = 30 mm, and R = 30 mm,
Substituting them for the formula in Example (1),
$\varepsilon = 0.0000017$ mm
Substituting them for the formula in Example (2),
$\varepsilon = 0.01$ mm
The error in Example (1) is usually negligible because it is a quadratic function of the angle θ. On the other hand, the error in Example (2) can be significant because it is a linear function of the angle θ.

6.2 Parallax Error

The parallax is the change in the apparent relative orientations of objects when viewed from different positions. It causes measurement errors when there is a height difference between two graduated faces as shown in **Fig. 6.3**. In this case, the apparent alignment of the graduation lines differs depending on the eye position.

In **Fig. 6.4**, letting,

A: Vertical distance between the sleeve surface to the eye
h: Height difference between the graduated faces of the sleeve and the thimble
B: Horizontal distance between the index line on the sleeve and the eye

then, the parallax error Δf is given as follows:

$$\Delta f = \frac{B\cdot h}{A} \text{ ----------(3)}$$

If,
A = 250 mm, h = 0.35 mm and B = 130 mm, (i.e., viewed from an angle at approximately 30°), then, the parallax error is calculated from formula (3) as follows:

$$\Delta f = 130\times\frac{0.35}{250} = 0.182 \text{ (mm)}$$

The measurement error caused by the parallax in this example can be obtained by dividing the parallax error by the micrometer's amplification (ratio of the thimble's graduation spacing to the corresponding displacement or discrimination of the spindle). If the outside diameter of the thimble is 14.5 mm and the thimble's circumference is graduated in 50 equal divisions, one graduation spacing is given as:

$$14.5 \times \frac{\pi}{50} = 0.911 \text{ (mm)}$$

Therefore, the measurement error due to the parallax is calculated as:

$$\text{Parallax} \div \frac{\text{graduation spacing}}{\text{discrimination}}$$

$$= 0.182 \div \frac{0.01}{0.911} = 0.002 \text{ (mm)}$$

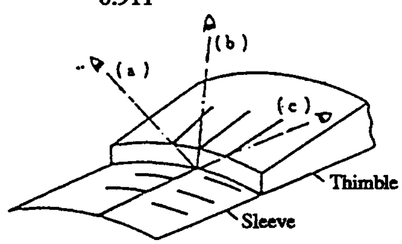


Fig. 6.3 Parallax

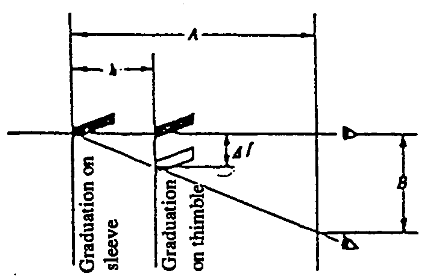


Fig. 6.4 Example of parallax error

6.3 Airy Point and Bessel Point

When horizontally supporting a long and thin bar, such as a standard bar used for outside micrometers with a long measuring length or a tubular inside micrometer, the amount of flexure due to its own weight varies significantly depending on the supporting positions. This variation can be a cause of measurement errors. Airy points and Bessel points are supporting points to obtain specific flexure conditions.

(1) Airy points

The Airy points are used to support end gages such as gauge blocks or standard bars so that the end faces are parallel (Fig. 6.5). The support points are given by the following formula:

$$a = \frac{L}{\sqrt{N^2 - 1}}$$

where, N = number of supporting points

If the two end faces of the gage and the measured surfaces are parallel, the measurement error is a linear function of the amount of flexure.

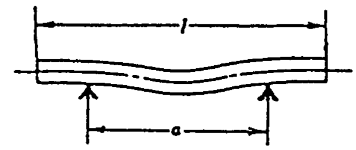


Fig. 6.5 Airy points (a = 0.5774L)

(2) Bessel points

Bessel points apply to two-point support of a bar. They minimize the contraction of the overall length (Fig. 6.6). This method is suitable for supporting tubular inside micrometers and standard scales that have graduations on the neutral surface*.

Bessel points are also used in the case where one end of a gage makes a point contact with a measured surface.

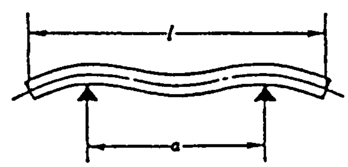


Fig. 6.6 Bessel points (a = 0.5594L)

* Neutral surface:

When a beam is bent downward by a force that causes no shearing stress, it is called "simple bending." In this case, the beam is compressed on the upper side and extended on the lower side. In the middle, there is a surface that is neither compressed nor extended. This surface is called "the neutral surface." If the beam has a rectangular cross section and is bent in two orthogonal directions, the line formed by the intersection of the two orthogonal neutral surfaces is called "the neutral axis".

6.4 Hooke's Law

Hooke's law shows the relationship between stress and strain. Within the elastic limit, the stress of an elastic solid is directly proportional to the strain applied to it.

When a longitudinal load is applied to a bar, the amount of contraction, δL (mm) is given as follows:
Letting,
A: Cross-sectional area (mm^2)
(For a bar with a diameter D: $A = \frac{\pi}{4} \times D^2$)
L: Length (mm)
E: Modulus of longitudinal elasticity (Young's modulus; kg/mm^2)
P: Load (kg)
Then,

$$\delta L \text{ (mm)} = \frac{PL}{EA}$$

Supposing that a standard bar (D = 8 mm, L = 100 mm) is measured using an outside micrometer with a measuring force, P = 1 kg, and letting $E = 2 \times 10^4$ kg/mm^2, the amount of contraction (δL) of the standard bar will be:

$$\delta L = \frac{1 \times 100}{20000 \times 16\pi} = \frac{100}{20000 \times 16\pi}$$
$$= 0.001 \text{ (mm)}$$

6.5 Hertz's Deformation

Hertz's formula is an empirical formula that gives the amount of surface deformation within the elastic limit when two surfaces (spherical, cylindrical, or planar surfaces) are pressed against each other under a certain force. The formula applies to specific combinations of surfaces, which include: a spherical surface against a plane, a cylindrical surface against a plane, and two cylindrical surfaces (whose axes are orthogonal). It is an important formula for determining the deformation of a workpiece caused by the measuring force.

When two surfaces contact at a point or along a line, as shown in **Fig. 6.7**, and are pressed against each other under a measuring force (P), the amount of deformation (δ_1 and δ_2) in each case is given as follows:
(a) Spherical surface and plane (point contact):

$$\delta_1 = 3.8 \sqrt[3]{\frac{P^2}{D}}$$

(b) Cylindrical surface and plane (line contact):

$$\delta_2 = 0.92 \frac{P}{L} \sqrt[3]{\frac{1}{D}}$$

where,
Modulus of elasticity (for steel): $E = 2 \times 10^4$ (kg/mm^2)
Amount of deformation: δ (µm)
D: Diameter of ball/cylinder (mm)
L: Length of cylinder (mm)
P: Load (kgf)
Supposing that a ball (D = 1 mm) and cylinder (D = 1 mm, L = 5 mm) is measured with a force (P = 1 kg), the amounts of deformation are:
(a) $\delta_1 = 3.8$ µm
(b) $\delta_2 = 0.18$ µm

Hertz's deformation must be taken into consideration when measuring a small workpiece that makes a point contact with the gaging head. However, it is difficult in practice to determine the amount of Hertz's deformation. A practical method may be used to compensate for the measurement error caused by the deformation. A comparison measurement of a reference gage that is made of the same material and has the same form and surface as those of the workpiece may be used to compensate for the measurement error caused by the deformation. This method is called the error compensation method or the zero method.

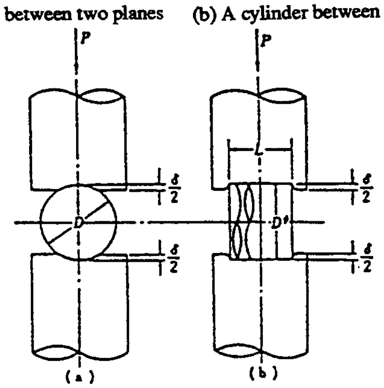


Fig. 6.7 Hertz's deformation

6.6 Effects of Temperature

Objects contract or expand with changes in temperature. Therefore, the temperature conditions must be specified when discussing dimensions. This consideration is particularly important when a high measuring accuracy is required, when a long workpiece is measured, or when a workpiece that is made of a different material from the gage is measured.
The international standard temperature for measurement is 20°C. Discussions on dimensions should be based on this temperature condition. A special facility such as a temperature-controlled chamber is required to maintain the standard temperature. It takes a long time for both a workpiece and a measuring instrument to thermally stabilize to the standard temperature.

Because of these problems, strictly conforming to the standard temperature is sometimes impractical in terms of cost and time. More practical measures may be used considering the fact that most products are machined, assembled, and used under similar room temperature conditions (generally 10°C to 35°C in Japan).
The change of length of a solid in a unit of length for a change in temperature of 1°C is called the coefficient of linear expansion. This coefficient is the same for objects of the same material and grain structure, and that have gone through the same treatment or process.

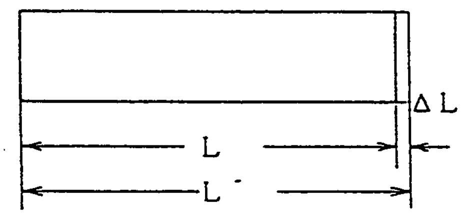


Fig. 6.8 Thermal expansion

In **Fig. 6.8**, supposing that a length L of an object at temperature t_1 changes to length L' at a different temperature t_2, an expansion or contraction ΔL of the object is;

$$\Delta L = L' - L$$

The linear expansion coefficient, α, of this object is expressed as follows:

$$\alpha = \frac{L' - L}{(t_2 - t_1)L} = \frac{\Delta L}{L} \times \frac{1}{\Delta t}$$

Therefore, the following formula can be obtained:

$$\Delta L = \alpha \cdot \Delta Lt \cdot L$$

$$\therefore\ L' = L(1 + \alpha \cdot \Delta Lt)$$

<Reference>

Linear expansion coefficients of some materials

Cast iron:	9.2 to 11.8 × 10^{-6}/°C
Carbon steel:	10 to 13 × 10^{-6}/°C
Brass:	18.5 × 10^{-6}/°C
Aluminum:	23.8 × 10^{-6}/°C

Zirconium-based ceramics: 10 to 11 × 10^{-6}/°C

In order to minimize measurement errors due to the effects of temperature, make sure that both the workpiece and the measuring instrument are at the same temperature. The following are some of the required precautions:

(1) Do not hold the workpiece or instrument in your hands for a long time.

(2) Do not expose the workpiece or instrument to direct sunlight.
In particular, special care should be taken when a large workpiece is to be measured and when the coefficients of linear expansion between the workpiece and the measuring instrument are different.

6.7 Instrumental Errors

No measuring instrument can be manufactured to be absolutely free from errors. As the accuracy requirements of a measuring instrument become higher the difficulty in manufacturing increases, and manufacturing costs increase accordingly. Therefore, measuring instruments should be selected according to the accuracy requirement. Even if a very accurate instrument is used, measurement errors may occur due to variations in environmental conditions and human errors.
The instrumental error is the error that is inherent to a measuring instrument. In other words, it is the difference between the true value and the measured value, when a measurement is taken under the standard conditions specified for that instrument. It is important to know the instrument error because by compensating for the error more accurate measurements can be obtained.
Instrumental errors are determined by calibration and are usually given in the inspection certificate or specifications that come with a measuring instrument. When compensating a measured value for the instrumental error, change the sign of the instrument error value and add it to the measured value.

7. USING MICROMETERS

7.1 General Care Required when Using Micrometers

The previous chapter discussed various types of errors that may be involved in micrometer measurements. The following is a description of the general care required to minimize measurement errors when using micrometers.

(1) Thoroughly wipe measuring faces clean of dust and oil. Check for scratches and burrs on measuring faces. Burrs are frequently found near the edges of the measuring face. Use a fine-grained oilstone (e.g. Arkansas stone or Mitutoyo CERASTON) to remove burrs.

(2) Check that (i) the sleeve turns evenly, (ii) the thimble doesn't stick to the sleeve when it is turned, (iii) the ratchet stop turns evenly, and (iv) the clamp is effective.

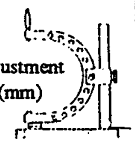
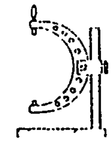
(3) Adjust the zero point.
Hold the ratchet between the thumb and the middle finger. Gently turn the ratchet to bring the measuring faces of the spindle and the anvil into contact. Next, rotate the ratchet by another 1-1/2 to 2 turns. Then, confirm that the zero line on the thimble is aligned with the index line on the sleeve. Repeat this process two or three times to confirm the alignment. (When measuring a workpiece, manipulate the ratchet in the same way as described above.)

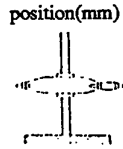
(4) When making measurements, check the zero point periodically to confirm that there is no discrepancy. Measurements should be taken under the same conditions (orientation, measuring force, etc.) that existed when setting the zero point for the measurement. This practice is particularly important when using a large-size micrometer.

(5) When making measurements, ensure that the micrometer is not subjected to sudden temperature changes, direct sunlight, radiant heat or air currents that may cause a significant variation in temperature.

(6) When measuring a heavy workpiece that is mounted on a machine, the micrometer should be carefully orientated. This is especially important when the measuring length exceeds 300 mm (see **Table 7.1**).

Table 7.1 Variation in measurements for different support positions (unit:mm)

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

Support position	Supported at center (horizontal)	Held by hand
Orientation / Maximum measuring length (mm)	Zero adjustment position(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

(7) When measuring a spherical or cylindrical workpiece where the workpiece surface contacts the micrometer measuring faces at a point or line, special care must be taken to; (i) prevent "spindle play", due to excessive clearance between the spindle and the spindle guide at the end of the inner sleeve, (ii) apply an appropriate measuring force, and (iii) make sure that measuring surfaces are flat and parallel.

(8) Minimize parallax errors by viewing from the correct angle. View the index line on the sleeve from directly above.

(9) Never measure a workpiece that is rotating. When measuring a workpiece on a machining stage, stop the machine and wait until the workpiece comes to rest. After cleaning the workpiece of dust and other contaminants, take measurements with a micrometer. Orient the micrometer properly.
(10) Feed the spindle by turning the thimble only. Never spin the micrometer by holding the thimble; such mishandling will damage the instrument.
(11) Do not attempt to turn the thimble when it is clamped.
(12) When the micrometer is dropped or imparted with a blow, readjust the zero point before resuming measurement.

- Refer to the "Basic Rules on Using Measuring Tools" textbook, from the Mitutoyo Metrology Institute, for other precautions.

7.2 Inspecting Micrometers

The following items should be checked on micrometers:
- Appearance and operation
- Accuracy

7.2.1 Checking appearance and operation

Check the following:
(1) Check the condition of the plating and paint. There should be no discoloration, peeling, rust, etc.
(2) Check the graduations or display. It should be free of marks and other damage. The graduation lines should have the same thickness.
(3) The measuring surfaces should be free of scratches and burrs, which could affect measurement.
(4) Check the fit of the threads. The screws should turn smoothly over the entire stroke and be free from backlash.
(5) The threads of the spindle and inner sleeve should permit easy adjustment of the fit when they become worn.
(6) Any misalignment that may exist between the spindle and the anvil should be small enough so as not to affect measurement.
(7) The spindle should be easy to clamp firmly. The micrometer reading should not change by more than 2 µm when the spindle is clamped.
(8) The ratchet stop or friction thimble should rotate smoothly.
(9) The clearance between the thimble and the sleeve should be even around the circumferences. The runout of the thimble should be minimal (should not be visible with the naked eye).
(10) When the zero line on the thimble is aligned with the index line on the sleeve, the end of the thimble should be aligned with a graduation line on the sleeve but should not overlap the graduation line so as to hide it.
(11) The zero point of the micrometer should be adjusted exactly.
(12) For micrometers with a mechanical counter, the counter should be adjusted exactly.
(13) For micrometers with a mechanical counter, the counter rings should rotate smoothly over the entire stroke of the spindle. The idling or play of the counter rings should be minimal so as not to affect the reading.
(14) The clearance between the spindle and the spindle guide at the end of the inner sleeve should not exceed 10 µm (see **Fig. 7.1**).

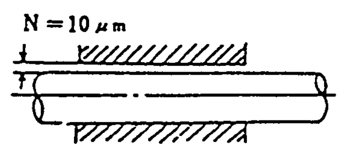


Fig. 7.1 Clearance between the spindle and spindle guide

(15) The play in the threads of the spindle and inner sleeve should not exceed 20 µm in the axial direction.

7.2.2 Checking accuracy

Inspection of measuring accuracy is required for all types of micrometers. In addition, flatness and parallelism must be checked on micrometers that have flat measuring faces.

(1) Checking the flatness of measuring faces
The flatness of measuring faces of a micrometer can be checked using an optical flat (**Fig. 7.2**) or optical parallel (**Fig. 7.3**). Clean the measuring face thoroughly, then place an optical flat or optical parallel on the

measuring face as shown in **Fig. 7.4**. Unless the measuring face is perfectly flat, red interference fringes will be produced under white light when seen through the optical flat or optical parallel. Observe the pattern of the interference fringes to check the surface condition and count the number of fringes to determine the flatness. The flatness is given by the number of interference fringes multiplied by 0.32 µm. **Fig. 7.4** shows some patterns of interference fringes.

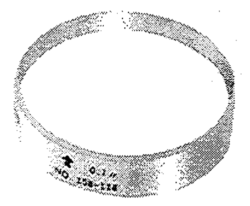


Fig. 7.2 Optical flat

Fig. 7.3 Optical parallel

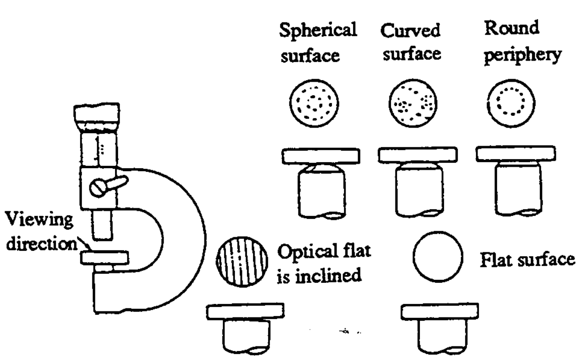


Fig. 7.4 Checking the flatness of a measuring face with an optical flat or optical parallel

(2) Checking the parallelism between measuring faces
The parallelism between measuring faces of a micrometer can be checked using optical paralles or gauge block, or a combination of these, depending on the size of the micrometer.

(a) Using optical parallels
If the micrometer to be checked has a measuring range of 25 mm, a parallelism check is carried out using optical paralleles. Place an optical parallel between the anvil and spindle, as shown in the diagram on the right in **Fig. 7.5**, and apply normal measuring force to the optical parallel. Determine the flatness by counting the number of the red interference fringes produced under white light.
When the micrometer has a measuring range of 50 mm or greater, use a gauge block between two optical parallels, as shown in the diagram on the left in **Fig. 7.5**.
When checking parallelism with the method described above, the optical parallel may be inclined with respect to the axis of the spindle as shown in **Fig. 7.6**. To avoid errors when measuring parallelism, repeat the same procedure four times using four paralles to change the angular position of the spindle by 90° intervals, and take the maximum value as the parallelism.
For micrometers with a measuring range exceeding 175 mm, the parallelism should be checked by method (b).

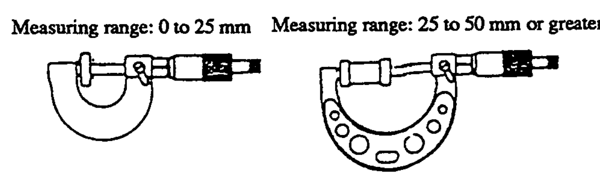


Fig. 7.5 Checking the parallelism between measuring faces with optical paralleles

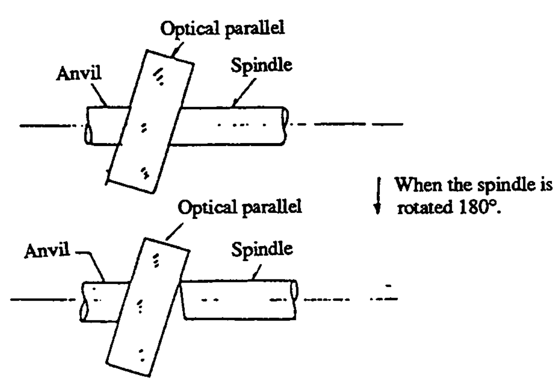


Fig. 7.6 Inclined optical parallel causes measurement errors

(b) Using gauge blocks
Place a gauge block between the measuring faces so that it can be measured at the center of the measuring faces. Measure the gauge block by applying normal measuring force. Then, measure the gauge block at four positions close to the edge of the measuring faces, as shown in **Fig. 7.7**. The parallelism is given as the difference between the maximum and minimum readings.

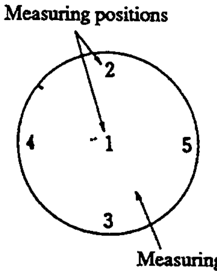


Fig. 7.7 Checking the parallelism between measuring faces with a gauge block

(3) Checking the instrumental error
Perform the zero point adjustment of a micrometer with the measuring length set to its minimum. Place a gauge block between the measuring faces and take a reading off the micrometer by applying normal measuring force. (For inside micrometers, use flat jaws attached on both sides of a gauge block and measure the distance between the jaws.) The instrumental error is the difference between the measured value and the actual size of the gauge block.

Note:
For inside micrometers, the instrumental error can be determined with a measuring machine.

(4) Checking the spindle feeding error
The feeding error of the spindle is determined by measuring several gauge blocks of different sizes.
As shown in **Fig. 7.8**, attach a spherical anvil to an anvil holder that is fixed to the micrometer so that the anvil is aligned with the axis of the spindle. After adjusting the zero point under normal measuring force, place a gauge block between the measuring faces and determine the difference between the micrometer reading and the gauge block size.
Repeat this procedure on several gauge blocks of different sizes. The feeding error is given as the difference between the maximum and minimum differences determined for each gauge block.

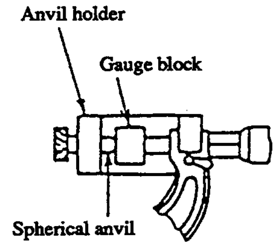


Fig. 7.8 Checking the spindle feeding error

Note:
The sizes of the gauge blocks used to determine the instrumental error or spindle feeding error should be selected so that measurements are taken in various angular positions of the spindle. For example, a set of 2.5 mm, 5.1 mm, 7.7 mm, 10.3 mm, 12.9 mm, 15 mm, 17.6 mm, 20.2 mm, 22.8 mm, and 25 mm gauge blocks is sufficient.

7.3 Maintenance and Periodic Inspection of Micrometers

It is essential to preserve the measuring accuracy and performance of measuring instruments to implement effective quality control. Poor maintenance of measuring instruments leads to poor quality control which may result in considerable losses due to out-of-tolerance parts. For example, an inaccurate micrometer could result in an entire lot of products failing to meet specifications. Even worse, the shipped products might be sent back to the company because of their poor quality, and tarnish the company's reputation and image.
Neglecting periodic inspection of measuring instruments may result in variations in measurements, which may result in confusion between the design department, shop floor, and inspection room. Proper maintenance of measuring instruments cannot be attained unless all employees concerned understand the importance of maintaining precision measuring equipment. This section discusses micrometer maintenance and periodic inspection.

7.3.1 Maintenance of micrometers

The following are required to maintain micrometer accuracy:

(1) Daily inspection
(2) Cleaning and rust prevention
(3) Special care in using and storing electronic micrometers

(1) Daily Inspection

(a) Checking the zero point

Even if the zero point of a micrometer has been accurately adjusted, it may need to be adjusted again after hours of use. Changes in temperature and other environmental conditions can also cause the zero point to deviate. It is therefore necessary to check the zero point before commencing each measurement session. The zero point must be checked more frequently when the micrometer is used in an environment where there is a significant variation in temperature. When checking the zero point of large micrometers, the micrometer must be orientated in the same position that will be used when measuring.

(b) Checking the measuring force

Variations in the measuring force significantly affects measuring accuracy. For micrometers with a ratchet stop or friction thimble, check that the ratchet stop or friction thimble turns smoothly and otherwise functions properly.

(c) Checking the fit

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

(d) Checking the micrometer after it has been dropped or subjected to a blow

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

(2) Cleaning and rust prevention

(a) After using a micrometer, wipe off oil, cutting or grinding fluid, fingerprints and other contaminants (fingerprints may cause rust). Carbide-tipped measuring faces should be wiped with a dry cloth thoroughly. If the measuring faces are not carbide-tipped, apply rust-preventing oil after wiping them clean. Separate the two measuring faces slightly before storing a micrometer.

(b) Wipe cutting or grinding chips from the spindle before using a micrometer. These particles may become trapped between the spindle and the spindle guide when the spindle is moved.

(c) When a micrometer is not going to be used for an extended period of time, wipe it thoroughly and apply a high-grade rust-preventing oil. Protect the micrometer from dampness by tightly wrapping the micrometer with oil-soaked paper or cloth before putting it in the case. Select a storage place where humidity is low and temperature changes are small.

If the micrometer has been stored for a long period of time, inspect it thoroughly.

(3) Special care in using and storing electronic micrometers

Because electronic components can be easily damaged, electronic micrometers require greater care than conventional mechanical micrometers. The following precautions must be observed when handling electronic micrometers:

- Do not drop or bump.
- Protect the micrometer from dust, oil, and water. Though most electronic micrometers are splash-proof to some extent, they shouldn't be handled in the same way as mechanical micrometers.
- Do not subject the micrometer to direct sunlight or ultraviolet rays. Ultraviolet rays accelerate deterioration of LCDs (liquid crystal displays).
- Do not subject the micrometer to sudden temperature changes or heat, which may cause condensation on the interior and affect the adhesive used in the micrometer.
- Do not apply voltage to the micrometer because it may damage internal ICs. For example, do not use an electric marker pen on the micrometer.
- Electrical interference may cause failure or malfunction of electronic components. Micrometers that use line power via an AC adapter are subject to electrical interference from other equipment that share the same power outlet. Electromagnetic fields, current leaks, and static electricity can also interfere

with electronic micrometers.

- Do not use an organic solvent to clean the micrometer; it may deteriorate the plastic parts of the micrometer. Use neutral detergent for cleaning.
- Make sure that the battery is orientated correctly, otherwise the micrometer will not operate and its electronic components may be damaged. If the micrometer is not going to be used for an extended period of time, remove the battery to prevent damage that may be caused by battery leakage.
- Do not disassemble the micrometer. Send the micrometer to the manufacturer for repair.

7.3.2 Periodic inspection

As with any instrument, deterioration is unavoidable after a long period of service. Micrometers are no exception. The degree of deterioration depends on the frequency of use, environmental conditions, handling, and so on. If one continues to use a micrometer, oblivious to accuracy deterioration, one can expect to suffer the consequences, in the form of rejected products.

To implement a periodic inspection schedule the following must be established:

(1) Accuracy standard
(2) Periodic inspection interval
(3) Items and procedures of inspection
(4) Criteria for inspection result judgments

(1) Accuracy standard

It is recommended that the in-house accuracy standards for the micrometers be classified for different work processes.

For example:

Class A: For inspection and grinding
Class B: For lathing
Class C: For milling and shaping

Table 7.2 In-house standards of micrometer accuracy

Measuring range	Class A Grinding	Class B Milling	Class C Casting
0 – 25mm	±2μm	±4μm	±8μm
25 – 50mm	±2μm	±5μm	±9μm

As shown in **Table 7.2**, specify the permissible instrument error of each class of micrometers according to the machining accuracy required in each process. In this classification system, Class A accuracy is equivalent to that of a new micrometer. When an accuracy deterioration exceeding ±2 μm is found on a Class A micrometer during periodic inspection, it should be used as a Class B micrometer and, in the same manner, Class B micrometers will be downgraded to Class C when they no longer satisfy Class B accuracy specifications.

A simpler method of accuracy classification is to use the relevant specifications given in a national standard. For the sake of economy, in this case, a certain allowance may be added to the specified tolerance limits depending on the accuracy requirements in each process. This will reduce the number of micrometers that need to be discarded.

Whatever the system of accuracy classification, it must be established in a written form and thoroughly known by all employees who use micrometers.

(2) Periodic inspection interval

There is no set rule as to the time interval between inspections. It depends on the frequency of use, accuracy requirements, environmental conditions, and other related factors. The normal practice adopted is two to four times a year. Obviously, inspection intervals should be shorter if the frequency of use is high or the accuracy requirements are high. Inspection intervals may also be determined based on the past inspection records, that is, if the proportion of micrometers that failed to pass the inspection is abnormally high or low, the interval should be adjusted accordingly.

(3) Items and procedures of inspection

The items to be inspected during a periodic inspection are as follows:

(Refer to **Section 7.2** for inspecting methods.)

(a) Fit
(b) Flatness and parallelism of measuring faces
(c) Function of ratchet stop or friction thimble
(d) Clearance between spindle and spindle guide and play between spindle and inner sleeve threads
(e) Clamp function
(f) Sleeve and thimble graduations
(g) Clearance between sleeve and thimble (runout of thimble)
(h) Zero point
(i) Instrument error
(j) Scratches, burrs, etc.

There are two optional inspection methods:

(a) Patrol method: Bring the necessary inspection tools to conduct the inspection on-site.

(b) Collection method: Gather all the micrometers and conduct a batch inspection in one place.

The patrol method is easier to implement, but may not be adequate for making thorough inspections. Also, it is difficult to attain accurate data when an inspection is conducted in a place with adverse environmental conditions.

The collection method is suitable for making thorough inspections. It also has the advantage of providing highly reliable inspection results, since inspections can be conducted in a room with the desired environmental conditions. However, the collection method is time consuming and requires spare micrometers to substitute for the ones being inspected.

Because both methods have their advantages and disadvantages, a combination of the two methods may be used depending on the situation.

Micrometers that have been inspected should be classified into groups by accuracy and marked for identification (by using colored ratchet stops, for example). Micrometers that have been found to be out of the specified tolerance should be marked (as being out of tolerance) if they are to be repaired, or discarded. Finally, an inspection record should be made for each micrometer.

(4) Criteria for inspection result judgments

Micrometers that failed to pass the periodic inspection should be either repaired or discarded according to the criteria shown in **Table 7.3**. Micrometers that require substantial repairs should be sent to the manufacturer. Unusable micrometers should be discarded quickly to prevent accidental use.

Table 7.3 Criteria for inspection result judgments

No.	Item	Degree of defect	Possibility of repair	Countermeasure
1	Fit	Spindle rotation is tight or sticky.	○	Disassembly and cleaning.
2	Ratchet	Ratchet rotation is tight or sticky.	○	Disassembly and cleaning. If the problem persists replace the ratchet.
3	Clamp	Spindle clamping is not sufficient.	○	Send the micrometer to the manufacturer for repair.
4	Burr on measuring face	Burr was created on the measuring face edge by a bump, drop, etc.	○	Remove the burr carefully with an Arkansas stone or CERASTON.
5	Parallelism	Luster of the measuring face reduced or the flatness error exceeds 0.6 µm.	○	Send the micrometer to the manufacturer for repair.
6	Parallelism	Parallelism error between the anvil and spindle exceeds the specified value.	○	Send the micrometer to the manufacturer for repair.
7	Instrument error	Instrument error exceeds the specified value.	○	Send the micrometer to the manufacturer for repair.
8	Locked screw threads	Locked because the spindle was rotated with dust or contaminants between the screw threads.	×	Discard the micrometer (depending on the severity).
9	Frame bent	Frame was bent by mishandling (e.g. micrometer caught in running lathe, used as a vice).	×	Discard the micrometer.
10	Excessive clearance in spindle guide	Though the parallelism between the measuring faces is satisfactory, there is a great difference between the two types of flatness measurements. One type uses a gauge block between the measuring faces, and the other type uses an optical parallel.	×	Discard the micrometer.
11	Play in screw threads caused by local wear	Even when the taper nut is tightened, sections of the threads are loose and other sections are tight.	×	Discard the micrometer.
12	Graduations	Hard to read because of scratched sleeve or damaged graduations.	○	Send the micrometer to the manufacturer for replacement of the thimble or sleeve.

APPENDIX 1
NATIONAL AND INTERNATIONAL STANDARDS FOR MICROMETERS

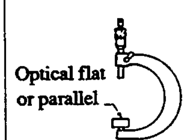
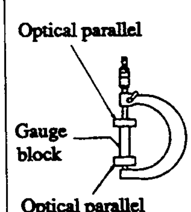
Table 1 lists code numbers of national and international standards for various types of micrometers. JIS specifications for micrometers are reviewed every three years for possible modification.

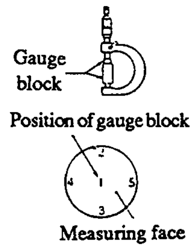
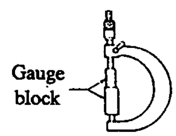
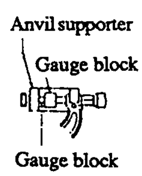
Table 2 shows the measurement methods of the performance of micrometers specified in JIS B 7502 (1979).

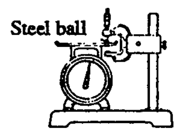
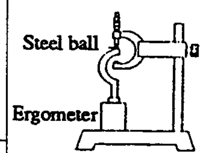
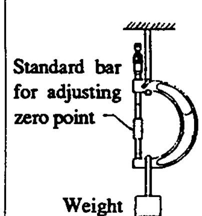
Table 1 Code numbers of national and international standards for various types of micrometers

	JIS	DIN	BS	Federal Specification	ISO
Outside micrometer	B7502-1979	863T1	870	GGG-C-105b	3611
Tubular inside micrometer (single rod type)	B7508-1981	863T4	---	GGG-C-105b	DIS-9121
Screw thread micrometer	B7530-1980	863T3	---	---	---
Indicating micrometer	B7520-1981	863T3	---	---	---
Micrometer head	B7504-1980	863T2	1734	---	---
Depth micrometer	B7544-1981	863T2	---	---	---

Table 2 Measurement of micrometer performance

No.	Performance	Item to be measured	Measuring method	Illustration	Measuring instrument	Description
1	Flatness of measuring face	Number of red interference fringes	Bring an optical flat or parallel into close contact with measuring face, and take reading of number of red interference fringes produced by white light.		Grade 1 or Grade 2 optical flat or Grade 1 optical parallel specified in JIS B7430 and JIS B7431, respectively	
2	Parallelism of measuring face	(a) Number of red interference fringes	Bring optical parallel or combination of optical parallel and gauge block into close contact with measuring face of anvil (until interference fringes get one colour or closed curve appears), and take reading of number of red interference fringes which are produced by white light and appears on measuring face of anvil under measurement force of micrometer (see No.5)		Grade 1 optical parallel specified in JIS B7431. Grade 0 or Grade 1 gauge block specified in JIS B7506.	Measure successively not only at the places corresponding to the integral number of spindle turning but also at four places corresponding to the number of spindle turning where the revolutional fraction equals to a multiple of 1/4 revolution, and take the largest value thus obtained as the parallelism. For a micrometer of the maximum measuring length exceeding 175mm, follow the method specified in (b) below.

No.	Performance	Item to be measured	Measuring method	Illustration	Measuring instrument	Description
2	Parallelism of measuring face	(b) Maximum difference in reading	Place gauge block in the middle of both measuring faces, and take reading under measuring force of micrometer (see No. 5). Next, insert the gauge block in four corners successively to take each reading, and obtain the maximum difference.	 Figures show the order of measurements.	Grade 0 or Grade 1 gauge block specified in JIS B7506.	For micrometers of the maximum measuring length exceeding 75mm, it is advisable to follow the method described below. Bring a gauge block of which dimension is equal to the minimum measuring length into close contact with the measuring face of anvil, insert a separate gauge block in the clearance between the gauge block above-mentioned and the measuring face of the spindle, change successively the position of the latter block, and take readings of each measurement.
3	Instrumental error	Difference between reading of micrometer and dimension of gauge block	After setting the error at the minimum measuring length as zero, insert a gauge block between both measuring faces, and obtain the difference between the readings of the micrometer and the dimension of the gauge block under the measuring force (see No.5)		Grade 0 or Grade 1 gauge block specified in JIS B7506.	
4	Deviation of traverse of spindle	Difference between readings of micrometer and length of gauge block	Fix an anvil supporter to the frame so that the center of measuring face of the spindle positioning at the place corresponding to the minimum measuring length be contact with the center of a spherical anvil of 3mm or more radius, calibrate while applying the measuring force, insert successively some gauge blocks of different dimensions between both measuring faces, and take each reading. Obtain the difference between the maximum and the minimum values obtained in each measurement from the reading of the micrometer and the length of the gauge block.		Anvil supporter Grade 0 or Grade 1 gauge block specified in JIS B7506.	For the micrometers of which minimum measuring length is laid down as zero, obtain the deviation of traverse of spindle from the value obtained by the measurement made for the instrumental error.

No.	Performance	Item to be measured	Measuring method	Illustration	Measuring instrument	Description
5	Measuring force	Reading indicated by a spring balance with pan or by an ergometer	Place a steel ball between loading point of the balance or ergometer and center of the measuring face of spindle. After adjusting the spindle axis as to stand vertically and the pointer of balance or ergometer as to indicate zero point, take the maximum reading of the balance or ergometer while turning the ratchet or friction drive.	 	Self-indicating spring balance with pan (20g or less in scale interval)	
6	Dispersion of measuring force	Difference in measuring force between the maximum and minimum values	Repeat the above sequences five times, and obtain the difference in measuring force between the maximum and minimum value obtained from above measurements.		Ergometer (0.2N or less in sensitiveness)	
7	Deflection of frame	Deflection of frame per loading of 10N (1.02kgf)	Hold the micrometer with its anvil positioning down and its spindle axis being vertical, suspend a weight of 5kg in mass from the anvil, and then measure the amount of deflection of the frame. Obtain the deflection per a loading of 10N (1.02kgf).		Standard bar for adjusting zero point Weight of 5kg in mass	

Remarks 1. It is recommended that the dimensions of the gauge blocks to be used for the measurement of instrumental error and deviation of traverse of spindle should be so selected that they facilitate the measurements of errors not only at the positions corresponding to the number of integral multiplies of spindle revolution but also at the intermediate positions.
It is, therefore, advisable to use the gauge blocks exampled below as a set:
2.5mm, 5.1mm, 7.7mm, 10.3mm, 12.9mm, 15mm, 17.6mm, 20.2mm, 22.8mm, 25mm

2. The tolerance on the dimension of the standard bar for adjusting zero point shall be obedient to the formula below, and the standard bar shall bear its nominal dimension and dimensional error marked at a conspicuous place.

$$\Delta m = (1 + \frac{L}{50})$$

where Δm: dimensional tolerance of standard bar for adjusting zero point (in μm)
L: nominal dimension of the bar (in mm)

APPENDIX 2
SUPPLEMENT TO THE THREE-WIRE METHOD FOR THREAD MEASUREMENT

App. 2.1 General Formula for Determining Pitch Diameter

In **Section 2.2.5**, a formula was given to express the pitch diameter when the thread angle is 60°. For any thread angle, the following general formula expresses the pitch diameter, E:

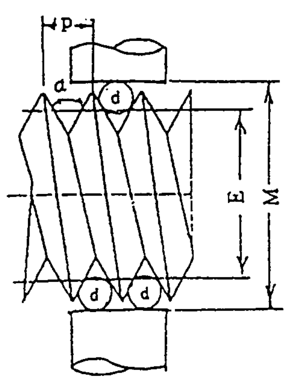
$$E' = M - d_m\left(1 + \frac{1}{\sin\frac{\alpha}{2}}\right) + \frac{P}{2}\cot\frac{\alpha}{2} \text{------} (1)$$

To minimize measurement error, the wires should contact the thread near the center of each flank. Use the following formula to determine the optimal wire diameter, d:

$$d = \frac{P}{2\cos\frac{\alpha}{2}}$$

For example, when the thread angle is 60° the optimal wire diameter is given by $d = 0.57735p$.

In the three-wire method, approximately three times the error in the wire diameter becomes the error in the pitch diameter measurement. Therefore, it is necessary to use high-precision wires. The following dimensional and form accuracies are required for the wires:
Difference in diameter between wires: 0.5 µm or less
Cylindricity of wires: 0.3 µm or less
Difference between nominal and actual wire diameters: ±2.5 µm or less
JIS B 0271 specifies the dimensional and form tolerances for the wires to be used in the three-wire method.



α: Thread angle
P: Thread pitch
d: Wire diameter
M: Measured value
E: Pitch diameter

Fig. 1 Pitch diameter measurement by three-wire method

App. 2.2 Compensating for the Lead Angle

For simplicity, the thread lead angle was not taken into account in formula (1). In other words, the formula assumes that the thread has no lead angle. In practice, however, the wires are in contact with the thread at certain angles with the axis of the thread because of the lead angle of the thread. A more elaborate formula must be used to determine the pitch diameter to high degree of accuracy.
According to JIS B 0261 "Measuring Method for Parallel Screw Gauges,"

(1) The pitch diameter *E* of metric and unified screw threads is calculated using the following formula:
$E = M - 3d + 0.866025p$
(This formula is obtained by substituting 60 (thread angle) for α in formula (1).)
(2) If the ratio of the pitch to the pitch diameter is greater than that of the coarse screw thread, the pitch diameter E' (mm) should be calculated using the following formula:

$$E' = M - d_m\left(1 + \frac{1}{\sin\frac{\alpha}{2}}\right) + \frac{P}{2}\cot\frac{\alpha}{2}$$
$$- \frac{d_\omega}{2}\cot\frac{\alpha}{2}\cos\frac{\alpha}{2}\left(1 + \frac{d_\omega}{E_0 + d_\omega \sin\frac{\alpha}{2}}\sin\frac{\alpha}{2}\right)$$
$$\times \left\{\frac{P}{\pi\left(E_0 + d_\omega \sin\frac{\alpha}{2}\right)}\right\}^2 + \frac{d_\omega}{8}\cot\frac{\alpha}{2}\left\{\frac{P}{\pi\left(E_0 + d_\omega \sin\frac{\alpha}{2}\right)}\right\}^4$$

where,
M: Measured value (mm)
d_m: Average diameter of wires (mm)
d_w: Nominal wire diameter (mm)
E_0: Basic pitch diameter (mm)
P: Pitch (mm)
α: Thread angle

This formula is applied only when the value of the last term in the formula falls within the required accuracy.

<Reference>

i) The standards adopted by some countries do not require the accuracy of the quadratic and higher degree terms in formula (2).
ii) The value of compensation terms (the quadratic and higher degree terms) in formula (2) does not exceed 3 µm for ordinary screw threads that have a steep lead angle. The compensation terms are

not used unless specified.

iii) Given the diameter of the wires, and the angle and pitch of the thread, the pitch diameter can be simply obtained by subtracting a predetermined constant, which is the sum of the second and third terms of formula (1), from the micrometer reading.

APPENDIX 3
TOOTH THICKNESS MICROMETER

App. 3.1 Principle of Tooth Thickness Micrometer

There are two types of tooth thickness micrometers, one for measuring chordal thickness and the other for measuring root tangent length.

App. 3.1.1 Tooth thickness micrometer for chordal thickness measurement

The best, and most accurate way to determine tooth thickness is by measuring the arc length along the pitch circle. However, because the arc length is practically impossible to measure, the tooth thickness is represented by the chordal thickness which is the length of the chord across the arc. There are two methods of measuring chordal thickness; one uses gear's addendum circle as a reference and the other uses a reference rack.

(1) Chordal thickness measurement with reference to addendum circle

This method uses the addendum circle of a gear as a reference and determines the chordal thickness of a gear tooth across the arc along the pitch circle. Fig. 2 is an explanatory diagram of this method.

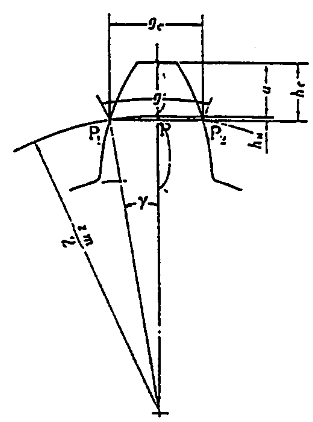


Fig. 2 Measuring chordal thickness with reference to addendum circle

As shown in **Fig. 2**, a gear-tooth micrometer measures h_c, instead of the true addendum, a. The following formulas are used to determine h_c and g_c.

$$h_c = a + h_a = m + \frac{mz}{2} - \frac{mz}{2} \cdot \cos\gamma$$
$$= m + \frac{mz}{2}(1 - \cos\gamma)$$
$$= m\left\{\frac{z}{2}(1 - \cos\gamma) + 1\right\}$$
$$g_c = mz \cdot \sin\gamma$$

where,

$$\gamma = \left(\frac{\pi}{2} + 2x \cdot \tan\alpha_n\right) \cdot \frac{1}{z}$$

m: Module
z: Number of gear teeth
α_n: Pressure angle
x: Addendum modification coefficient
h_c: Chordal height
g_c: Chordal thickness

The chordal height and thickness can be calculated from the above formulas. **Table 3** lists chordal height and thickness values for different numbers of gear teeth, which eliminates the trouble of making complicated calculations.

(2) Chordal thickness measurement using a reference rack

As shown in **Fig. 3**, this method determines the chordal thickness, g_{cc}, which is the distance between the two contact points when the gear is engaged with a reference rack. The advantage of this method is that for a given pressure angle, the chordal thicknesses, g_{cc}, and the chordal height, h_{cc}, take constant values regardless of the number of teeth, z. On the other hand, method (1) which uses the addendum circle, requires that the chordal height be calculated or looked up in a reference table in order to determine the chordal thickness along the pitch circle.

Table 3 Chordal thickness of standard gears (m =1, x = 0, α_n = 14.5°)

Number of teeth (z)	Chordal thickness (g_c)	Chordal height (h_c)	Number of teeth (z)	Chordal thickness (g_c)	Chordal height (h_c)	Number of teeth (z)	Chordal thickness (g_c)	Chordal height (h_c)	Number of teeth (z)	Chordal thickness (g_c)	Chordal height (h_c)
5	1.545	1.1224	24	1.570	1.0257	58	1.571	1.0105	100	1.571	1.0062
6	1.553	1.1022	25	1.570	1.0247	60	1.571	1.0103	105	1.571	1.0059
7	1.558	1.0878	26	1.570	1.0237	62	1.571	1.0099	110	1.571	1.0056
8	1.561	1.0769	27	1.570	1.0228	64	1.571	1.0096	115	1.571	1.0054
9	1.563	1.0684	28	1.570	1.0220	66	1.571	1.0093	120	1.571	1.0051
10	1.564	1.0616	30	1.570	1.0206	68	1.571	1.0091	125	1.571	1.0049
11	1.565	1.0560	32	1.570	1.0193	70	1.571	1.0088	130	1.571	1.0047
12	1.566	1.0513	34	1.570	1.0181	72	1.571	1.0086	135	1.571	1.0046
13	1.567	1.0484	36	1.570	1.0171	76	1.571	1.0081	140	1.571	1.0044
14	1.568	1.0440	38	1.570	1.0162	78	1.571	1.0079	145	1.571	1.0043
15	1.568	1.0411	40	1.570	1.0154	80	1.571	1.0077	150	1.571	1.0041
16	1.568	1.0385	42	1.570	1.0147	82	1.571	1.0075	155	1.571	1.0040
17	1.569	1.0363	44	1.570	1.0140	84	1.571	1.0073	160	1.571	1.0039
18	1.569	1.0342	46	1.571	1.0134	86	1.571	1.0072	165	1.571	1.0037
19	1.569	1.0324	48	1.571	1.0129	88	1.571	1.0070	170	1.571	1.0036
20	1.569	1.0308	50	1.571	1.0123	90	1.571	1.0069	180	1.571	1.0034
21	1.569	1.0294	52	1.571	1.0119	92	1.571	1.0067	190	1.571	1.0032
22	1.569	1.0280	54	1.571	1.0114	95	1.571	1.0065	200	1.571	1.0031
23	1.570	1.0264	56	1.571	1.0110	98	1.571	1.0063		1.571	1.0000

* h_c is fixed when g_c is measured.

For $\alpha_n = 20°$,
$g_{cc} = (1.3870 + 0.6428 \cdot x) \cdot m$
$h_{cc} = (0.7476 - 0.8830 \cdot x) \cdot m$

For $\alpha_n = 14.5°$,
$g_{cc} = (1.4723 + 0.4048 \cdot x) \cdot m$
$h_{cc} = (0.8096 - 0.9373 \cdot x) \cdot m$

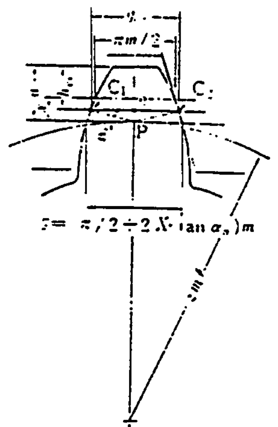


Fig. 3 Measuring chordal thickness using a reference rack

(3) Zero point adjustment of a gear-tooth micrometer
When measuring the chordal tooth thickness of a gear, the edges of the micrometer measuring faces make contact with the flanks of the gear tooth. The measuring faces should be adjusted so that they make contact with the flanks at the same angle as the pressure angle of the gear, as shown in **Fig. 4**. (The pressure angle is the angle between a radial line from the center of the gear and the tangent to the tooth flank.) Otherwise, a compensation value should be determined. The following expressions show the relationships between S, L, d, and α_n.

$$S = \frac{d}{2}(1 - \sin \alpha_n)$$

$$L = d \cdot \cos \alpha_n$$

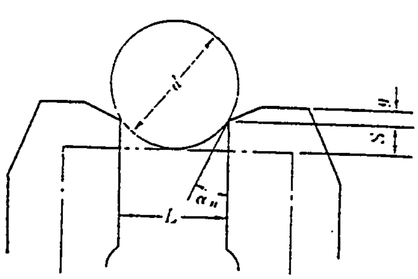


Fig. 4 Adjusting the zero point of a gear-tooth micrometer

App. 3.1.2 Tooth thickness micrometer for root tangent length

The tooth thickness micrometer for chordal tooth thickness measures the thickness of one tooth. The tooth thickness micrometer for root tangent length measures the distance across a certain number of teeth by bringing the micrometer's measuring faces into contact with the two outermost flanks of the teeth. A micrometer with large-area disc measuring faces is used for this measurement. The spindle may be either a rotating or non-rotating type, of which the latter is easier to operate.
Fig. 5 shows the principle of this measurement. Two parallel measuring faces measure the distance between flanks across multiple teeth.
The variables used in **Fig. 5**, in which an involute spur gear is used as an example, are defined as follows:

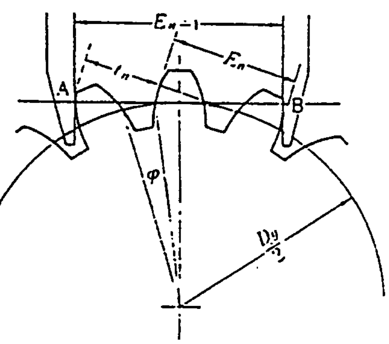


Fig. 5 Principle of root tangent length measurement

z = Number of teeth
T_n = Normal pitch
m = Module
D_g = Base circle diameter ($z \cdot t_n / \pi$)
α_n = Pressure angle
Ψ = Tooth spacing angle along base circle
n = Number of teeth included between measuring faces
E_n = Distance between flanks (root tangent length) when number of teeth included is n.
x = Addendum modification coefficient ($x = 0$ in standard gear)

From **Fig. 5**, it is obvious that the normal pitch, t_n, is given as $E_{n+1} - E_n$. When the value E_n is found from calculation, the measured value can be compared with the calculated value.

$E_n = \cos\alpha_n\{z\ \mathrm{inv}\alpha_n + n(n-0.5)\}m + 2\sin\alpha_n \cdot xm$

For $\alpha_n = 20°$,
$E_n = (0.01400554z + 2.95213n - 1.47606)m + 0.68404xm$

For $\alpha_n = 14.5°$,
$E_n = (0.00536822z + 3.04152n - 1.52076)m + 0.50076xm$

Tables 4 and **5** show the optimal number (n_0) of teeth to be included between the measuring faces for different gears (m = 1, x = 0) and the corresponding root tangent lengths.

The base circle diameter is obtained from the following formula:

$$D_g = \frac{z \cdot tn}{\pi} = \frac{z}{\pi}(E_{n+1} - E)$$

<Reference>

• Measuring the tooth thickness of helical gears

Because the teeth of helical gears have helicoid surfaces, their tooth thickness should be represented as the distance between two parallel lines that contact tooth flanks, instead of the distance between two parallel planes which are used to measure tooth thickness of spur gears. This can be done by applying two parallel measuring faces to gear teeth so that the line of measurement is normal to the teeth, as shown in **Fig. 6**. This is where the measuring faces are inclined by β_g, which is the oblique angle of the base cylinder, with respect to a plane that is normal to the gear axis.

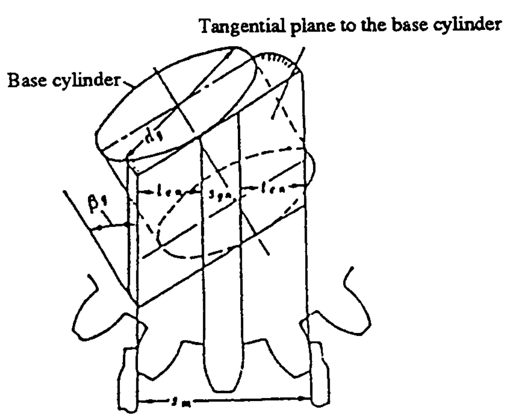


Fig. 6 Measuring root tangent length of a helical gear

The optimal number of teeth, Z_m, to be included between two measuring faces is calculated from the formula below, which assumes that the measuring faces make contact with the gear teeth on the circumference of a circle whose diameter is gear's transverse module, m_s.

$$z_m = z \cdot K(f, \beta_0) + 0.5$$

$$K(f, \beta_0) = \frac{1}{\pi}\left[\left(1 + \frac{\sin^3\beta_0}{\cos^2\beta_0 + \tan^2\alpha_{cn}}\right) \times \sqrt{(\cos^2\beta_0 + \tan^2\alpha_{cn})(\sec\beta_0 + 2f)^2 - 1} - \mathrm{inv}\left\{\tan^{-1}\left(-\frac{\tan\alpha_{cn}}{\cos\beta_0}\right)\right\} - 2f \cdot \tan\alpha_{cn}\right]$$

$$f = \frac{x_n}{z}$$

• Tool cutting depth

The tooth thickness must be measured in an intermediate check during a machining process of a gear to determine the additional cutting depth for the specified or design tooth thickness. **Fig. 7** shows the relationship between the specified and measured tooth thicknesses, and the additional cutting depth, δ_t.

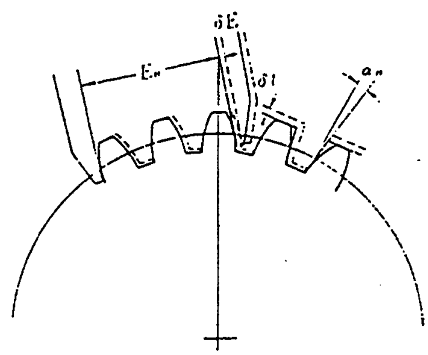


Fig. 7 Tooth thickness measurement to determine additional cutting depth

The relationship between the specified and measured tooth thicknesses, δE, and the additional cutting depth, δt, is as follows:

$$\delta t = \frac{\delta E}{2 \cdot \sin\alpha_n}$$

Substituting tool pressure angles 14.5° and 20° for α_n in the formula,

For $\alpha_n = 14.5°$, $\delta t = 1.9969\ \delta E \approx 2\delta E$
For $\alpha_n = 20°$, $\delta t = 1.4619\ \delta E \approx 1.5\delta E$

Table 4 Root tangent length of standard spur gears (m = 1, α_n = 20°)

z	no	En	z	no	En	z	no	En	z	no	En	z	no	En
5	2	4.4982	20	3	7.6605	35	4	10.8227	50	6	16.9370	65	8	23.0513
6	2	4.5122	21	3	7.6745	36	5	13.7888	51	6	16.9510	66	8	23.0654
7	2	4.5263	22	3	7.6885	37	5	13.8082	52	6	16.9649	67	8	23.0794
8	2	4.5403	23	3	7.7025	38	5	13.8168	53	6	16.9790	68	8	23.0934
9	2	4.5543	24	3	7.7165	39	5	13.8308	54	7	19.9451	69	8	23.1074
10	2	4.5683	25	3	7.7305	40	5	13.8448	55	7	19.9592	70	8	23.1214
11	2	4.5823	26	3	7.7445	41	5	13.8588	56	7	19.9732	71	8	23.1354
12	2	4.5963	27	4	10.7106	42	5	13.8728	57	7	19.9872	72	9	26.1015
13	2	4.6103	28	4	10.7246	43	5	13.8868	58	7	20.0012	73	9	26.1155
14	2	4.6243	29	4	10.7386	44	5	13.9009	59	7	20.0152	74	9	26.1295
												75	9	26.1435
15	2	4.6383	30	4	10.7526	45	6	16.8669	60	7	20.0292	76	9	26.1575
16	2	4.6523	31	4	10.7666	46	6	16.8810	61	7	20.0432	77	9	26.1715
17	2	4.6663	32	4	10.7806	47	6	16.8950	62	7	20.0572	78	9	26.1856
18	2	7.6324	33	4	10.7946	48	6	16.9090	63	8	20.0233	79	9	26.1996
19	2	7.6464	34	4	10.8086	49	6	16.9230	64	8	23.0373	80	9	26.2136

* Multiply the values in the table by the gear module (if it is not 1).

Table 5 Root tangent length of standard spur gears (m = 1, α_n = 14.5°)

z	no	En	z	no	En	z	no	En	z	no	En	z	no	En
5	2	4.5891	20	3	4.6697	35	4	7.7917	50	6	13.9553	65	6	17.0773
6	2	4.5945	21	3	4.6750	36	5	7.7971	51	6	13.9607	66	6	17.0827
7	2	4.5999	22	3	4.6804	37	5	10.8439	52	6	13.9660	67	6	17.0881
8	2	4.6052	23	3	4.6858	38	5	10.8493	53	6	13.9714	68	6	17.0934
9	2	4.6106	24	3	4.6912	39	5	10.8547	54	7	13.9768	69	6	17.0988
10	2	4.6160	25	3	7.7380	40	5	10.8601	55	7	13.9821	70	6	17.1042
11	2	4.6214	26	3	7.7434	41	5	10.8655	56	7	13.9875	71	6	17.1095
12	2	4.6267	27	4	7.7488	42	5	10.8708	57	7	13.9929	72	6	17.1149
13	2	4.6321	28	4	7.7541	43	5	10.8762	58	7	13.9982	73	6	17.1203
14	2	4.6374	29	4	7.7595	44	5	10.8861	59	7	14.0036	74	6	17.1257
												75	7	20.1725
15	2	4.6428	30	4	7.7649	45	6	10.8869	60	7	14.0090	76	7	20.1779
16	2	4.6482	31	4	7.7702	46	6	10.8923	61	7	14.0144	77	7	20.1833
17	2	4.6534	32	4	7.7756	47	6	10.8977	62	7	17.0612	78	7	20.1886
18	2	4.6589	33	4	7.7810	48	6	10.9030	63	8	17.0666	79	7	20.1940
19	2	4.6643	34	4	7.7864	49	6	10.9084	64	8	17.0720	80	7	20.1994

* Multiply the values in the table by the gear module (if it is not 1).

App. 3.2 Principle of Over-pin Diameter Method

Like the three-wire method which measures pitch diameters of threads over the wires, the over-pin diameter method measures the diameter (over-pin or over-ball diameter) of a gear over the two pins or balls that are fitted in the clearances between gear teeth. It requires a great deal of expertise to hold the pins or balls in position between gear teeth. The ball-tipped gear tooth micrometer facilitates this measurement. The structure of this micrometer is almost the same as that of the screw-thread micrometer with interchangeable anvils and spindle tips.

In **Fig. 8**,

when the number of teeth is an even number,

$$F = L + d = d + \frac{zm \cos\alpha_n}{\cos\phi}$$

when the number of teeth is an odd number,

$$F' = d + \frac{zm \cos\alpha_n}{\cos\phi} \cdot \cos\frac{90^\circ}{z}$$

and,

$$\mathrm{inv}\phi = \frac{d}{zm \cdot \cos\alpha_n} - \left(\frac{\pi}{2z} - \mathrm{inv}\alpha_n\right) + \frac{2\tan\alpha_n \cdot x}{z}$$

here, α_n = cutter pressure angle
m = module
z = number of teeth
x = addendum modification coefficient

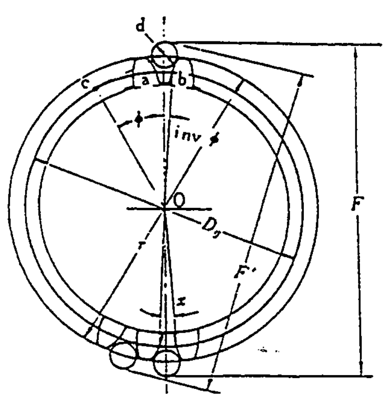


Fig. 8 Principle of over-pin diameter method

The optimal pin (or ball) diameter, d, in this measurement is such that the pin or ball makes contact with the center of the flank near the pitch circle, whose diameter is $(z + 2x)m$. The ball may be larger than this.

Referring to **Fig. 9**, the optimal diameter, d, can be obtained from the following formula:

$$d = zm \cos\alpha_n\left(\mathrm{inv}\phi + \frac{\psi}{2}\right)$$

$$\phi = \tan\alpha + \frac{\psi}{2}$$

$$= \tan\alpha + \left(\frac{\pi}{2z} - \mathrm{inv}\alpha_n\right) - \frac{2\tan\alpha_n \cdot x}{z}$$

$$\therefore \cos\alpha = \frac{z\cos\alpha_n}{z + 2x}$$

Table 6 lists the optimal pin diameter for different gear modules.

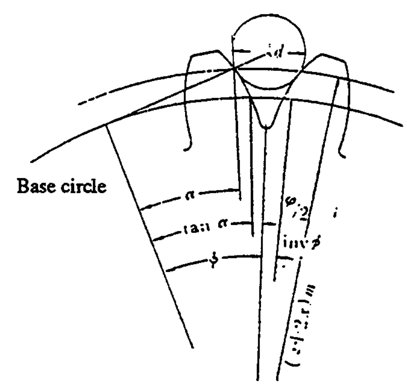


Fig. 9 Relationship between pin (ball) diameter and gear teeth

The over-pin diameter measurement can be used to determine the tool cutting depth in an intermediate check during the machining process of a gear. The following formulas give the additional cutting depth, δt, that is required when the difference between the theoretical and measured over-pin diameters (F) for standard spur gears is δf. The value δf' is the compensation value to be deducted from the over-pin diameter to allow for backlash, Sn, in the direction normal to the tooth flanks.

In **Fig. 10**,

when the number of teeth is an even number,

$$\delta t = \frac{\sin\phi}{2\sin\alpha_n} \times \delta f$$

$$\delta f' = \frac{S_n}{\sin\phi}$$

when the number of teeth is an odd number,

$$\delta t = \frac{\sin\phi}{2\sin\alpha_n}\cos\frac{90^\circ}{z} \cdot \delta f$$

$$\delta f' = \frac{S_n}{\sin\phi} \cdot \cos\frac{90^\circ}{z}$$

Here,

$$\mathrm{inv}\phi = \frac{d}{zm \cdot \cos\alpha_n} - \left(\frac{\pi}{2z} - \mathrm{inv}\alpha_n\right) + \frac{2\tan\alpha_n \cdot x}{z}$$

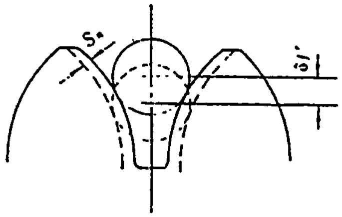


Fig. 10 Over-pin diameter compensation to allow for backlash

<Reference>

Care required in using ball-tipped gear tooth micrometer

(1) Adjust the zero point each time the ball tips are replaced.

(2) Use a 1 mm gauge block for adjusting the zero point when small-diameter ball tips (5 mm or less) are used.

(3) Check the ball tips for wear before use.

(4) Use the appropriate ball tip sizes for the gear teeth to be measured.

(5) Do not slide the ball tips along tooth flanks to take them off the gear teeth.

(6) Measure at two end portions of flanks and use the average value.

(7) Do not apply excessive measuring force.

(8) Store the ball tips in pairs after use.

(9) Interchange the ball tips between the spindle and anvil sides periodically.

Table 6 Optimal pin (ball) diameters for different gear modules

Module, m (approximate diametral pitch)	Nominal pin (ball) diameter:inch (mm)	JIS B 1501 Steel Balls for Ball Bearings) (inch)	JIS B 1506 (Rollers for Roller Bearings) (mm)	JIS B 0271 (Three Wires for Screw Thread Measuring)
0.5(50)	1/32(0.7938)	---	---	0.7954
0.55	1/32(0.7938)	---	---	0.8949
0.6	(1.0)	---	---	1.0227
0.65(38)	(1.0)	---	---	1.0227
0.7	(1.0)	---	---	1.1547
0.75(34)	3/64(1.1906)	---	---	1.1932
0.8(32)	3/64(1.1906)	---	---	1.3016
0.9(28)	(1.5)	---	---	1.4434
1.0(26)	1/16(1.5875)	---	---	1.5908
1.25	5/64(1.9844)	---	---	2.0454
1.5(17)	3/32(2.3812)	---	---	2.3863
1.75	7/64(2.7781)	---	3 x 3	2.5951, 2.8868
2.0(13)	9/64(3.5719)	5/32	3 x 3	3.1817, 3.5794
2.25	5/32(3.9688)	5/32	4 x 4	4.0908
2.5(10)	11/64(4.3656)	3/16	4 x 4	4.4055
2.75	3/16(4.7625)	3/16	5 x 5	4.7726
3.0(8)	13/16(5.1594)	7/32	5 x 5	4.9801, 5.2065
3.25	7/32(5.5562)	7/32	5 x 5	5.4544
3.5(7)	15/64(5.9531)	1/4	6 x 6	5.7271
3.75	1.4(6.35)	1/4	6 x 6	---
4.0(6)	17/64(6.7469)	9/32	7 x 7	---
4.5	9/32(7.1438)	9/32	7 x 7	---
5.0(5)	19/64(7.5406)	5/16	7 x 7	---
5.25	5/16(7.9375)	5/16	8 x 8	---

APPENDIX 4
MEASUREMENT OF THE PITCH DIAMETER OF A TAP WITH A V-ANVIL MICROMETER

The pitch diameter of cutting heads of a tap with an odd-number of flutes cannot be measured by the three-wire method using a standard outside micrometer. The single-wire method using a V-anvil micrometer is used to make such measurements.
Determine the pitch diameter, E, as follows:

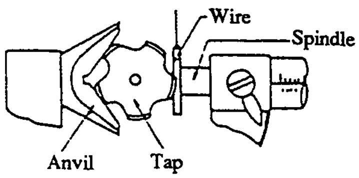


Fig. 11 Measuring the pitch diameter of a tap by the single-wire method

(1) Measure the tap by the single-wire method using a V-groove micrometer and take the reading, M'. Determine the tap diameter, D, using a conversion table or by calculation*.

* Note:
Some V-groove micrometers provide direct reading of diameters.

(2) Substitute the values obtained in <1> for M' and D in either of the following formulas to obtain the value M*.
For three-flute tap: $M = 3M' - 2D$
For five-flute tap: $M = 2.2360M' - 1.23606D$

* Note:
The above value M corresponds to the M obtained using the three-wire method.

(3) Substitute the value obtained in <2> for M in either of the following formulas* to obtain the pitch diameter, E.

For $\alpha = 60°$,
$E = M - 3d + 0.866025p$
For $\alpha = 55°$,
$E = M - 3.16567d + 0.96049p$
where,

α: Tap thread angle
p: Tap thread pitch
d: Wire diameter

* Note:
These formulas are the same as those used in the three-wire method.

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