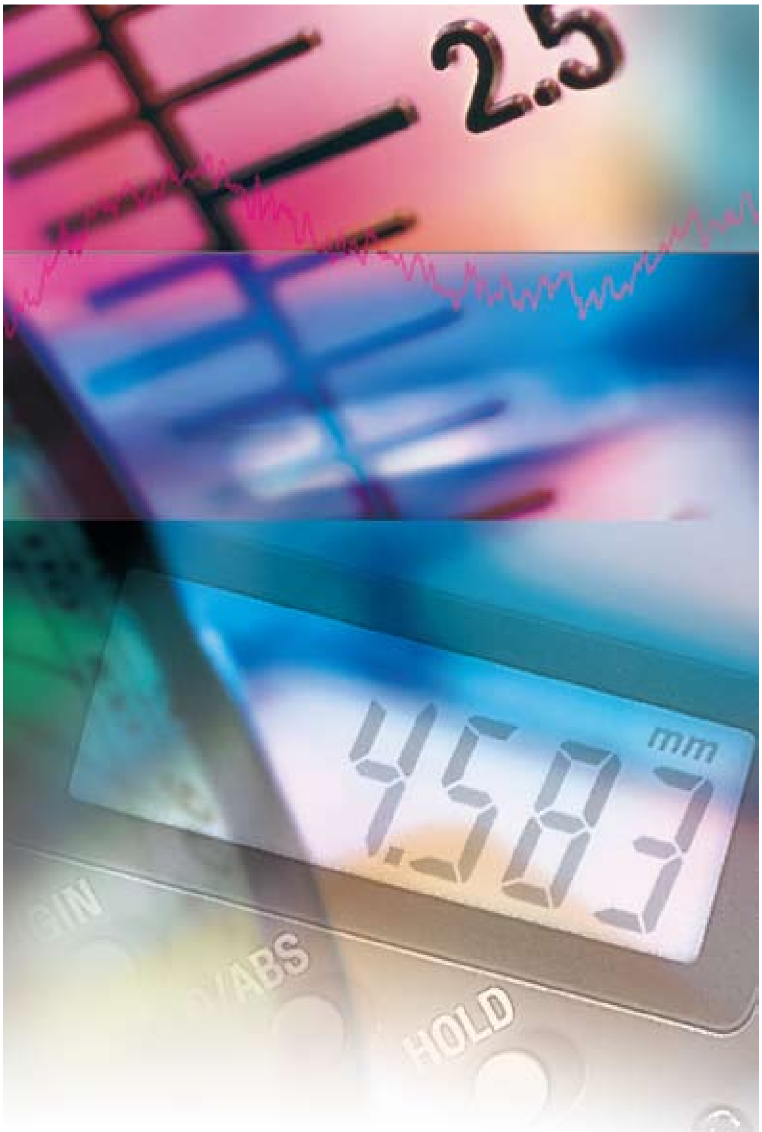
E4329

Quick Guide to Precision Measuring Instruments



Mitutoyo


0.05mm
0.5µm
Sampling length
Stylus
Time fingers are released
The gauge block is held with five fingers
Elongation (µm)
Lapse of time (minutes)
Difference in expansion (µm)
Nominal length (mm)

CONTENTS

Meaning of Symbols

ABSOLUTE Linear Encoder

ABSOLUTE
Absolute System Patented by MITUTOYO

Mitutoyo's technology has realized the absolute position method (absolute method). With this method, you do not have to reset the system to zero after turning it off and then turning it on. The position information recorded on the scale is read every time. The following three types of absolute encoders are available: electrostatic capacitance model, electromagnetic induction model and model combining the electrostatic capacitance and optical methods. These encoders are widely used in a variety of measuring instruments as the length measuring system that can generate highly reliable measurement data.

Advantages:

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

*1: Unless the battery is removed.
*2: In the case of the ABSOLUTE Digimatic caliper.

- The electromagnetic-induction-type absolute encoder is patent-protected in Japan, the United States, the United Kingdom, Germany, France, India and China.
- The absolute encoder combining the electrostatic capacitance and optical methods is patent-protected in Japan, the United States, the United Kingdom, Germany, Switzerland, Sweden and China.

IP Codes

These are codes that indicate the degree of protection provided (by an enclosure) for the electrical function of a product against the ingress of foreign bodies, dust and water as defined in IEC standards (IEC 60529) and JIS C 0920. Due to ongoing development of new length measuring systems, Mitutoyo builds metrology products qualified to protection codes IP65, IP66 and IP67, which signifies that these products may be used in hostile environments. [IEC: International Electrotechnical Commission]

IP65 IP66 IP67

IP□□

First characteristic numeral	Degrees of protection against solid foreign objects	
	Brief description	Definition
0	Unprotected	—
1	Protected against solid foreign objects of Sø50mm and greater	A Sø50mm object probe shall not fully penetrate enclosure[1)]
2	Protected against solid foreign objects of Sø12,5mm and greater	A Sø12,5mm object probe shall not fully penetrate enclosure[1)]
3	Protected against solid foreign objects of Sø2,5mm and greater	A Sø2,5mm object probe shall not penetrate enclosure[1)]
4	Protected against solid foreign objects of Sø1,0mm and greater	A Sø1,0mm object probe shall not penetrate enclosure[1)]
5	Protected against dust	Ingress of dust is not totally prevented, but dust that does penetrate must not interfere with satisfactory operation of the apparatus or impair safety
6	Dust-proof	No ingress of dust allowed

1)The full diameter of the object probe shall not pass through an opening in the enclosure.

Second characteristic numeral	Degrees of protection against water	
	Brief description	Definition
0	Unprotected	—
1	Protected against vertically falling water drops	Vertically falling drops shall have no harmful effects
2	Protected against vertically falling water drops when enclosure title up to 15°	Vertically falling drops shall have no harmful effects when the enclosure is tilted at any angle up to 15 degrees either side of the vertical
3	Protected against spraying water	Water sprayed at an angle up to 60° either side of the vertical shall have no harmful effects
4	Protected against splashing water	Water splashed against the enclosure from any direction shall have no harmful effects
5	Protected against water jets	Water projected in moderately powerful jets against the enclosure from any direction shall have no harmful effects
6	Protected against powerful water jets	Water projected in powerful jets against the enclosure from any direction shall have no harmful effects
7	Protected against the effects of temporary immersion in water	Ingress of water in quantities causing harmful effects shall not be possible when the enclosure is temporarily immersed in water under standardized conditions of pressure and time
8	Protected against the effects of continuous immersion in water	Ingress of water in quantities causing harmful effects shall not be possible when the enclosure is continuously immersed in water under conditions which shall be agreed between manufacturer and user but which are more severe than for IPX7

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

Independent Confirmation of Compliance

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

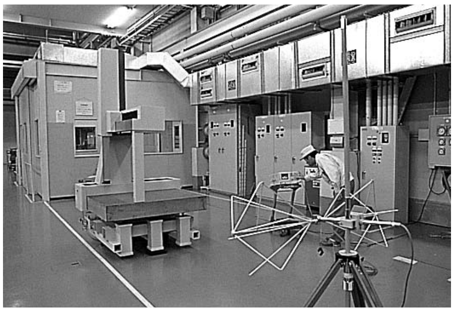
www.tuv.com TÜV TÜV Rheinland ID:4011207400
- Staubdicht + strahlwassergeschützt IP65

www.tuv.com TÜV TÜV Rheinland ID:3011207400
- Staubdicht und wassergeschützt IP66

www.tuv.com TÜV TÜV Rheinland ID:2011207400
- Staub- und wasserdicht IP67

Conformance to CE Marking

In order to improve safety, each plant has programs to comply with the Machinery Directives, the EMC Directives, and the Low Voltage Directives. Compliance to CE marking is also satisfactory. CE stands for *Conformité Européenne*. CE marking indicates that a product complies with the essential requirements of the relevant European health, safety and environmental protection legislation.



RoHS Directive Compliance

The RoHS directive* is a set of European regulations for the use of certain hazardous substances. Since July 1, 2006, selling specified electronic equipment containing more than the regulation amount of the specified six substances (lead, cadmium, mercury, hexavalent chromium, polybrominated biphenyl (PBB), and polybrominated diphenyl ether (PBDE)) is prohibited in Europe.
The scope of the RoHS directive is based on the 10 categories in the WEEE** directive. However, medical devices and monitoring and control instruments are excluded.
Mitutoyo is actively promoting environmental protection by developing RoHS-compliant products.

* RoHS directive: Directive of the European Parliament and of the Council on the restriction of the use of certain hazardous substances in electrical and electronic equipment
** WEEE directive: Waste Electrical and Electronic Equipment Directive

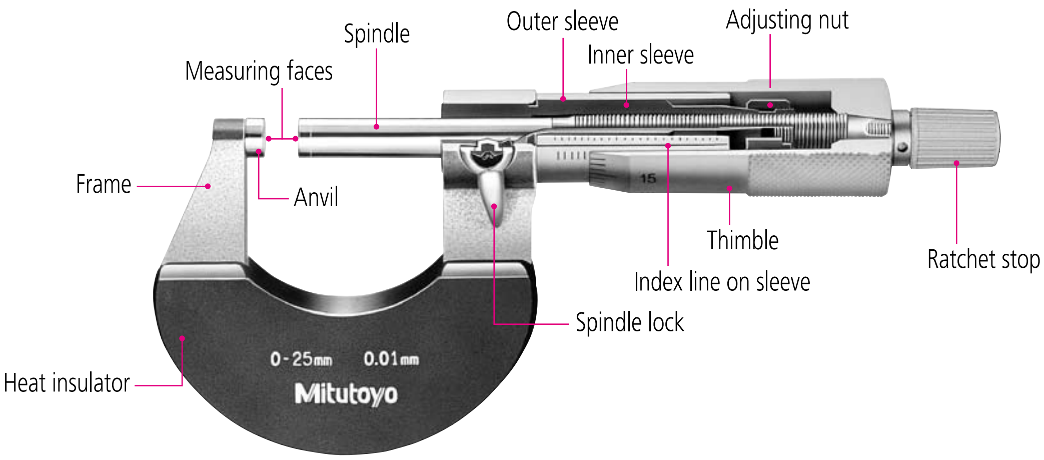
EC Directives Related to Mitutoyo Products

Directive	Scope
Machinery directive	Equipment that has parts moved by an actuator such as a motor and might cause human injury
EMC (electromagnetic compatibility) directive	Apparatus (devices) that is likely to generate, or be affected by, electromagnetic disturbance
Low voltage directive	Apparatus (devices) that operate at the voltages below, and might cause electrical shock, electrocution, heat, or radiation AC voltage: 50 to 1,000 V DC voltage: 75 to 1,500 V

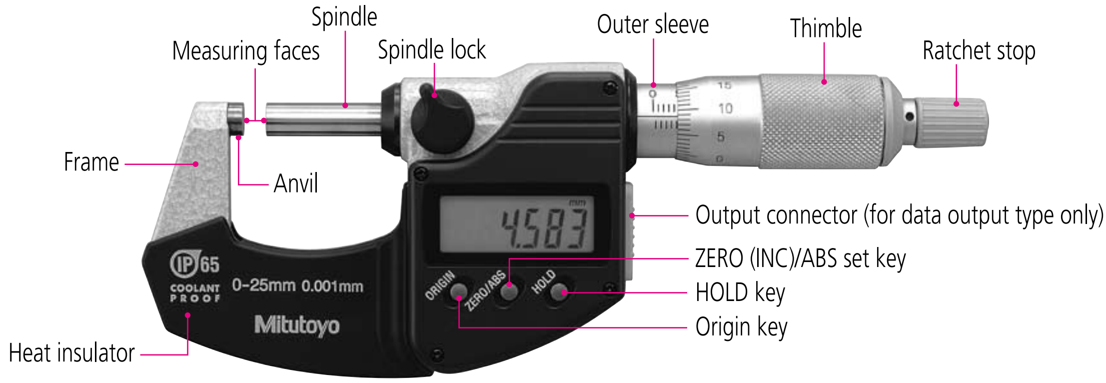
Micrometers

Nomenclature

Standard Outside Micrometer

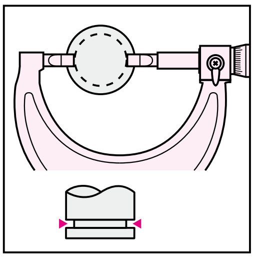


Digimatic Outside Micrometer



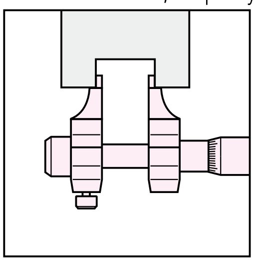
Special Purpose Micrometer Applications

Blade micrometer



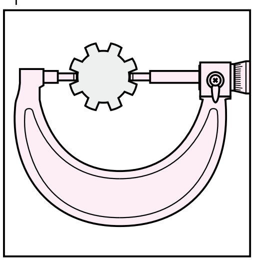
For diameter inside narrow groove measurement

Inside micrometer, caliper type



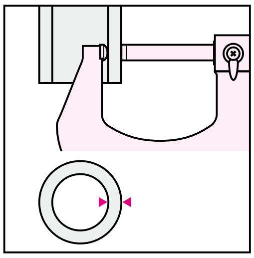
For small internal diameter, and groove width measurement

Spline micrometer



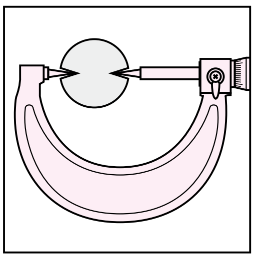
For splined shaft diameter measurement

Tube micrometer



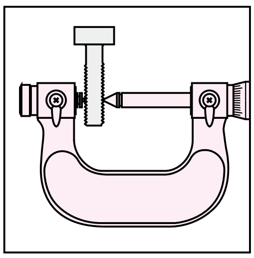
For pipe thickness measurement

Point micrometer



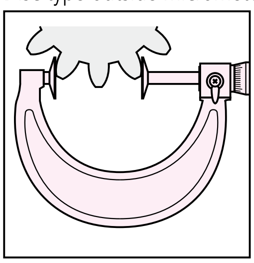
For root diameter measurement

Screw thread micrometer



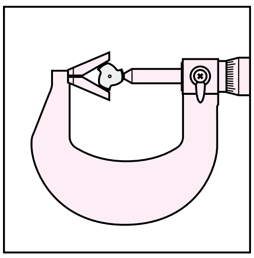
For effective thread diameter measurement

Disc type outside micrometer



For root tangent measurement on spur gears and helical gears

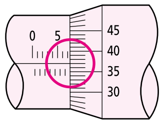
V-anvil micrometer



For measurement of 3- or 5-flute cutting tools

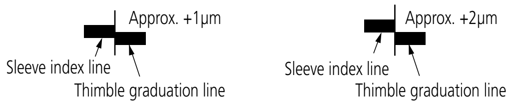
How to Read the Scale

Micrometer with standard scale (graduation: 0.01mm)



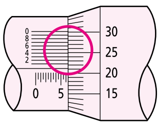
Sleeve reading	7. mm
Thimble reading	+ .37mm
Micrometer reading	7.37mm

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



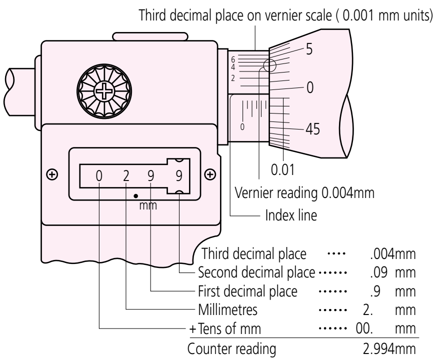
Micrometer with vernier scale (graduation: 0.001mm)

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

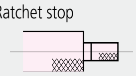
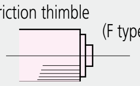
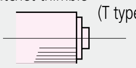
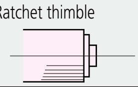


Sleeve reading	6. mm
Thimble reading	.21mm
Reading from the vernier scale marking and thimble graduation line	.003mm
Micrometer reading	6.213mm

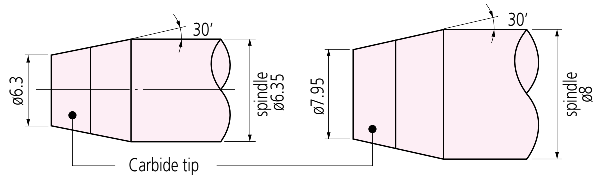
Micrometer with digital display (resolution: 0.001mm)



Constant-force Devices

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

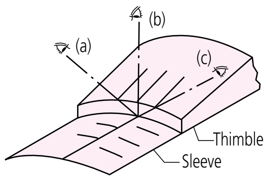
Detailed Shape of Measuring Faces



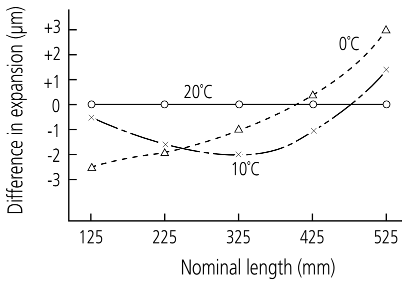
These drawings above are used for explaration and they are not to scale

Potential Reading Error Due to Parallax

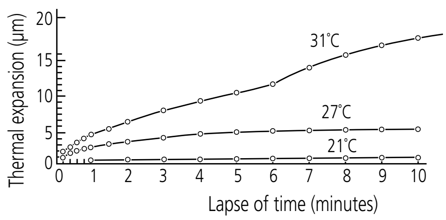
When a scale and its index line do not lie in the same plane it is possible to make a reading error due to parallax, as shown below. The viewing directions (a) and (c) will produce this error, whereas the correct reading is that seen from direction (b).



Difference in Thermal Expansion between Micrometer and Standard Bar



Standard Bar Expansion with Change of Temperature (for 200mm bar initially at 20˚C)

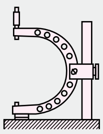
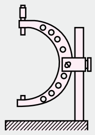


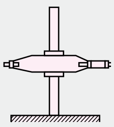
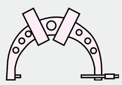
The graphs above show the change in size of a standard length bar when held in the hand at palm temperatures of 21˚C, 27˚C and 31˚C.

Micrometers

Measurement Error Depending on Attitude and Supporting Point (Unit: µm)

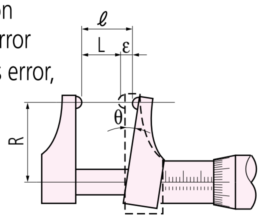
Since the measurement value is changed by the supporting point and maximum measuring length, it is recommended to use the instrument by performing zero-setting with the same orientation as it will be used in practice.

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

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

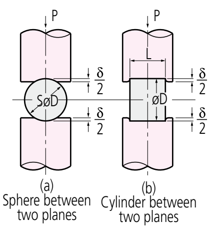
Abbe's Principle

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



Hertz's Formulae

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



(a) Sphere between two planes
(b) Cylinder between two planes

Assuming that the material is steel and units are as follows:
Modulus of elasticity: E=196 GPa
Amount of deformation: δ (µm)
Diameter of sphere or cylinder: D (mm)
Length of cylinder: L (mm)
Measuring force: P (N)

a) Apparent reduction in diameter of sphere
$\delta 1 = 0.82\sqrt[3]{P^2/D}$

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

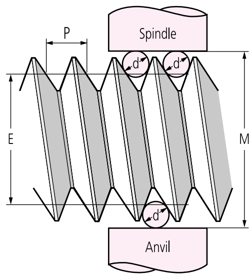
Effective Diameter of Thread Measurement

● Three-wire Method of Thread Measurement. The effective diameter of a thread can be measured by using three wires contacting the thread as shown in figure below. Effective diameter E can be calculated by using formula (1) or (2).

For metric or unified screw threads (60˚ thread angle)
E=M−3d+0.866025P ....(1)

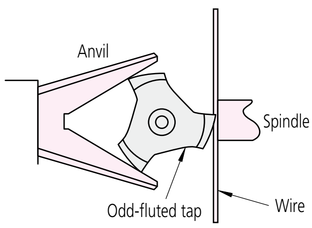
For Whitworth screw threads (55˚ thread angle)
E=M−3.16568d+0.960491P ....(2)

Where, P: Screw thread pitch (A pitch in inches is converted to its metric equivalent for unified screw threads.)
d: Mean diameter of the three wires
E: Effective diameter of the thread
M: Measurement over the three wires



Screw thread type	Best wire size
Metric screw thread (60°)	0.577P
Whitworth screw thread (55°)	0.564P

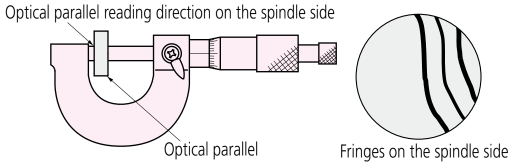
Single-wire Method of Thread Measurement. An Odd-fluted tap can be measured using a V-anvil micrometer and a single wire in contact with the thread flanks as shown. This method uses two measurements and a calculation to obtain an equivalent value for M as was obtained by direct measurement in the 'three-wire' method.
Where, M1: Maximum micrometer reading over the single wire (at cutting edge)
D: Maximum diameter of tap (at cutting edge)
For a three-flute tap: $M = 3M_1 - 2D$
Or for a five-flute tap: $M = 2.2360M_1 - 1.23606D$
Then, the effective diameter E can be calculated by substituting this M in formula (1) or (2)



Hooke's Law

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

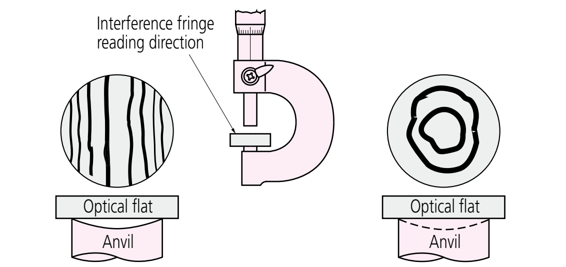
Testing Parallelism of Micrometer Measuring Faces



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

Testing Flatness of Micrometer Measuring Faces

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



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

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

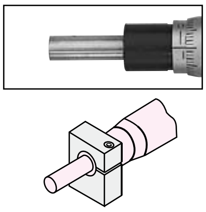
Micrometer Heads

Key Factors in Selection

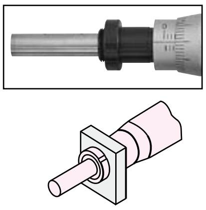
Key factors in selecting a micrometer head are the measuring range, spindle face, stem, graduations, thimble diameter, etc.

Stem

Plain stem

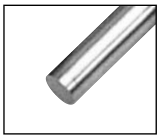


Stem with clamp nut

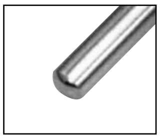


- The stem used to mount a micrometer head is classified as a "plain type" or "clamp nut type" as illustrated above. The stem diameter is manufactured to a nominal Metric or Imperial size with an h6 tolerance.
- The clamp nut stem allows fast and secure clamping of the micrometer head. The plain stem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

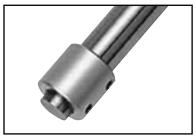
Measuring Face



Flat face



Spherical face



Anti-rotation device

- A flat measuring face is often specified where a micrometer head is used in measurement applications.
- When a micrometer head is used as a feed device, a spherical face can minimize errors due to misalignment (Figure A). Alternatively, a flat face on the spindle can bear against a sphere, such as a carbide ball (Figure B).

Figure A

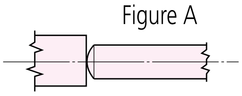
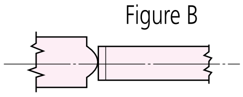
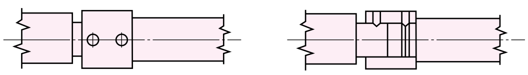


Figure B



- A non-rotating spindle type micrometer head or one fitted with an anti-rotation device on the spindle (Figure C) can be used if a twisting action on the workpiece must be avoided.

Figure C



- If a micrometer head is used as a stop then a flat face both on the spindle and the face it contacts provides durability.

Non-Rotating Spindle

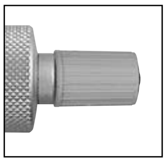
A non-rotating spindle type head does not exert a twisting action on a workpiece, which may be an important factor in some applications.

Spindle Thread Pitch

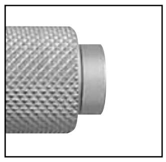
- The standard type head has 0.5mm pitch.
- 1mm-pitch type: quicker to set than standard type and avoids the possibility of a 0.5mm reading error. Excellent load-bearing characteristics due to larger screw thread.
- 0.25mm or 0.1mm-pitch type
  This type is the best for fine-feed or fine-positioning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

Constant-force Device

- A micrometer head fitted with a constant-force device (ratchet or friction thimble) is recommended for measurement applications.



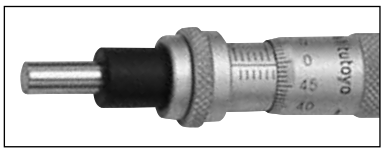
Micrometer head with constant-force device



Micrometer head without constant-force device (no ratchet)

- If using a micrometer head as stop, or where saving space is a priority, a head without a ratchet is probably the best choice.

Spindle Lock

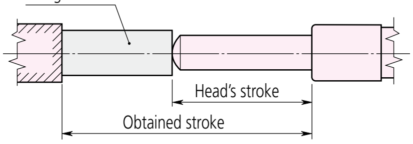


- If a micrometer head is used as a stop it is desirable to use a head fitted with a spindle lock so that the setting will not change even under repeated shock loading.

Measuring Range (Stroke)

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

Figure D

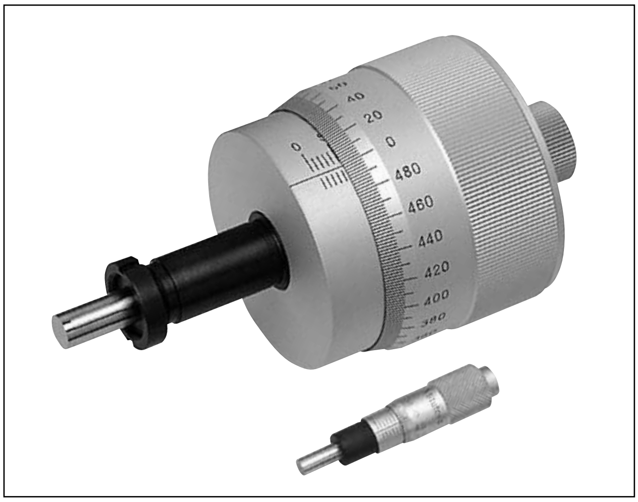


Ultra-fine Feed Applications

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

Thimble Diameter

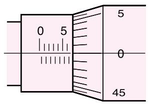
- The diameter of a thimble greatly affects its usability and the "fineness" of positioning. A small-diameter thimble allows quick positioning whereas a large-diameter thimble allows fine positioning and easy reading of the graduations. Some models combine the advantages of both features by mounting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



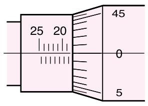
Graduation Styles

- Care is needed when taking a reading from a mechanical micrometer head, especially if the user is unfamiliar with the model.
- The "normal graduation" style, identical to that of an outside micrometer, is the standard. For this style the reading increases as the spindle retracts into the body.
- On the contrary, in the “reverse graduation” style the reading increases as the spindle advances out of the body.
- The "bidirectional graduation" style is intended to facilitate measurement in either direction by using black numerals for normal, and red numerals for reverse, operation.
- Micrometer heads with a mechanical or electronic digital display, which allow direct reading of a measurement value, are also available. These types are free from misreading errors. A further advantage is that the electronic digital display type can enable computer-based storage and statistical processing of measurement data.

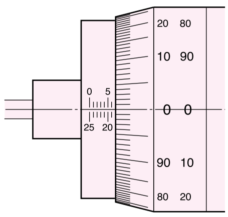
Normal graduation style



Reverse graduation style



Bidirectional graduation style

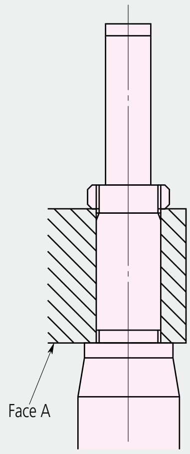
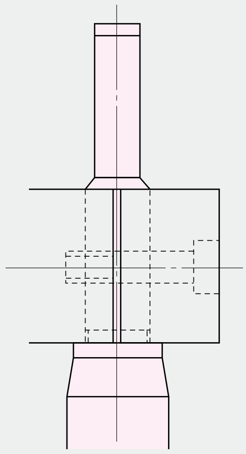
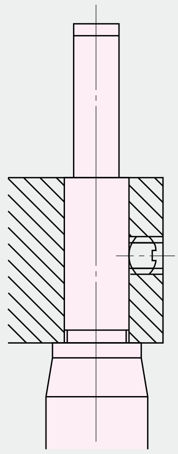


Micrometer Heads

Guidelines for Self-made Fixtures

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

(Unit: mm)

Mounting method / Points to keep in mind	(1) Clamp nut				(2) Split-body clamp				(3) Setscrew clamp			
												
Stem diameter	ø9.5	ø10	ø12	ø18	ø9.5	ø10	ø12	ø18	ø9.5	ø10	ø12	ø18
Mounting hole Fitting tolerance	G7 +0.006 to +0.024		G7 +0.005 to +0.020		G7 +0.005 to +0.020		G7 +0.006 to +0.024		H5 0 to +0.006		H5 0 to +0.008	
Precautions	Care should be taken to make Face A square to the mounting hole. The stem can be clamped without any problem at squareness within 0.16/6.5.				Remove burrs generated on the wall of the mounting hole by the slitting operation.				M3x0.5 or M4x0.7 is an appropriate size for the setscrew. Use a brass plug under setscrew (if thickness of fixture allows) to avoid damaging stem.			

Maximum Loading Capacity on Micrometer Heads

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

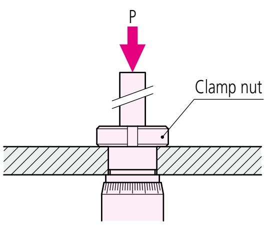
1. Recommended maximum loading limit

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

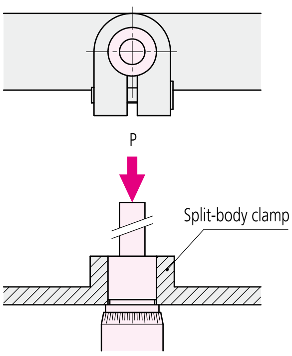
* Up to approx. 2kgf only for MHT

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

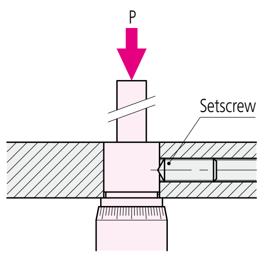
(1) Clamp nut



(2) Split-body clamp



(3) Setscrew clamp



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

Mounting method	Damaging/dislodging load*
(1) Clamp nut	Damage to the main unit will occur at 8.63 to 9.8kN (880 to 1000kgf).
(2) Split-body clamp	The main unit will be pushed out of the fixture at 0.69 to 0.98kN (70 to 100kgf).
(3) Setscrew clamp	Damage to the setscrew will occur at 0.69 to 1.08kN (70 to 110kgf).

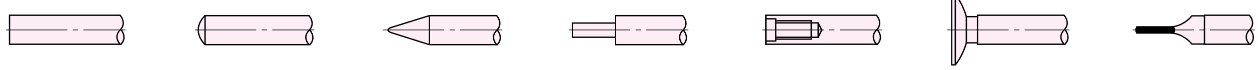
* These load values should only be used as an approximate guide.

Custom-built Products (Product Example Introductions)

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

1. Spindle-end types

● Standard ● Spherical ● Pointed ● Spline ● Tapped ● Flanged ● Blade (for non-rotating spindle type only)

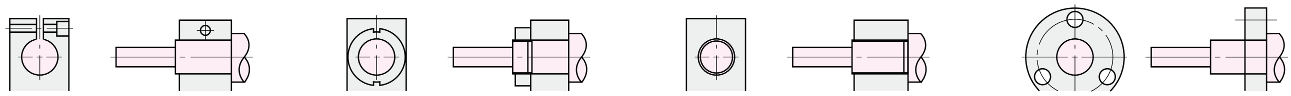


● Long spindle type is also available. Please consult Mitutoyo.

2. Stem types

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

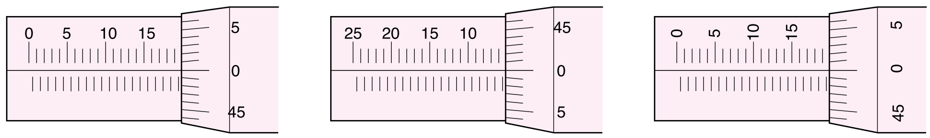
● Plain ● Clamp nut ● Threaded ● Flanged



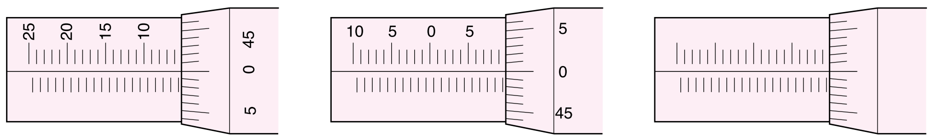
3. Scale graduation schemes

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

● Standard ● Reverse ● Vertical



● Reverse vertical ● Offset zero ● Graduations only

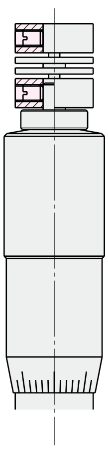


4. Logo engraving

A specific logo can be engraved as required.

5. Motor Coupling

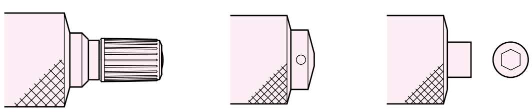
Couplings for providing motor drive to a head can be designed.



6. Thimble mounting

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

● Ratchet ● Setscrew ● Hex-socket head screw



7. Spindle-thread pitch

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

8. Lubricant for spindle threads

Lubrication arrangements can be specified by the customer.

9. All-stainless construction

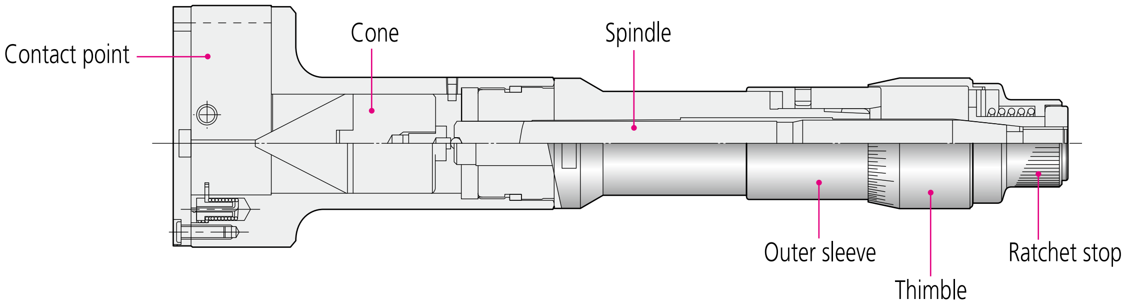
All components of a head can be manufactured in stainless steel.

10. Simple packaging

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

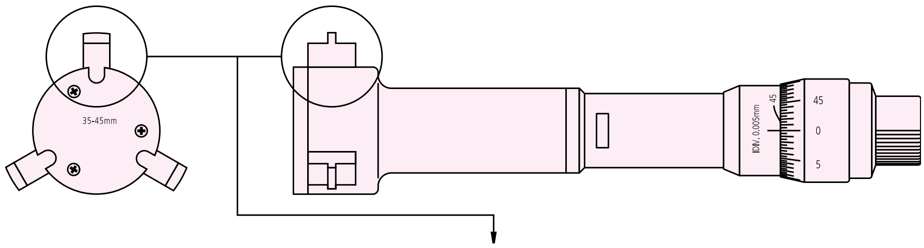
Internal Micrometers

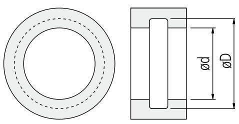
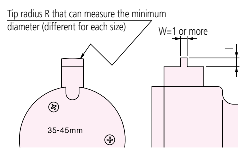
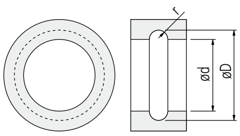
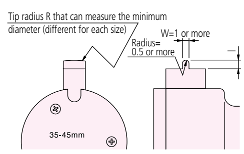
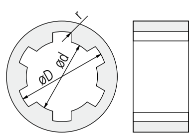
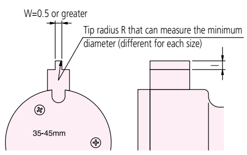
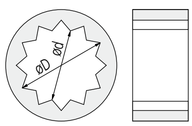
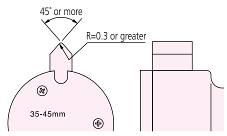
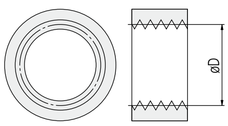
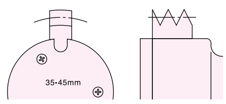
Nomenclature



Custom-ordered Products (Holtest/Borematic)

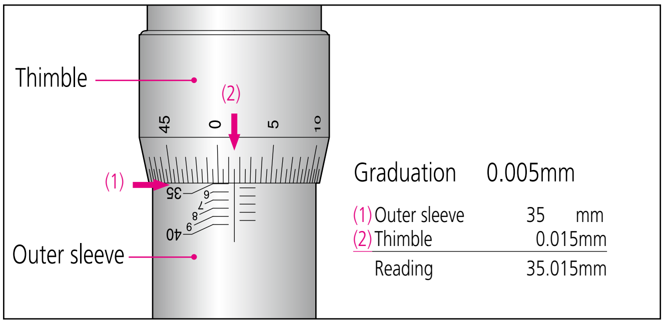
Mitutoyo can custom-build an internal micrometer best-suited to your special application. Please feel free to contact Mitutoyo about the possibilities - even if only one custom-manufactured piece is required. Please note that, depending on circumstances, such a micrometer will usually need to be used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



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

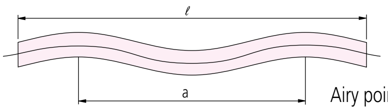
* Mitutoyo can manufacture other custom designs of internal micrometer according to the application. Cost and delivery depends on the order terms and conditions. To place a custom order please contact the nearest Mitutoyo Sales Center.

How to Read the Scale



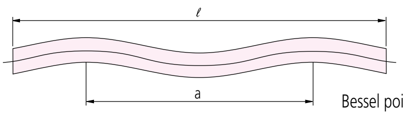
Airy and Bessel Points

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



Airy points (a ~ 0.577ℓ)

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



Bessel points (a ~ 0.554ℓ)

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

Misalignment Errors

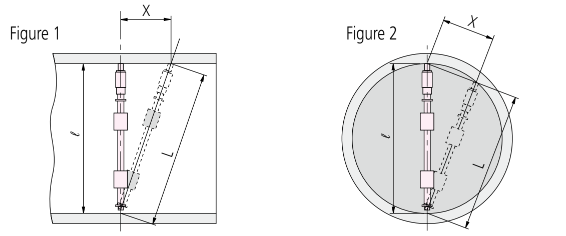


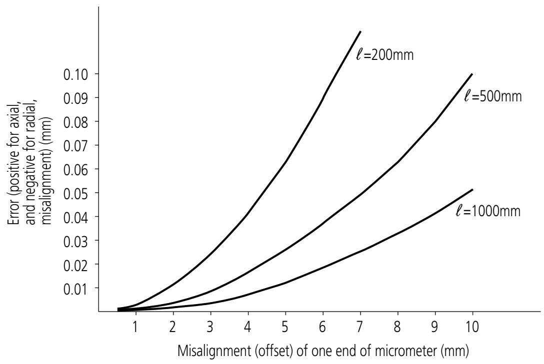
Figure 1:

ℓ: Inside diameter to be measured
L: Length measured with axial offset X
X: Offset in axial direction
$\Delta\ell$: Error in measurement
$\Delta\ell$: $L-\ell=\sqrt{\ell^2+X^2}-\ell$

Figure 2:

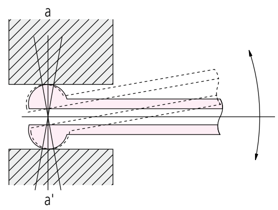
ℓ: Inside diameter to be measured
L: Length measured with radial offset X
X: Offset in radial direction
$\Delta\ell$: Error in measurement
$\Delta\ell$: $L-\ell=\sqrt{\ell^2-X^2}-\ell$

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

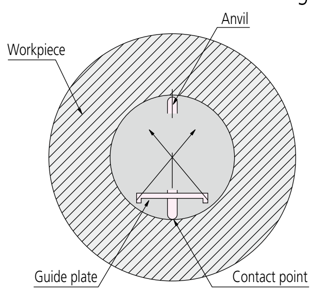


Bore Gages

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



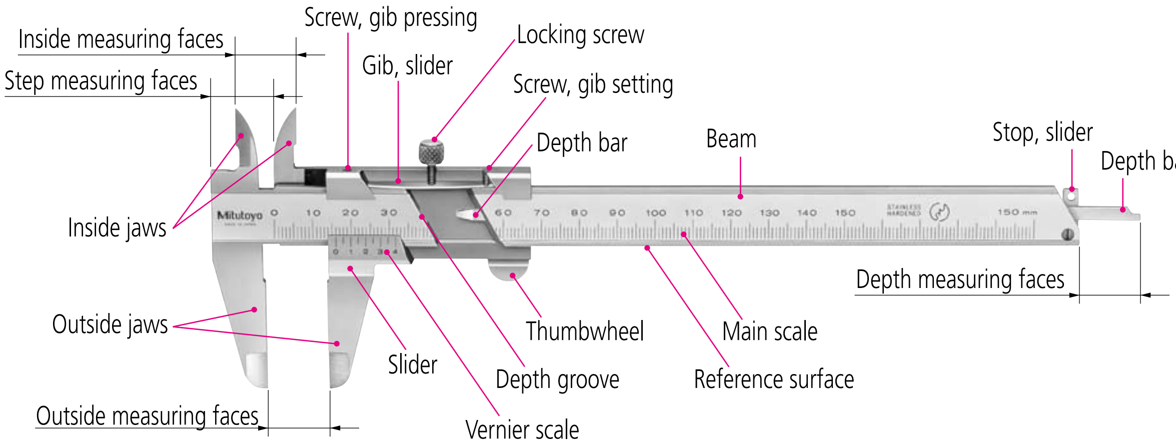
- The spring-loaded guide plate on a Mitutoyo two-point bore gage automatically ensures radial alignment so that only an axial rocking movement is needed to find the minimum reading (true diameter).



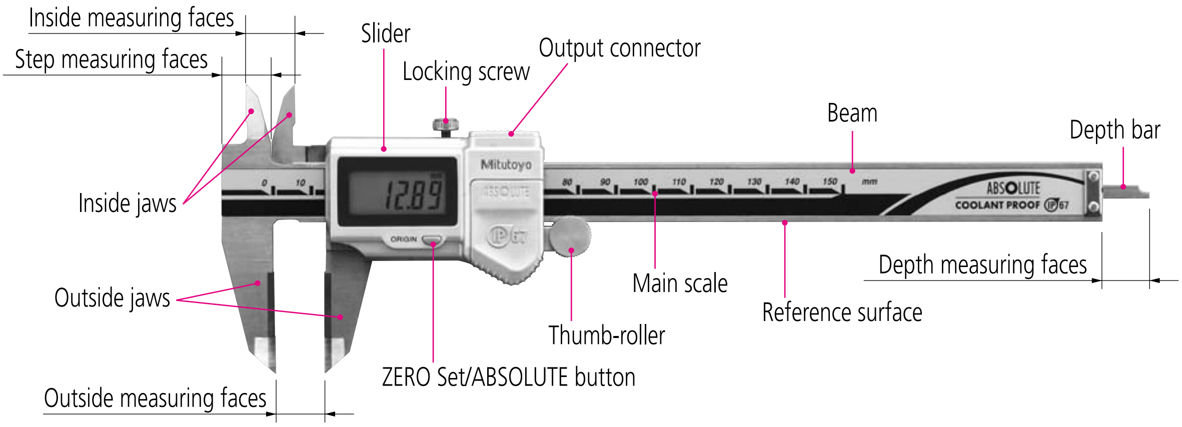
Calipers

Nomenclature

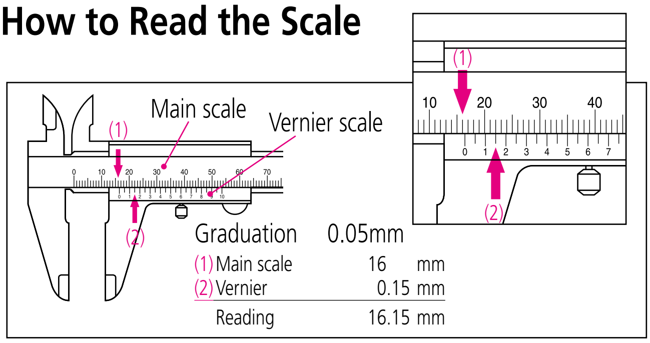
Vernier Caliper

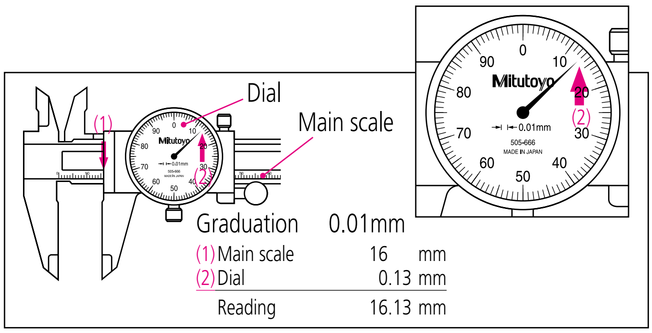


Absolute Digimatic Caliper



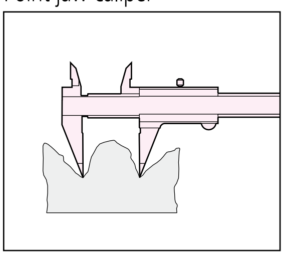
How to Read the Scale





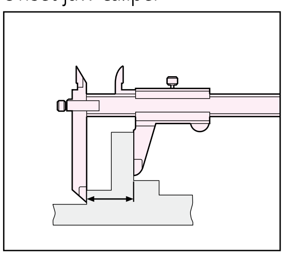
Special Purpose Caliper Applications

Point jaw caliper



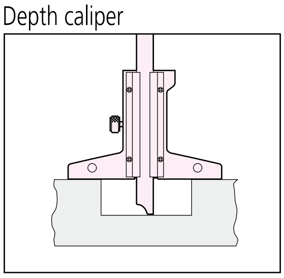
For uneven surface measurement

Offset jaw caliper



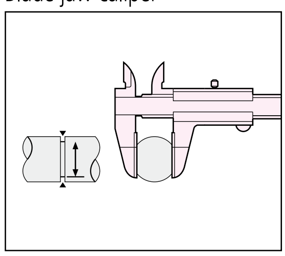
For stepped feature measurement

Depth caliper



For depth measurement

Blade jaw caliper

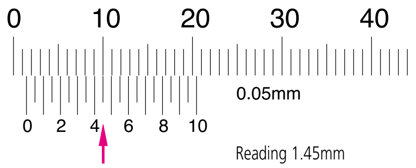


For diameter of narrow groove measurement

Types of Vernier Scale

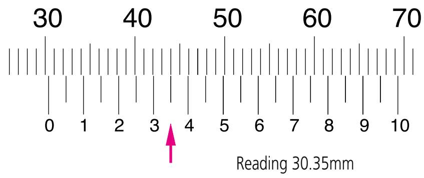
The Vernier scale is attached to the caliper's slider and each division on this scale is made 0.05mm shorter than one main scale division of 1 mm. This means that, as the caliper jaws open, each successive movement of 0.05mm brings the succeeding vernier scale line into coincidence with a main scale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

● Standard Vernier scale (resolution 0.05mm)



Reading 1.45mm

● Long Vernier scale (resolution 0.05mm)

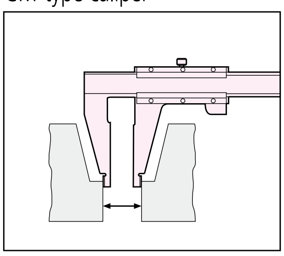


Reading 30.35mm

Sources of Error

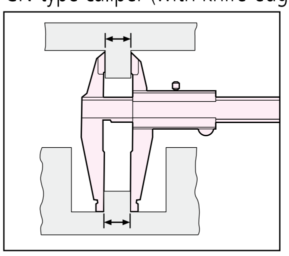
Main sources of error include scale misreading (parallax effect), excessive measuring force causing jaw tilt, thermal expansion caused by a temperature difference between the caliper and workpiece, and small-hole diameter error caused by inside jaw offset. There are other minor error sources such as graduation accuracy, reference edge straightness, main scale flatness and squareness of the jaws. These sources are allowed for within the specified accuracy of a new caliper and only cause significant error in case of wear or damage.
The JIS standard emphasizes that care must be used to ensure that measurement is performed with an appropriate and constant measuring force, since a caliper has no constant-force device, and that the user must be aware of the increased possibility of error due to measuring a workpiece using the tips of the jaws (Abbe's Principle).

CM-type caliper



For outside measurement
For measurement of inside bore

CN-type caliper (with knife-edge)

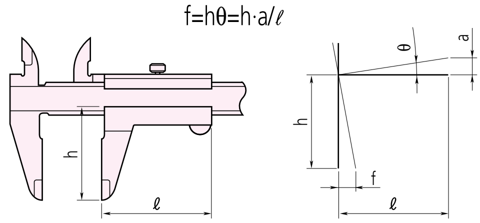


For outside measurement
For stepped feature measurement

Moving Jaw Tilt Error

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

$f = h\theta = h \cdot a / \ell$



Example: Assume that the error slope of the jaws due to tilt of the slider is 0.01mm in 50mm and the outside measuring jaws are 40mm deep, then the error (at the jaw tip) is calculated as (40/50)x0.01mm = 0.008mm.
If the guide face is worn then an error may be present even using the correct measuring force.

About Long Calipers

Steel rules are commonly used to roughly measure large workpieces but if a little more accuracy is needed then a long caliper is suitable for the job. A long caliper is very convenient for its user friendliness but does require some care in use. In the first place it is important to realize there is no relationship between resolution and accuracy. Resolution is constant whereas the accuracy obtainable varies dramatically according to how the caliper is used.
The measuring method with this instrument is a concern since distortion of the main beam causes a large amount of the measurement error, so accuracy will vary greatly depending on the method used for supporting the caliper at the time. Also, be careful not to use too much measuring force when using the outside measuring faces as they are furthest away from the main beam so errors will be at a maximum here. This precaution is also necessary when using the tips of the outside measuring faces of a long-jaw caliper.

Inside Measurement with a CM-type Caliper

Because the inside measuring faces of a CM-type caliper are at the tips of the jaws the measuring face parallelism is heavily affected by measuring force, and this becomes a large factor in the measurement accuracy attainable.

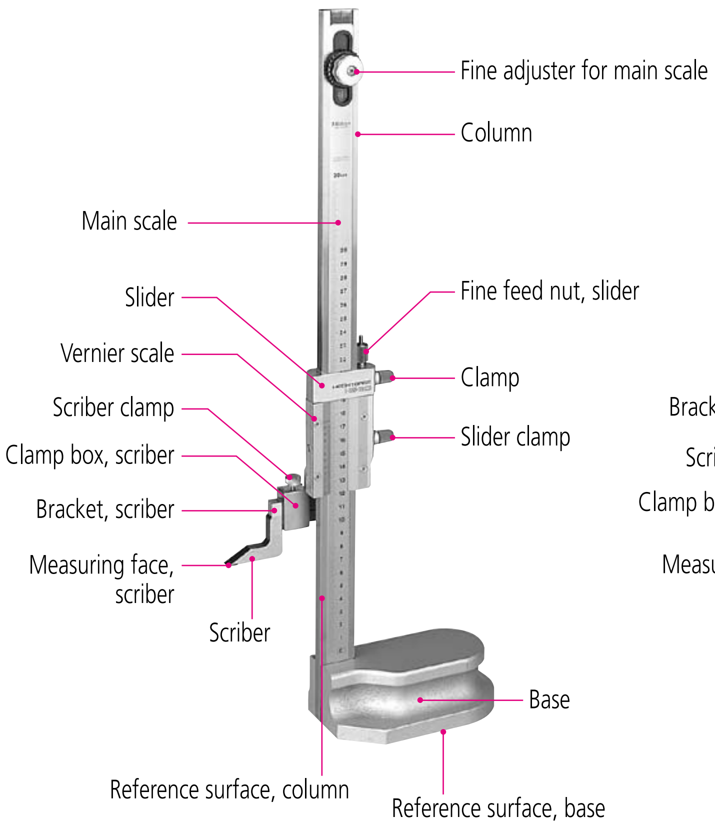
In contrast to an M-type caliper, a CM-type caliper cannot measure a very small hole diameter because it is limited to the size of the stepped jaws, although normally this is no inconvenience as it would be unusual to have to measure a very small hole with this type of caliper. Of course, the radius of curvature on the inside measuring faces is always small enough to allow correct hole diameter measurements right down to the lowest limit (jaw closure).

Mitutoyo CM-type calipers are provided with an extra scale on the slider for inside measurements so they can be read directly without the need for calculation, just as for an outside measurement. This useful feature eliminates the possibility of error that occurs when having to add the inside-jaw-thickness correction on a single-scale caliper.

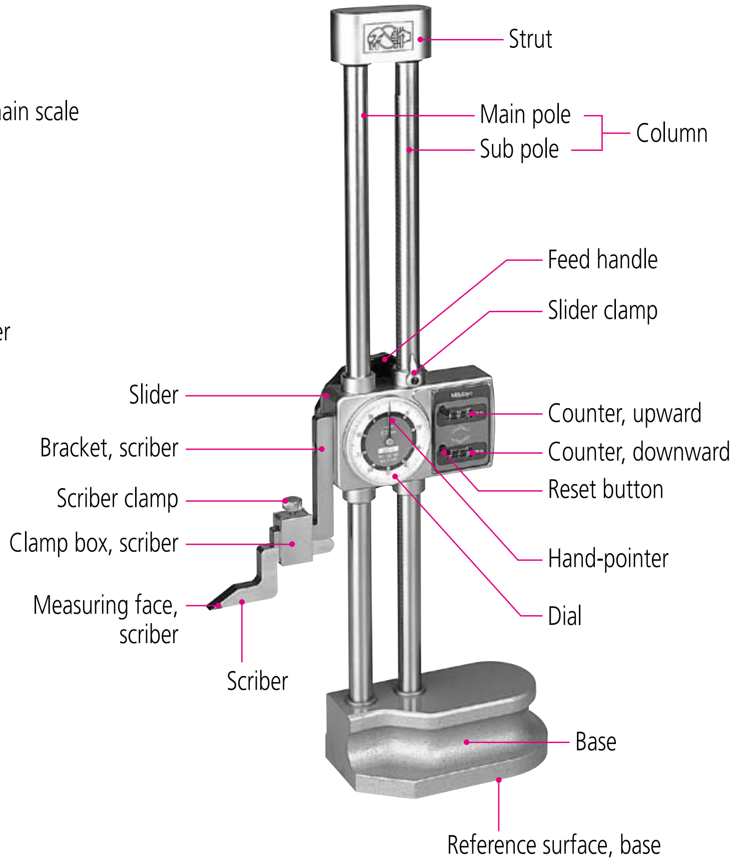
Height Gages

Nomenclature

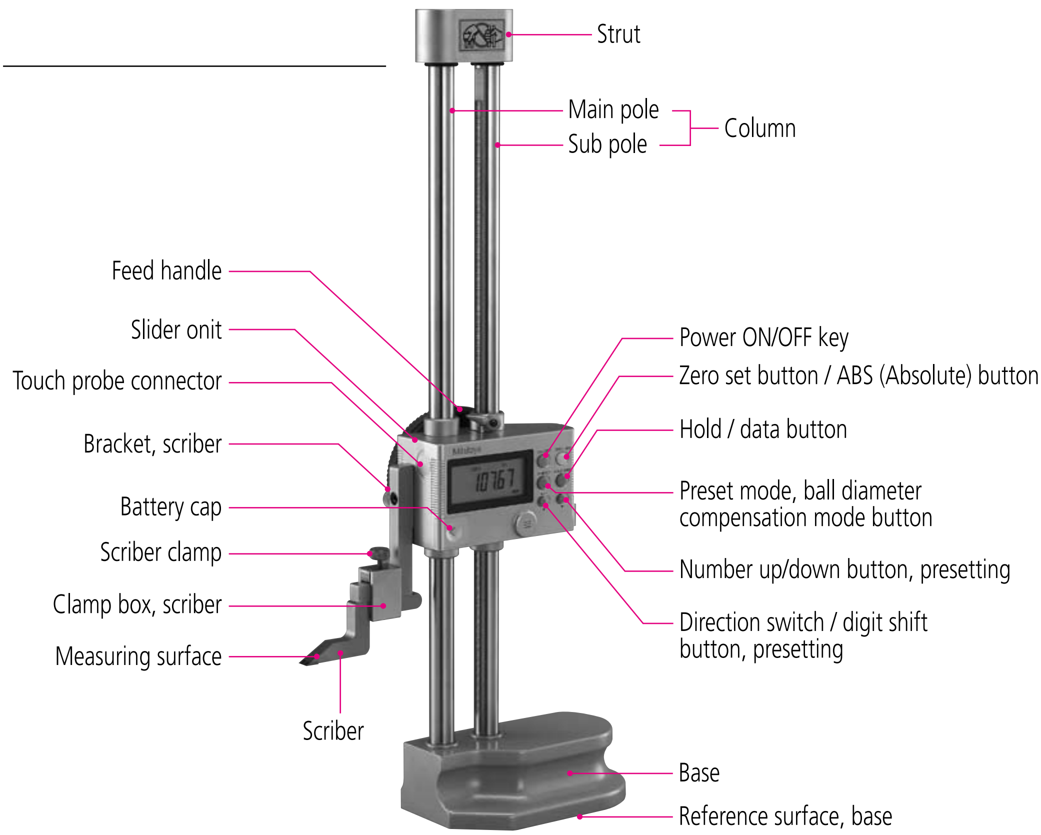
Vernier Height Gage



Mechanical Digit Height Gage

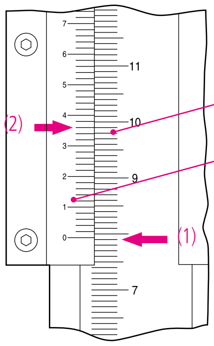


Digimatic Height Gage



How to read

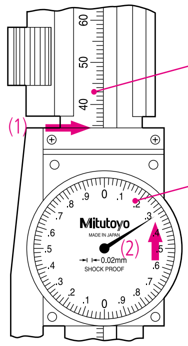
Vernier Height gage



Graduation 0.02mm

(1) Main scale	79 mm
(2) Vernier	0.36 mm
Reading	79.36 mm

Dial Height gage

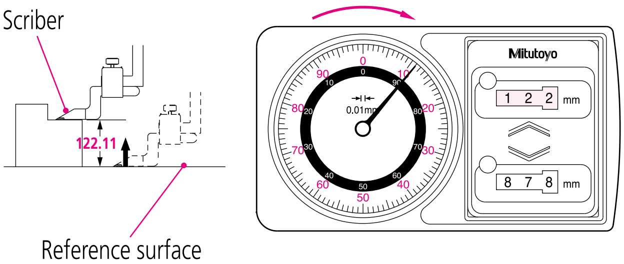


Graduation 0.02mm

(1) Main scale	34 mm
(2) Dial	0.32 mm
Reading	34.32 mm

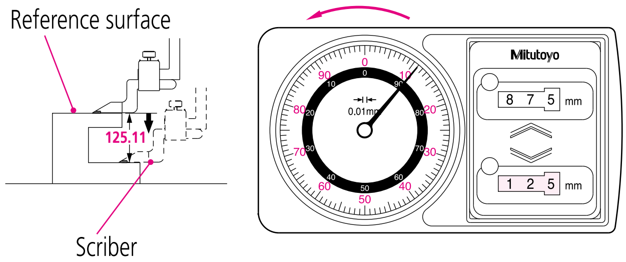
Mechanical Digit Height gage

Measuring upwards from a reference surface



Counter	122 mm
Dial	0.11 mm
Reading	122.11 mm

Measuring downwards from a reference surface



Counter	125 mm
Dial	0.11 mm
Reading	125.11 mm

General notes on using the height gage

1. Make sure that the base is free of burrs that would otherwise adversely affect scribing and measuring stability. If there is a burr, remove it by using an oilstone.
2. Keep the leaf spring of the slider and reference face of the main scale clean. Accumulated dust might cause poor sliding.
3. Tighten the slider clamp to prevent the slider from moving during scribing.
4. The scriber edge might move by up to 0.01 mm when the slider clamp is tightened. Check the movement by using a test indicator.
5. The parallelism between the scriber mounting bracket, scriber measuring face, and reference surface of the base is 0.01 mm or less. Avoid moving the scriber forward or backwards during measurement because movement can cause errors.
6. Use the fine feed to ensure accurate adjustment to final position.
7. Be aware of possible parallax error on vernier instruments and always read the scales from the normal direction.

Dial Indicators/Dial Test Indicators

Nomenclature

Dial faces

0.01mm


Continuous dial (Dual reading)


Balanced dial (Multi-revolution)


Continuous dial (Reverse reading)


Balanced dial (One revolution)

0.001mm


Continuous dial (Dual reading)

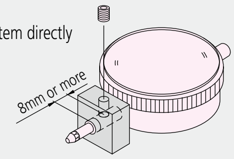
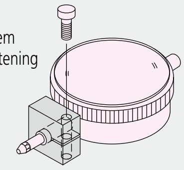
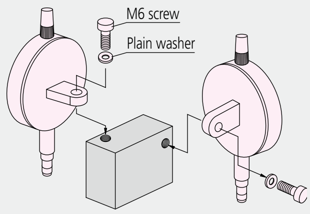

Balanced dial (Multi-revolution)


Continuous dial (Double scale spacing)


Balanced dial (One revolution)

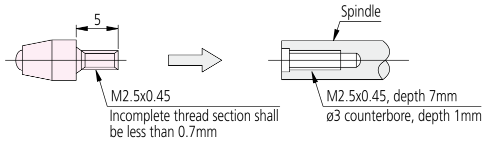
Continuous dial:	For direct reading
Balanced dial:	For reading the difference from a reference surface
Reverse reading dial:	For depth or bore gage measurement
One revolution dial:	For error free reading of small differences

Mounting a Dial Indicator

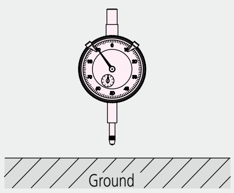
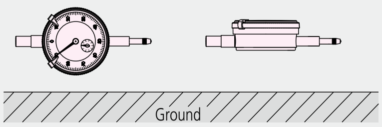
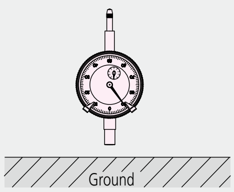
Stem mounting	Method	Clamping the stem directly with a screw 	Clamping the stem by split-body fastening 
	Note	● Mounting hole tolerance: ø8G7(+0.005 to 0.02) ● Clamping screw: M4 to M6 ● Clamping position: 8mm or more from the lower edge of the stem ● Maximum clamping torque: 150N·cm when clamping with a single M5 screw ● Note that excessive clamping torque may adversely affect spindle movement.	● Mounting hole tolerance: ø8G7(+0.005 to 0.02)
Lug mounting	Method		
	Note	● Lugs can be changed 90 degrees in orientation according to the application. (The lug is set horizontally when shipped.) ● Lugs of some Series 1 models (Nos. 1911, 1913-10, & 1003), however, cannot be altered to horizontal. ● To avoid cosine-effect error, ensure that a dial indicator is mounted with its spindle in line with the intended measurement direction.	

Dial Indicator Contact Point

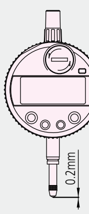
- Screw thread section is standardized on M2.5x0.45 (Length: 5mm).
- Incomplete thread section at the root of the screw shall be less than 0.7mm when fabricating a contact point.



Dial gage and Digimatic indicator positions

Position		Remarks
Contact point down (normal position)		—
Spindle horizontal (lateral position)		If measurement is performed with the spindle horizontal or contact point up, the measuring force is less than when the contact point is down. In this case be sure to check the operation and repeatability of the indicator or digital display. For guaranteed-operation specifications according to positions of Digimatic indicators and dial gages, refer to the product descriptions in a general catalog.
Contact point up (upside-down position)		

Setting the origin of a Digimatic indicator

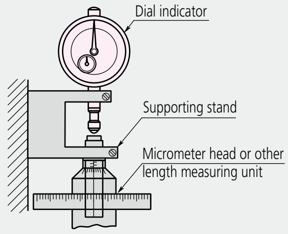
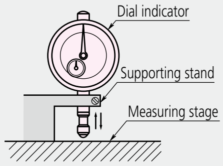
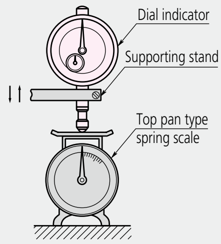
	Repeatability in the range of 0.2 mm from the end of the stroke is not guaranteed for Digimatic indicators. When setting the zero point or presetting a specific value, be sure to lift the spindle at least 0.2 mm from the end of the stroke.

Notes on using dial gages and Digimatic indicators

- Do not lubricate the spindle. Doing so might cause dust to accumulate, resulting in a malfunction.
- If the spindle movement is poor, wipe the upper and lower spindle surfaces with a dry or alcohol-soaked cloth. If the movement is not improved by this cleaning, contact Mitutoyo for repair.

Dial Indicators/Dial Test Indicators

Dial Indicator B7503-1997 (Extract from JIS/Japanese Industrial Standards)

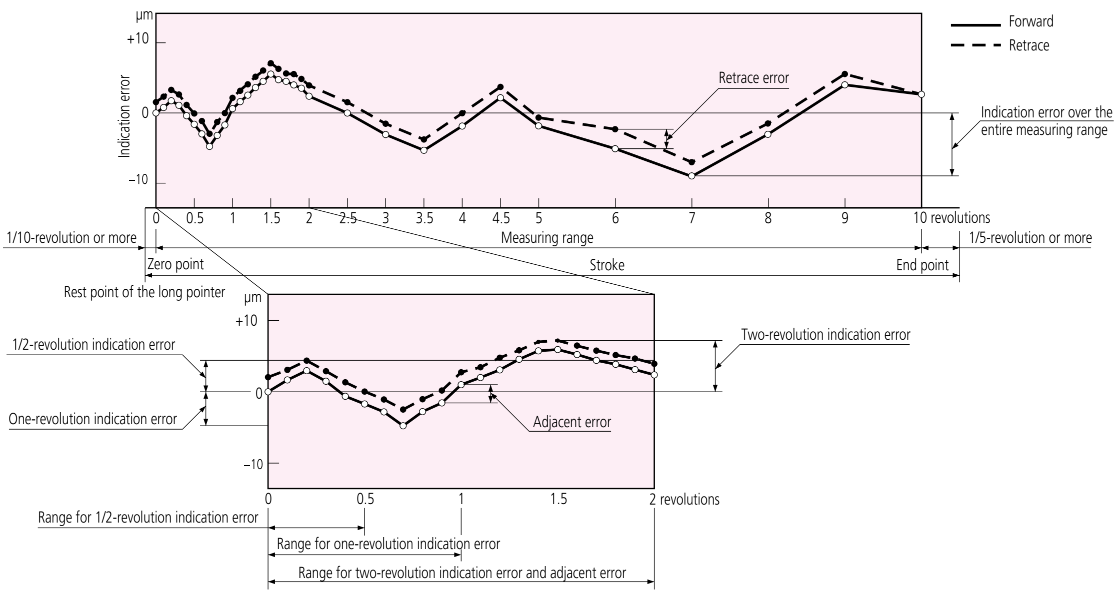
No.	Item	Calibration method	Diagram of calibration setup	Tools for calibration
1	Indication error	Holding the dial indicator with its spindle set vertically downward, follow the procedure prescribed below and determine the error of indication with reference to the dial graduations. First, displace the spindle upward over the entire measuring range while plotting errors at every 1/10 revolution of the pointer for the first two revolutions from the zero point, at every half revolution for the next five revolutions, and at every revolution after the fifth revolution, then reverse the spindle displacement at the end of the measuring range of the dial indicator and plot errors at the same points measured during upward spindle displacement. Determine errors from a bidirectional error curve thus obtained. (Fig. 1)		For 0.001mm or 0.002mm graduation dial indicators with a 2mm measuring range or less: A micrometer head or other measuring unit with 0.5μm graduation or less and instrumental error of ±1μm and a supporting stand. For dial indicators other than the above: A micrometer head or other measuring unit with 1μm graduation or less and ±1μm instrumental error and a supporting stand.
2	Adjacent error			
3	Retrace error			
4	Repeatability	Apply the contact point of the dial indicator perpendicularly to the upper face of a measuring stage, displace the spindle quickly and slowly five times at a desired position within the measuring range and determine the maximum difference between the five indications obtained.		Measuring stage Supporting stand
5	Measuring force	Holding a dial indicator with its spindle set vertically downward, displace the spindle upward and then downward continuously and gradually and take measurements of the measuring force at the zero, middle, and end points in the measuring range in both the upward and downward directions.		Supporting stand Top pan type spring scale (graduation: 2gf or less) or force gage (sensitivity: 0.02N or less)

Maximum permissible error of indication

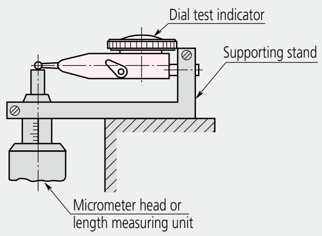
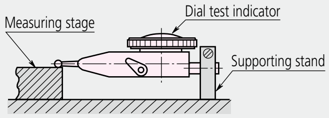
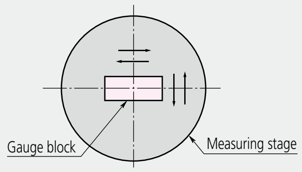
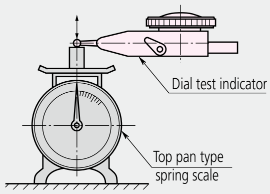
Unit: μm

		Graduation and measuring range					
		0.01mm	0.002mm		0.001mm		
Measuring range		10mm or less	2mm or less	Over 2mm and up to 10mm	1mm or less	Over 1mm and up to 2mm	Over 2mm and up to 5mm
Retrace error		5	3	4	3	3	4
Repeatability		5	0.5	1	0.5	0.5	1
Indication error	1/10 revolution *1	8	4	5	2.5	4	5
	1/2 revolution	±9	±5	±6	±3	±5	±6
	One revolution	±10	±6	±7	±4	±6	±7
	Two revolutions	±15	±6	±8	±4	±6	±8
	Entire measuring range	±15	±7	±12	±5	±7	±10

*1: Adjacent accuracy
Remarks: Values in the table above apply at at 20˚C.
Performance: Maximum permissible errors of a dial indicator shall comply with the table above.
Permissible errors of indication shall be evaluated inclusive of the uncertainty of calibration.



Dial Test Indicator B7533-1990 (Extract from JIS/Japanese Industrial Standards)

No.	Item		Calibration method	Diagram of calibration setup	Tools for calibration
1	Wide-range accuracy		(1) For an indicator of 0.01 mm graduation: Displace the contact point so as to move the pointer clockwise in increments of 0.1 mm with reference to the graduations from the zero point to the end point of the measuring range while taking readings of the calibration tool at each point and determine this accuracy from the error curve drawn by plotting the differences of each "indicator reading - calibration tool reading". (2) For an indicator of 0.002 mm graduation: Displace the contact point so as to move the pointer clockwise in increment of 0.02 mm with reference to the graduations from the zero point to the end point of the measuring range while taking readings of the calibration tool at each point and determine this accuracy from the error curve drawn by plotting the differences of each "indicator reading - calibration tool reading". The instrumental error of the calibration tool shall be compensated prior to this measurement.		Micrometer head or measuring unit (graduation: 1µm or less, instrumental error: within ±1µm), supporting stand
2	Adjacent error				
3	Retrace error		After the completion of the wide-range accuracy measurement, reverse the contact point from the last point of measurement while taking readings at the same scale graduations as for the wide-range accuracy measurement and determine the retrace error from the error curve plotted.		
4	Repeatability	a	Holding the dial test indicator with its stylus parallel with the top face of the measuring stage, displace the contact point quickly and slowly five times at a desired position within the measuring range and determine the maximum difference in indication.		Measuring stage, Supporting stand, and Gauge block of grade 1 as stipulated by JIS B7506 (Gauge block)
		b	Holding the stylus parallel to a gauge block placed on the measuring stage, move the gauge block to and fro and left to right under the contact point within the measuring range and determine the maximum difference in indication.		
5	Measuring force		Holding an indicator by the case or stem, displace the contact point gradually and continuously in the forward and backward directions respectively and take a reading of measuring force at the zero, middle and end points of the measuring range in each direction. ●Performance The maximum measuring force in the forward direction shall not exceed 0.5N. The difference between the maximum and minimum measuring forces in one direction shall not exceed 0.2N (20gf). Note that the smallest possible measuring force is desirable for indicators.		Top pan type spring scale (graduation: 2gf or less) or force gage (sensitivity: 0.02N or less)

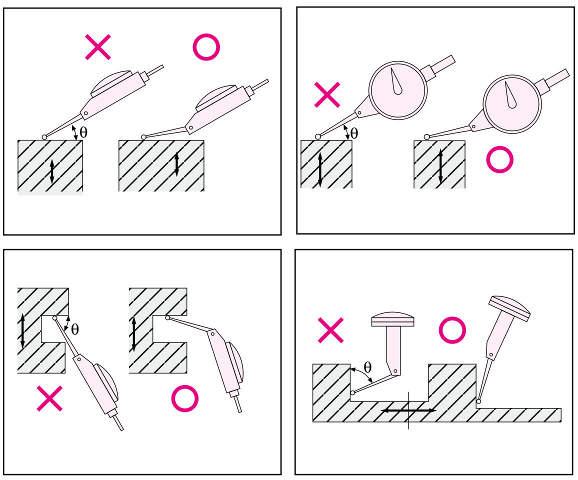
● Accuracy of indication

Permissible indication errors of dial test indicators are as per the table below. (Unit: µm)

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

*[1]: Applies to indicators with a contact point over 35 mm long.
Remarks: Values in the table above apply at 20°C.

Dial Test Indicators and the Cosine Effect



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

Compensating for a non-zero angle

Angle	Compensation value
10˚	0.98
20˚	0.94
30˚	0.86
40˚	0.76
50˚	0.64
60˚	0.50

Examples

If a 0.200mm measurement is indicated on the dial at various values of θ, the true measurements are:
For θ=10˚, 0.200mm×.98=0.196mm
For θ=20˚, 0.200mm×.94=0.188mm
For θ=30˚, 0.200mm×.86=0.172mm

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

Gauge Blocks

Definition of the Meter

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

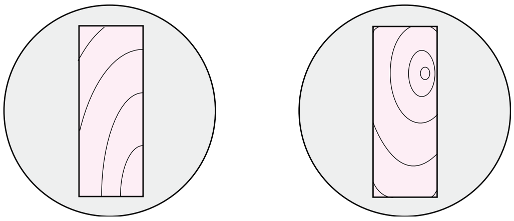
Selection, Preparation and Assembly of a Gauge Block Stack

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

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

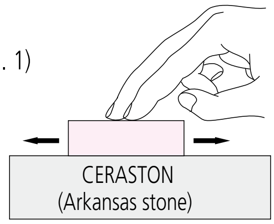
(2) Clean the gauge blocks with an appropriate cleaning agent.

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

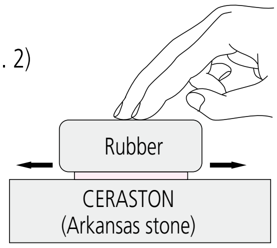


  a. Wipe each measuring face clean.
  b. Gently place the optical flat on the gauge block measuring face.
  c. Lightly slide the optical flat until interference fringes appear.
    Judgment 1: If no interference fringes appear, it is assumed that there is a large burr or contaminant on the measuring face.
  d. Lightly press the optical flat to check that the interference fringes disappear.
    Judgment 2: If the interference fringes disappear, no burr exists on the measuring face.
    Judgment 3: If some interference fringes remain locally while the flat is gently moved to and fro, a burr exists on the measuring face. If the fringes move along with the optical flat, there is a burr on the optical flat.
  e. Remove burrs, if any, from the measuring face using a flat, fine-grained abrasive stone.
    ① Wipe off any dust or oil from the gauge block and the Ceraston (or Arkansas stone) using a solvent.
    ② Place the gauge block on the Ceraston so that the measuring face that has burrs is on the abrasive surface of the stone. While applying light pressure, move the gauge block to and fro about ten times (Fig. 1). Use a block rubber for thin gauge blocks to apply even pressure (Fig. 2).

(Fig. 1)



(Fig. 2)



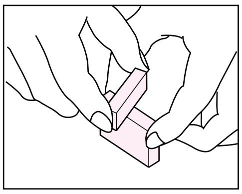
    ③ Check the measuring face for burrs with an optical flat. If the burrs have not been removed, repeat step (2). If burrs are too large to be removed with a stone, discard the gauge block.

Note: The abrasive surface of a Ceraston must be made flat by lapping it from time to time. After lapping the Ceraston, the lapping powder must be completely removed from the stone to prevent the surface of the gauge block being scratched. Mitutoyo does not supply the Arkansas stone.

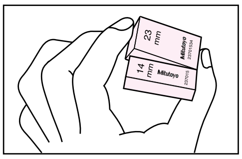
(4) Apply a very small amount of oil to the measuring face and spread it evenly across the face. (Wipe the face until the oil film is almost removed.) Grease, spindle oil, vaseline, etc., are commonly used.

(5) Gently overlay the faces of the gauge blocks to be wrung together.
There are the following three methods depending on the size of wringing:

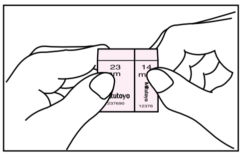
A. Wringing thick gauge blocks



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

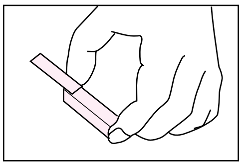


Rotate the gauge blocks while applying slight force to them. You will get a sense of wringing by sliding the blocks.

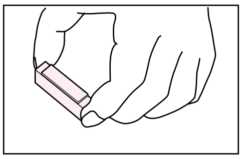


Align the measuring faces with each other.

B. Wringing a thick gauge block to a thin gauge block

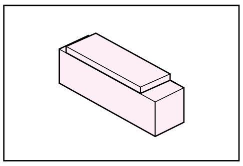


Overlap one side of a thin gauge block on one side of a thick gauge block.

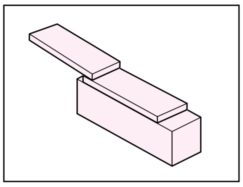


Slide the thin gauge block while pressing the entire overlapped area to align the measuring faces with each other.

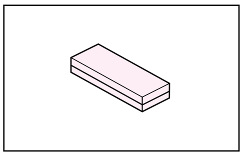
b. Wringing thin gauge blocks



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

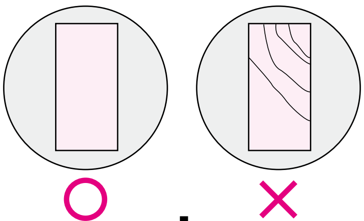


Then, wring the other thin gauge block onto the first thin gauge block.

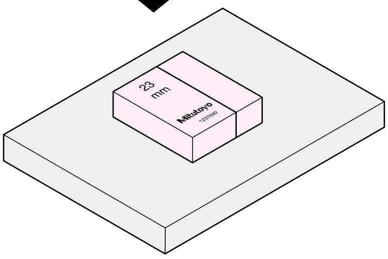


Finally, remove the thick gauge block from the stack.

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



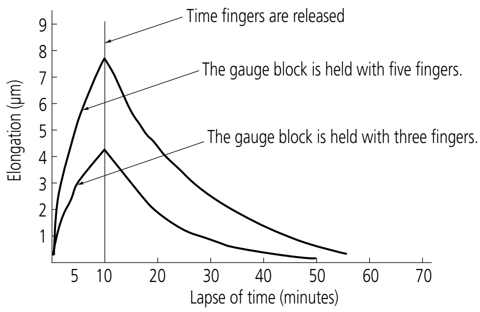
Irregular interference fringes



Wipe the exposed measuring face(s) and continue building up the stack, in the same manner as above, until complete.
The stack can then be thermally stabilized on a surface plate before use, if required. Do not leave the stack assembled for longer than is necessary, and clean and apply rustproofing protection to the blocks before packing them away in their box after use.

■ Thermal Stabilization Time

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



Laser Scan Micrometers and Laser Indicators

■ Compatibility

Every LSM Measuring Head is supplied with an ID Unit and they must always be used together. The ID Unit carries the same serial number as the Emission Unit and is inserted into the chosen display unit before use. However, the 500S series LSM is not compatible with older models (LSM-3000, 3100, 4000, 4100, 400, 500, and 500H series).

■ Workpieces and Measurement Conditions

A measurement error may be caused due to the difference between visible and invisible lasers and depending on the shape or surface roughness of a workpiece. To minimize this possibility, calibrate the instrument using a master of the same shape and the same value of surface roughness as the workpiece whenever possible. If measured values vary greatly depending on the measurement conditions, it is possible to improve accuracy by making as many measurements as possible and averaging the results.

■ Noise Suppression

To prevent malfunction due to electrical interference, do not run an LSM's signal cable or relay cable alongside a cable subject to high voltage or high surge currents. The LSM unit must be grounded.

■ Connecting to a Computer

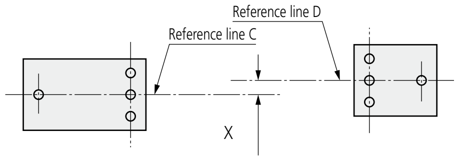
When connecting an LSM to a computer via an RS-232C interface, ensure that the connector pins are wired correctly.

■ Laser Beam Alignment

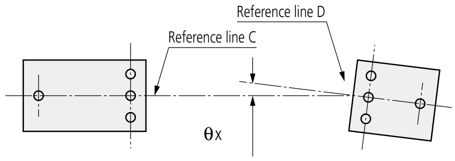
To minimize errors due to laser-beam misalignment when using those models that can be disassembled and built into jigs and fixtures, ensure that the emission and reception unit axes are aligned and spaced according to the following specification for the particular model:

■ Aligning the optical axes in the horizontal plane (using the hole patterns in the bases)

a. Distance between lines C and D
→ X alignment

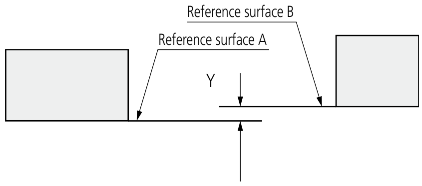


b. Angle between lines C and D
→ θx alignment

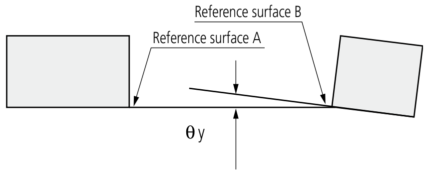


■ Aligning the optical axes in the vertical plane (using the base mounting surfaces)

c. Distance between planes A and B
→ Y alignment



d. Angle between planes A and B
→ θy alignment

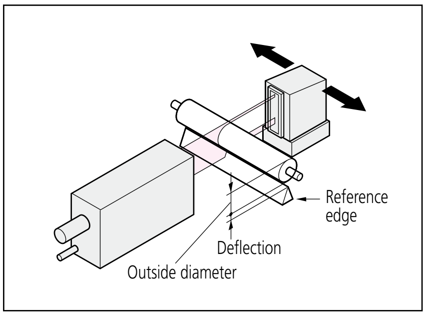


● Permissible unit spacing and optical axis misalignment limits

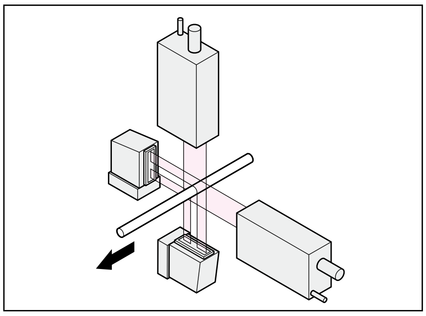
Application Model	Distance between emission unit and reception unit	X and Y	θx and θy
LSM-501S	68mm or less	within 0.5mm	within 0.4° (7mrad)
	100mm or less	within 0.5mm	within 0.3° (5.2mrad)
LSM-503S	135mm or less	within 1mm	within 0.4° (7mrad)
	350mm or less	within 1mm	within 0.16° (2.8mrad)
LSM-506S	273mm or less	within 1mm	within 0.2° (3.5mrad)
	700mm or less	within 1mm	within 0.08° (1.4mrad)
LSM-512S	321mm or less	within 1mm	within 0.18° (3.1mrad)
	700mm or less	within 1mm	within 0.08° (1.4mrad)
LSM-516S	800mm or less	within 1mm	within 0.09° (1.6mrad)

Measurement Examples

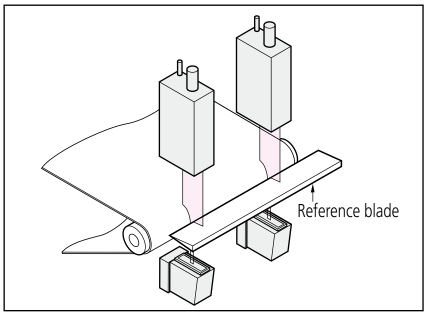
Simultaneous measurement of the diameter and deflection of a roller



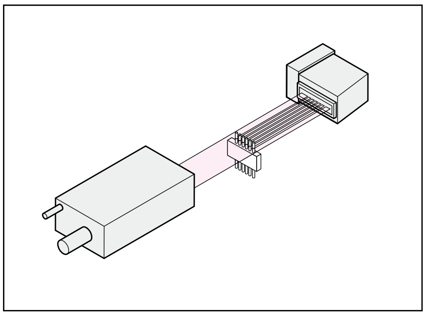
Simultaneous measurement of X and Y of an electric wire, optical fiber, or roller



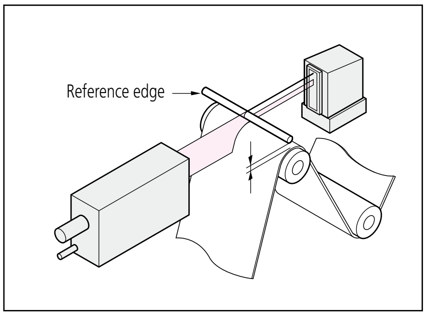
Measurement of thickness variation of a film or sheet (at dual points)



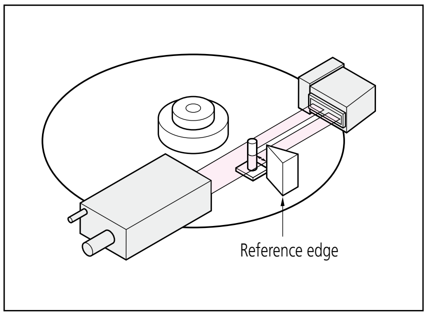
Measurement of pin pitch, width, or gap of an IC component



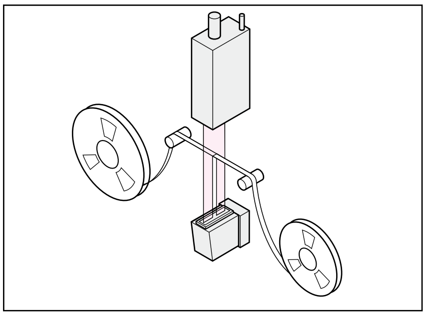
Measurement of thickness of a film or sheet



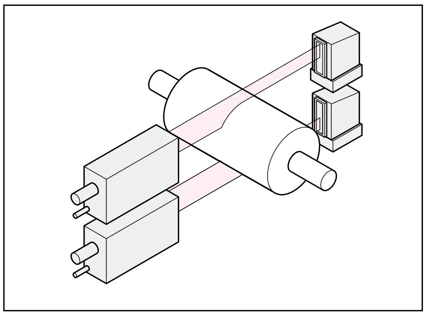
Measurement of displacement of an optical disk magnetic disk head



Continuous measurement of tape width



Dual system for measuring a large outside diameter



Safety Precautions

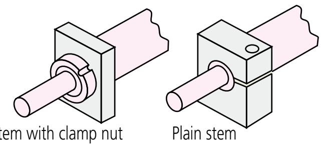
The LSM uses a low-power visible laser beam for measurement, which conforms to Class 2 of JIS C 6802 "Safety Standard for Emission from a Laser Product". The Class 2 Caution/Description label as shown below is affixed to those parts related to measurement.

Linear Gages

Head

Plain Stem and Stem with Clamp Nut

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



Precautions in Mounting a Gage Head

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

Measuring Force

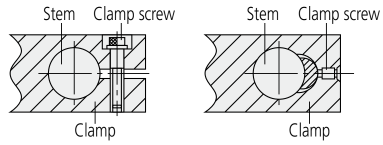
This is the force exerted on a workpiece during measurement by the contact point of a linear gage head, at its stroke end, expressed in Newtons.

Comparative Measurement

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

Precautions in Mounting a Laser Hologage

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



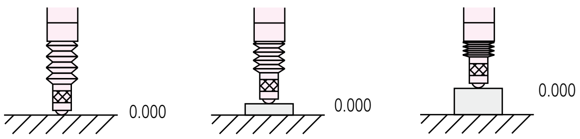
Recommended hole diameter on the fixing side: 15mm +0.034/-0.014

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

Display Unit

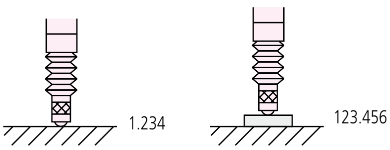
Zero-setting

A display value can be set to 0 (zero) at any position of the spindle.



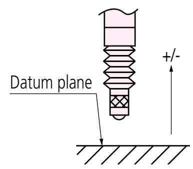
Presetting

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



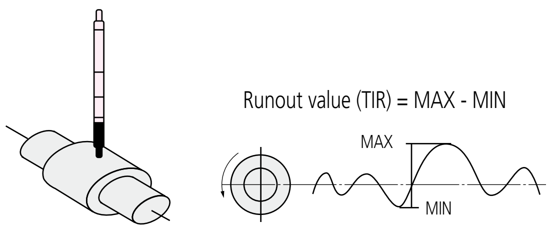
Direction changeover

The measuring direction of the gage spindle can be set to either plus (+) or minus (-) of count.



MAX, MIN, TIR Settings

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



Tolerance Setting

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

Digimatic Code

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

Open Collector Output

An external load, such as a relay or a logic circuit, can be driven from the collector output of an internal transistor which is itself controlled by a Tolerance Judgement result, etc.

BCD Output

A system for outputting data in binary-coded decimal notation.

RS-232C Output

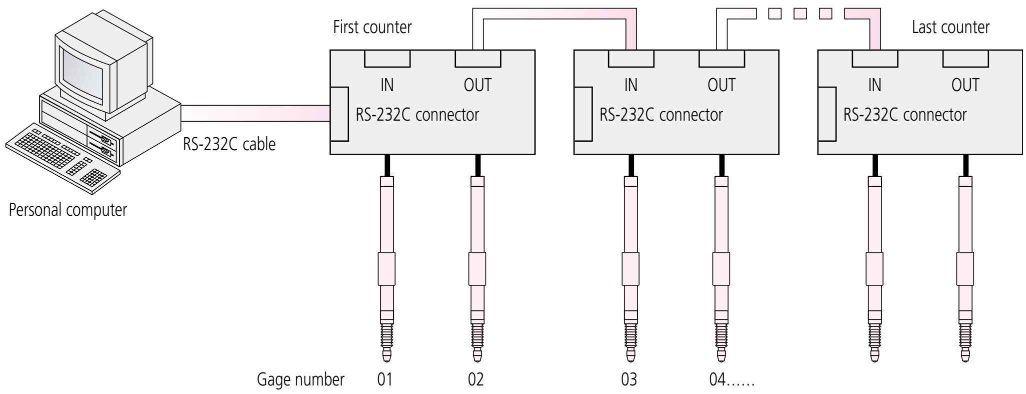
A serial communication interface in which data can be transmitted bi-directionally under the EIA Standards.
For the transmission procedure, refer to the specifications of each measuring instrument.

RS Link Function

Multi-point measurement can be performed by connecting multiple EH or EV counters with RS-link cables.

RS Link for EH Counter

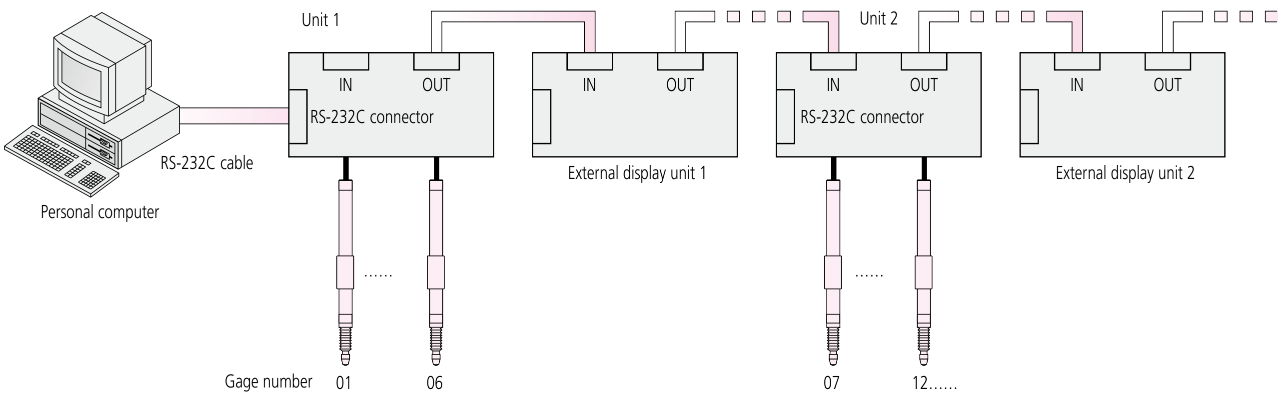
It is possible to connect a maximum of 10 counter units and handle up to 20 channels of multi-point measurement at a time.
For this connection use a dedicated RS link cable No.02ADD950 (0.5m), No.936937 (1m) or No.965014 (2m). (The total length of RS link cables permitted for the entire system is up to 10m.)



RS Link for EV Counter

It is possible to connect a maximum of 10* counter units and handle up to 60 channels of multi-point measurement at a time.
For this connection use a dedicated RS link cable No.02ADD950 (0.5m), No.936937 (1m) or No.965014 (2m). (The total length of RS link cables permitted for the entire system is up to 10m.)

* The maximum number of counter units that can be connected is limited to 6 (six) if an EH counter is included in the chain.



Linear Scales

Tests for Evaluating Linear Scales

1. Testing within the service temperature range

Confirms that there is no performance abnormality of a unit within the service temperature range and that data output is according to the standard.

2. Temperature cycle (dynamic characteristics) test

Confirms that there is no performance abnormality of a unit during temperature cycling while operating and that data output is according to the standard.

3. Vibration test (Sweep test)

Confirms that there is no performance abnormality of a unit while subject to vibrations of a frequency ranging from 30Hz to 300Hz with a maximum acceleration of 3g.

4. Vibration test (Acceleration test)

Confirms that there is no performance abnormality of a unit subject to vibrations at a specific, non-resonant frequency.

5. Noise test

This test conforms to the following
EMC Directives:
EN550111991: Group 1, Class B
EN50082-1: 1992

6. Package drop test

This test conforms to JISZ0200 (Heavy duty material drop test)

Glossary

■ Absolute system

A measurement mode in which every point measurement is made relative to a fixed origin point.

■ Incremental system

A measurement mode in which a point measurement is made relative to the point measured immediately before the current one.

■ Origin offset

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

■ Restoring the origin point

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

■ Sequence control

Refers to a type of control that sequentially performs control step by step according to the prescribed order of control.

■ Numerical control

Refers to a type of control that controls the tool position relative to a workpiece to be machined with corresponding numerical control commands.

■ Binary output

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

■ RS-232C

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

■ Line driver output

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

■ BCD

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

■ RS-422

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

■ Accuracy

The accuracy specification refers to the maximum difference between the indicated and true positions at any point, within the range of a scale, at a temperature of 20ºC. Since there is no international standard defined for scale units, each manufacturer has a specific way of specifying accuracy. The accuracies given in our catalog have been determined using laser interferometry.

Narrow range accuracy

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

Principle of the Absolute Linear Scale (Example: AT300, 500-S/H)

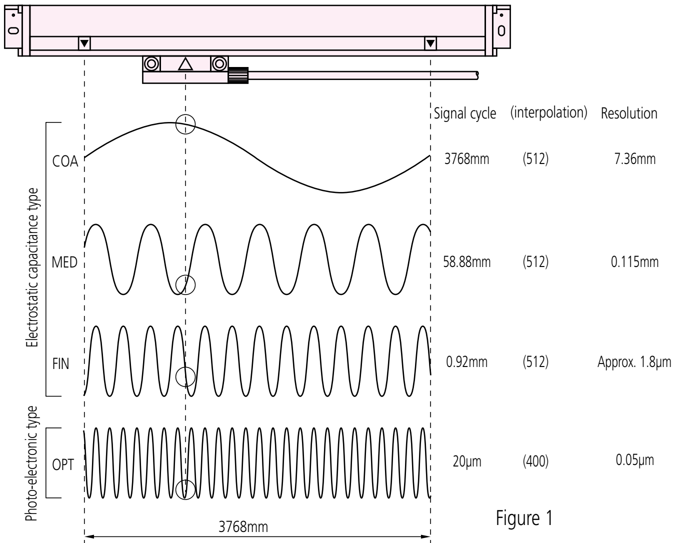


Figure 1

Upon supply of power to a linear scale, position readings from three capacitance-type sub-scales (COArse, MEDium and FINe) and one from a photoelectric sub-scale (OPTical) are taken. These sub-scales use such a combination of pitches, and are so positioned relative to each other, that the readings at any one position form a unique set and allow a microprocessor to calculate the position of the read head on the scale to a resolution of 0.05µm.

A laser holo-scale provides accurate measurements... why?

1. Hyperfine gratings

Very fine-pitched scale grids (0.5µm) are used in hologram analysis. These grids are much finer than the conventional lithographic grids used in reduction-exposure systems (1/15th to 1/200th the thickness of lithography grids). Hologram technology is essential to achieving high resolution in measuring scales.

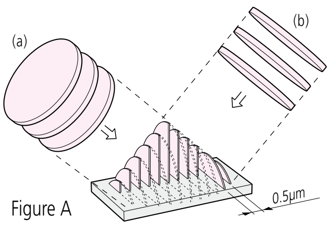


Figure A

As shown in Figure A, interference of light takes place three-dimensionally at the point of intersection when two parallel laser beams (a) and (b) intersect, generating interference fringes. The pitch of the interference fringes is approximately the same as that of the wavelength of light and exactly measures 0.5µm for the Mitutoyo hologram scale. This allows an extra-fine pitch scale to be made by recording the interference fringes.

2. Diffraction is fundamental

The mechanism of light diffraction is used to detect scale displacement as a change in the phase of light. Since the amount of phase change is equivalent to the hologram's grid pitch, an accurate length-measurement system can be created to detect scale displacement in 0.5µm steps.

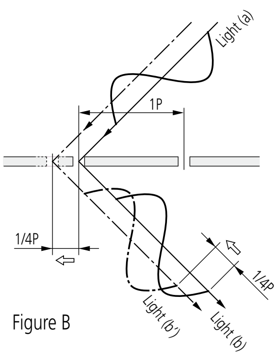


Figure B

As shown in Figure B, a light beam (a) is diffracted by the hologram grid and becomes a diffracted light beam (b). When the scale moves by a quarter of the hologram's grid pitch, the diffracted light beam (b) shows the equivalent change in the phase of light, as the light beam (b')

3. Complete sinewaves are best

Displacement is detected via the interference of diffracted light, in the form of bright-to-dark signals with a pitch equal to one-half that of the hologram grid (0.25µm). Unlike ordinary scales which use quasi-sinewaves, signals available with this scale are complete sinewaves, which are extremely immune to division error and regarded as a key factor for high resolution.

Since it is impossible to directly detect a phase shift of light with current technology, two diffracted light beams are transformed by means of interference into dark-light signals to be detected as shown in Figure C. Dividing the obtained signals by 250 makes it possible to measure down to 1nm.

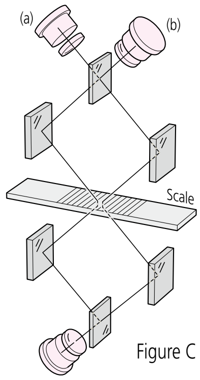


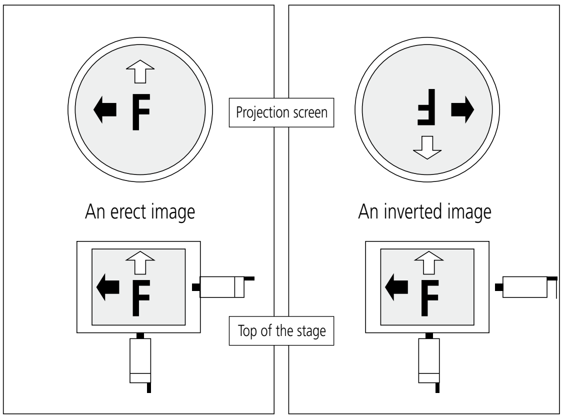
Figure C

To identify the direction of scale displacement, two light receptors (a) and (b) are used to detect one light beam as a signal having a 90-degree phase difference from the other.

Profile Projectors

Erect Image and Inverted Image

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



F Workpiece
X-axis movement
Y-axis movement

Magnification Accuracy

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

(Note that magnification accuracy is not the same as measuring accuracy.)

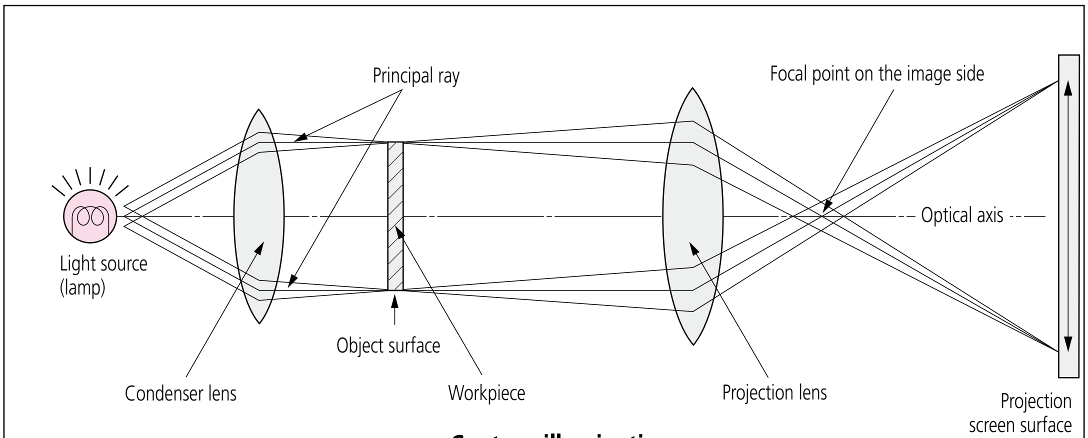
$$\Delta M(\%)=((L-\ell M)\ /\ \ell M)\times 100$$

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

Telecentric Optical System

An optical system based on the principle that the principal ray is aligned parallel to the optical axis by placing a lens stop on the focal point on the image side. Its functional feature is that the center of an image will not vary in size though the image blurs even if the focal point is shifted along the optical axis.

For measuring projectors and measuring microscopes, an identical effect is obtained by placing a lamp filament at the focal point of a condenser lens instead of a lens stop and illuminating with parallel beams. (See the figure below.)



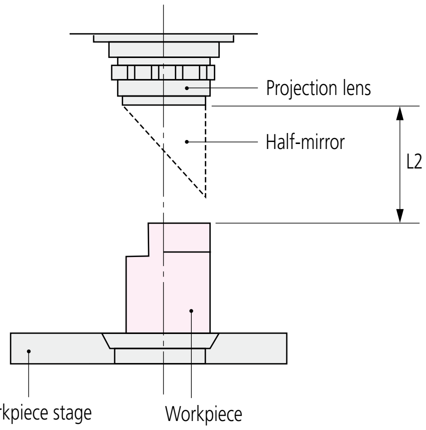
Contour illumination

■ Type of Illumination

- Contour illumination: An illumination method to observe a workpiece by transmitted light and is used mainly for measuring the magnified contour image of a workpiece.
- Coaxial surface illumination: An illumination method whereby a workpiece is illuminated by light transmitted coaxially to the lens for the observation/measurement of the surface. (A half-mirror or a projection lens with a built-in half-mirror is needed.)
- Oblique surface illumination: A method of illumination by obliquely illuminating the workpiece surface. This method provides an image of enhanced contrast, allowing it to be observed three-dimensionally and clearly. However, note that an error is apt to occur in dimensional measurement with this method of illumination.
  (An oblique mirror is needed. Models in the PJ-H30 series are supplied with an oblique mirror.)

■ Working distance

Refers to the distance from the face of the projection lens to the surface of a workpiece in focus. It is represented by symbol L2 in the diagram below.



■ Field of view diameter

The diameter of a workpiece projected onto the projection screen.

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

[Example]

If a 5X projection lens is used for a projector with a projection screen of ø500mm:

Field of view diameter is given by 500mm/5 = ø100mm

Microscopes

Numerical Aperture (NA)

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

$$NA = n \cdot \sin\theta$$

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

Resolving Power (R)

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

$$R = \lambda / 2 \cdot NA \ (\mu m)$$

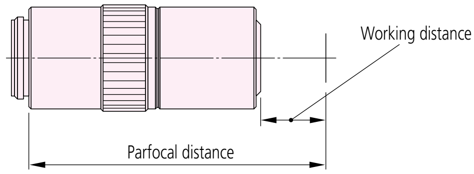
λ=0.55μm is often used as the reference wavelength

Working Distance (W.D.)

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

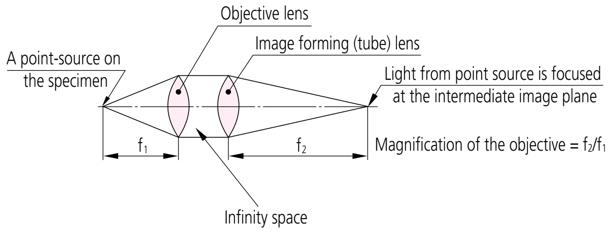
Parfocal Distance

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



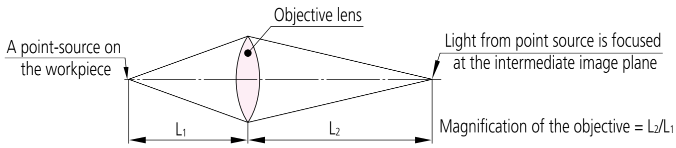
Infinity Optical System

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



Finite Optical System

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



Focal Length (f)

unit: mm

The distance from the principal point to the focal point of a lens: if f1 represents the focal length of an objective and f2 represents the focal length of an image forming (tube) lens then magnification is determined by the ratio between the two. (In the case of the infinity-correction optical system.)

Objective magnification = Focal length of the image-forming (tube) lens/Focal length of the objective

Examples: 1X=200/200
10X=200/20

Real Field of View

unit: mm

(1)Diameter of surface observed through eyepiece

Real field of view = Eyepiece field number/Objective magnification

Example: Real field of view of 10X lens (ø2.4 eyepiece)=24/10=2.4

(2)Diameter of surface observed on video monitor

Real field of view=Size(length x width) of CCD camera pickup device/ Objective magnification

*Size (length x width) of 1/2-inch CCD camera pickup device=4.8x6.4

Example: Real field of view of 1X lens (length x width)=4.8x6.4
Real field of view of 10X lens (length x width)=0.48X0.64

Focal Point

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

Depth of Focus (DOF)

unit: µm

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

DOF= $\lambda/2\cdot(NA)^2$ λ = 0.55µm is often used as the reference wavelength

Example: For an M Plan Apo 100X lens (NA = 0.7), and light wavelength of 0.55µm, the depth of focus of this objective is $0.55/(2 \times 0.7^2) = 0.6$µm.

Bright-field Illumination and Dark-field Illumination

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

Apochromat Objective and Achromat Objective

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

Magnification

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

Principal Ray

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

Aperture Diaphragm

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

Field Stop

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

Telecentric System

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

Erect Image

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

Field Number

The field of view size (diameter) of an eyepiece, expressed in millimeters.

Precautions in Using a Microscope for YAG Laser Machining

Laser machining with a microscope is used on thin films such as semiconductors and liquid crystals, but high-power laser radiation cannot be transmitted through a normal objective lens. Therefore, if using a YAG laser, limit the laser power output as follows:

YAG laser wavelength	Irradiation energy density (output)	Pulse width	Applicable objective
1064nm	0.2J/cm^2	10ns	M Plan NIR
532nm	0.1J/cm^2	10ns	M Plan NUV
355nm	0.05J/cm^2	10ns	
266mm	0.04J/cm^2	10ns	M Plan UV

* If the pulse width of a laser becomes shorter, the irradiation energy density is reduced by the root of the ratio of the pulse widths.
Example: If the pulse width decreases to 1/4, the energy density is reduced to approximately 1/2.

Note: When intending to use a laser with a microscope, contact the nearest Mitutoyo Sales Center beforehand to prevent unexpected damage to equipment and materials.

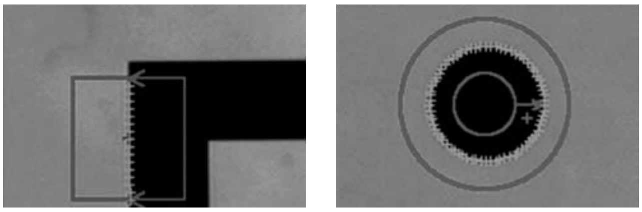
Vision Measuring Machines

Vision Measurement

Vision measuring machines mainly provide the following processing capabilities.

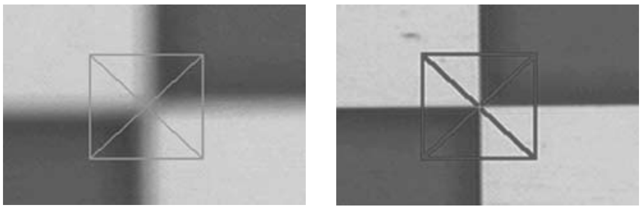
Edge detection

Detecting/measuring the edge in the XY plane



Auto focusing

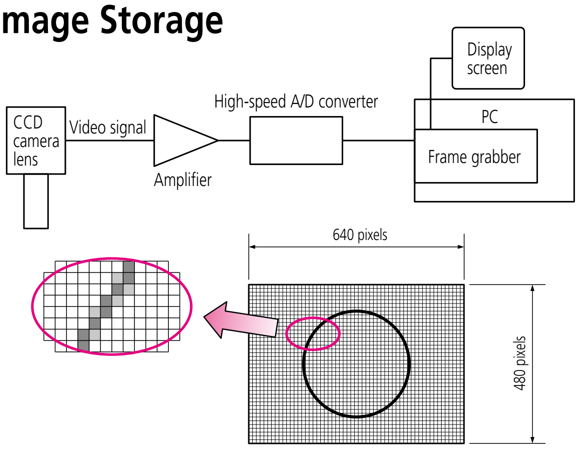
Focusing and Z measurement



Pattern recognition

Alignment, positioning, and checking a feature

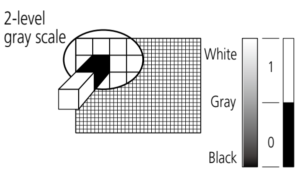
Image Storage



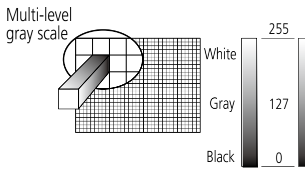
An image is comprised of a regular array of pixels. This is just like a picture on fine plotting paper with each square solid-filled differently.

Gray Scale

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



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



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

Difference in Image Quality

Difference between 2-level and 256-level gray-scale images

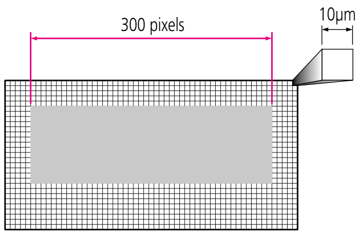
Sample image displayed in 2-level gray scale — Sample image displayed in 256-level gray scale

Variation in Image Depending on Threshold Level

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

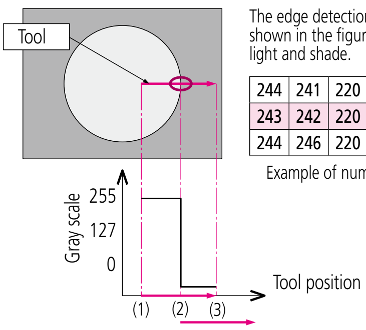
Dimensional Measurement

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



Edge Detection

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



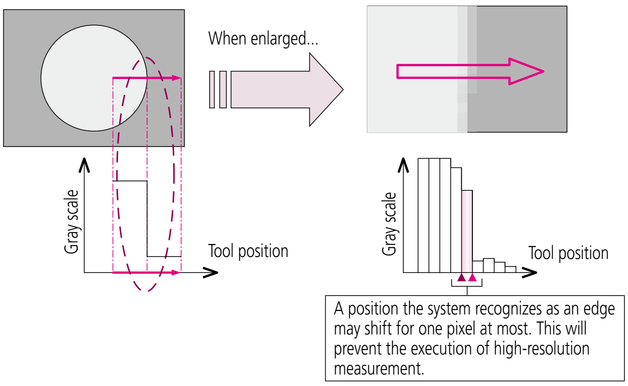
The edge detection system scans within the tool area as shown in the figure at left and detects the boundary between light and shade.

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

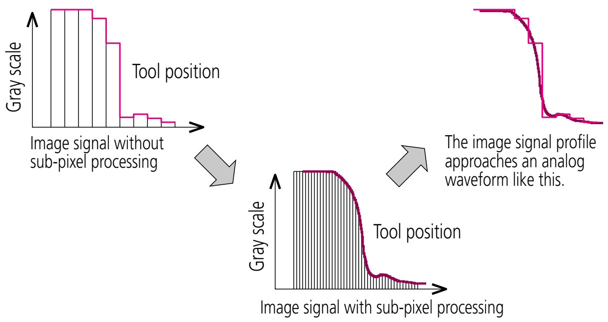
Example of numeric values assigned to pixels on the tool

(1) Scan start position
(2) Edge detection position
(3) Scan end position

High-resolution Measurement

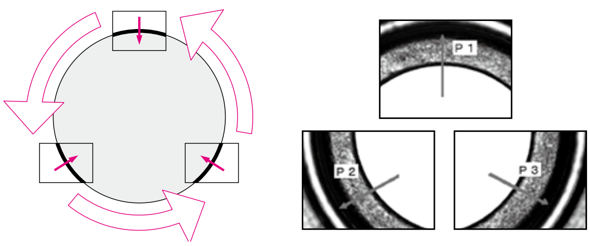


As the image processing for increasing the resolution of edge detection, sub-pixel processing is used.
Edge is detected by determining interpolation curve from adjacent pixel data as shown below.
As a result, it allows measurement with resolution higher than 1 pixel.

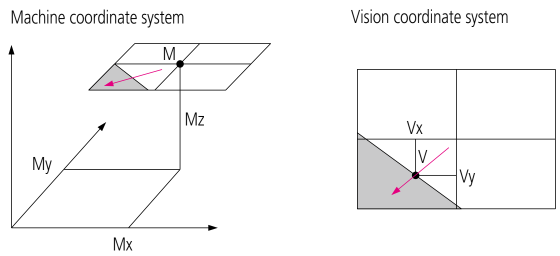


Measurement along Multiple Portions of an Image

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



Determining a Measurement Point



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

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

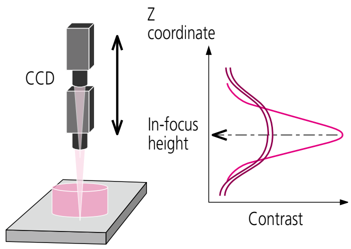
Actual coordinates are given by X = (Mx + Vx), Y = (My + Vy), and Z = Mz, respectively.

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

Principle of Auto Focusing

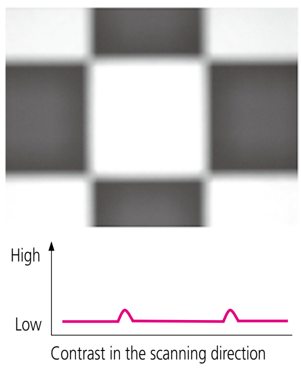
The system can perform XY-plane measurement, but cannot perform height measurement only from the CCD camera image. The system is commonly provided with the Auto Focus (AF) mechanism for height measurement. The following explains the AF mechanism that uses a common image, although some systems may use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

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

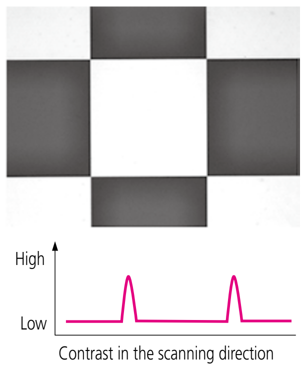


Variation in Contrast Depending on the Focus Condition

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



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

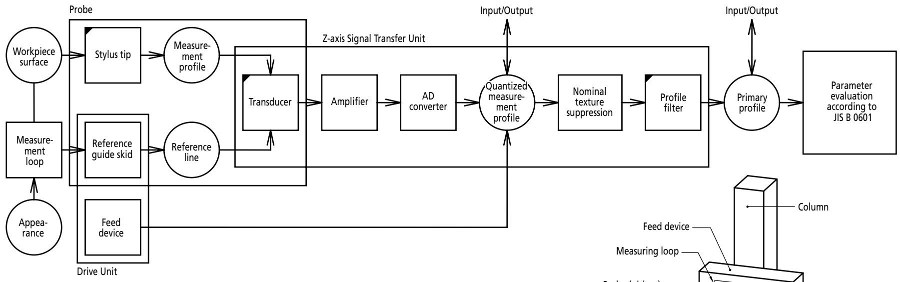


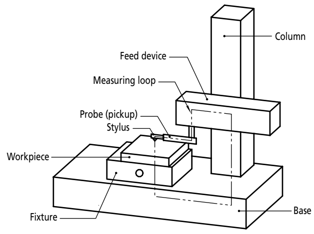
Surftest (Surface Roughness Testers)

JIS B 0601: 2001 Geometric Product Specifications (GPS) –Surface Texture: Profile method–
JIS B 0632: 2001 Geometric Product Specifications (GPS) –Surface Texture: Profile method–
JIS B 0633: 2001 Geometric Product Specifications (GPS) –Surface Texture: Profile method–
JIS B 0651: 2001 Geometric Product Specifications (GPS) –Surface Texture: Profile method–

Nominal Characteristics of Contact (Stylus) Instruments

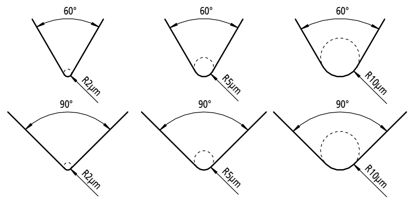
JIS B 0651: 2001 (ISO 3274: 1996)





Stylus Shape

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



Static Measuring Force

Measuring force at the mean position of a stylus: 0.75mN
Ratio of measuring force variations: 0N/m
Standard characteristic value: Static measuring force at the mean position of a stylus

Nominal radius of curvature of stylus tip: µm	Static measuring force at the mean position of stylus: mN	Toleranced ratio of static measuring force variations: mN/µm
2	0.75	0.035
5	0.75 (4.0) Note 1	0.2
10		

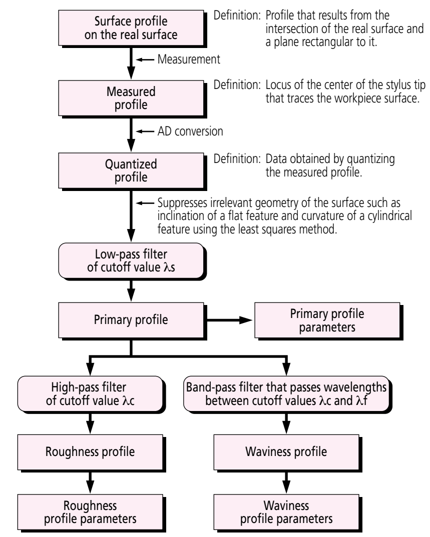
Note 1: The maximum value of static measuring force at the average position of a stylus is to be 4.0mN for a special structured probe including a replaceable stylus.

Metrological Characterization of Phase Correct Filters

JIS B 0632: 2001 (ISO 11562: 1996)

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

Data Processing Flow



Relationship between Cutoff Value and Stylus Tip Radius

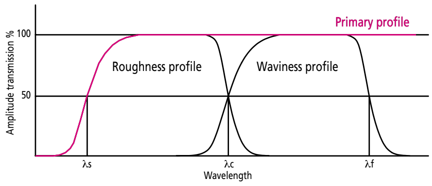
The following table lists the relationship between the roughness profile cutoff value λc, stylus tip radius r_{tip}, and cutoff ratio λc/λs.

λc mm	λs µm	λc/λs	Maximum r_{tip} µm	Maximum sampling length mm
0.08	2.5	30	2	0.5
0.25	2.5	100	2	0.5
0.8	2.5	300	2 Note 1	0.5
2.5	8	300	5 Note 2	1.5
8	25	300	10 Note 2	5

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

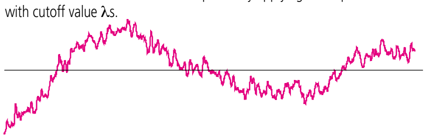
Surface Profiles

JIS B 0601: 2001 (ISO 4287: 1997)



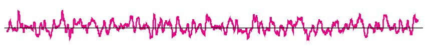
Primary Profile

Profile obtained from the measured profile by applying a low-pass filter with cutoff value λs.



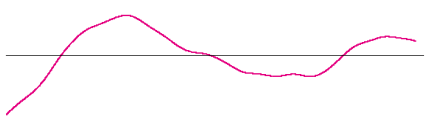
Roughness Profile

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



Waviness Profile

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



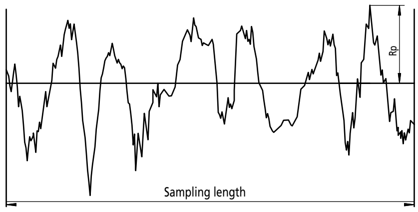
Definition of Parameters

JIS B 0601 : 2001 (ISO 4287 : 1997)

Amplitude Parameters (peak and valley)

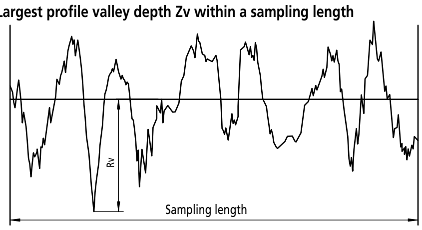
Maximum peak height of the primary profile Pp
Maximum peak height of the roughness profile Rp
Maximum peak height of the waviness profile Wp

Largest profile peak height Zp within a sampling length



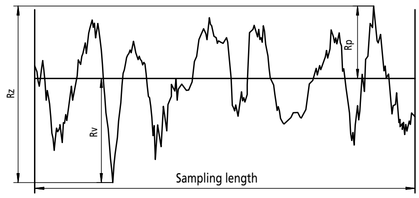
Maximum valley depth of the primary profile Pv
Maximum valley depth of the roughness profile Rv
Maximum valley depth of the waviness profile Wv

Largest profile valley depth Zv within a sampling length



Maximum height of the primary profile Pz
Maximum height of the roughness profile Rz
Maximum height of the waviness profile Wz

Sum of height of the largest profile peak height Zp and the largest profile valley depth Zv within a sampling length

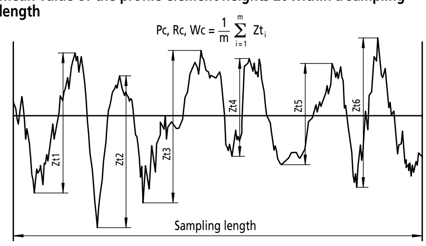


In Old JIS and ISO 4287-1: 1984, Rz was used to indicate the "ten point height of irregularities". Care must be taken because differences between results obtained according to the existing and old standards are not always negligibly small. (Be sure to check whether the drawing instructions conform to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

Mean height of the primary profile elements Pc
Mean height of the roughness profile elements Rc
Mean height of the waviness profile elements Wc

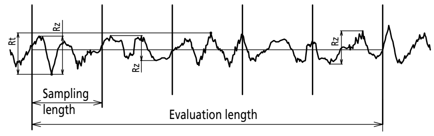
Mean value of the profile element heights Zt within a sampling length

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



Total height of the primary profile Pt
Total height of the roughness profile Rt
Total height of the waviness profile Wt

Sum of the height of the largest profile peak height Zp and the largest profile valley depth Zv within the evaluation length



Terms, definitions, and surface texture parameters
Metrological characterization of phase-correct filters
Rules and procedures for the assessment of surface texture
Nominal characteristics of contact (stylus) instruments

Amplitude Parameters (average of ordinates)

Arithmetical mean deviation of the primary profile Pa
Arithmetical mean deviation of the roughness profile Ra
Arithmetical mean deviation of the waviness profile Wa

Arithmetic mean of the absolute ordinate values Z(x) within a sampling length

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

with l as lp, lr, or lw according to the case.

Root mean square deviation of the primary profile Pq
Root mean square deviation of the roughness profile Rq
Root mean square deviation of the waviness profile Wq

Root mean square value of the ordinate values Z(x) within a sampling length

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

with l as lp, lr, or lw according to the case.

Skewness of the primary profile Psk
Skewness of the roughness profile Rsk
Skewness of the waviness profile Wsk

Quotient of the mean cube value of the ordinate values Z(x) and the cube of Pq, Rq, or Wq respectively, within a sampling length

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

The above equation defines Rsk. Psk and Wsk are defined in a similar manner. Psk, Rsk, and Wsk are measures of the asymmetry of the probability density function of the ordinate values.

Kurtosis of the primary profile Pku
Kurtosis of the roughness profile Rku
Kurtosis of the waviness profile Wku

Quotient of the mean quartic value of the ordinate values Z(x) and the fourth power of Pq, Rq, or Wq respectively, within a sampling length

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

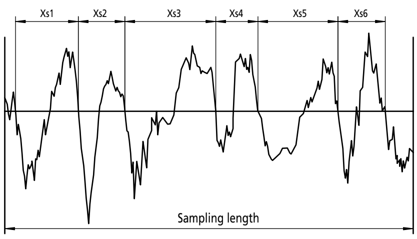
The above equation defines Rku. Pku and Wku are defined in a similar manner. Pku, Rku, and Wku are measures of the sharpness of the probability density function of the ordinate values.

Spacing Parameters

Mean width of the primary profile elements PSm
Mean width of the roughness profile elements RSm
Mean width of the waviness profile elements WSm

Mean value of the profile element widths Xs within a sampling length

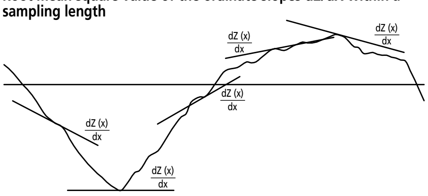
$$PSm, RSm, WSm = \frac{1}{m}\sum_{i=1}^{m} X_{Si}$$



Hybrid Parameters

Root mean square slope of the primary profile PΔq
Root mean square slope of the roughness profile RΔq
Root mean square slope of the waviness profile WΔq

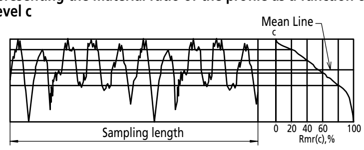
Root mean square value of the ordinate slopes dZ/dX within a sampling length



Curves, Probability Density Function, and Related Parameters

Material ratio curve of the profile (Abbott-Firestone curve)

Curve representing the material ratio of the profile as a function of section level c



Material ratio of the primary profile Pmr(c)
Material ratio of the roughness profile Rmr(c)
Material ratio of the waviness profile Wmr(c)

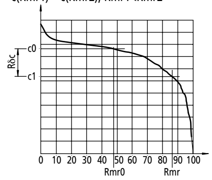
Ratio of the material length of the profile elements Ml(c) at a given level c to the evaluation length

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

Section height difference of the primary profile Pdc
Section height difference of the roughness profile Rdc
Section height difference of the waviness profile Wdc

Vertical distance between two section levels of a given material ratio

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



Relative material ratio of the primary profile Pmr
Relative material ratio of the roughness profile Rmr
Relative material ratio of the waviness profile Wmr

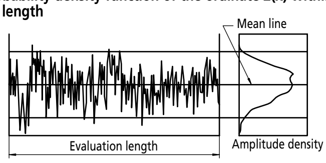
Material ratio determined at a profile section level Rδc (or Pδc or Wδc), related to the reference section level c0

$$Pmr, Rmr, Wmr = Pmr(c1), Rmr(c1), Wmr(c1)$$

where $c1 = c0 - R\delta c$ (or $P\delta c$ or $W\delta c$)
$c0 = c(Pm0, Rmr0, Wmr0)$

Probability density function
(profile height amplitude distribution curve)

Sample probability density function of the ordinate Z(x) within the evaluation length

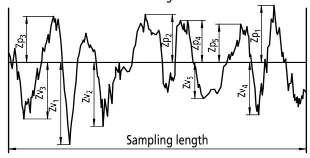


JIS Specific Parameters

Ten-point height of irregularities, Rz_{JIS}

Sum of the absolute mean height of the five highest profile peaks and the absolute mean depth of five deepest profile valleys, measured from the mean line within the sampling length of a roughness profile. This profile is obtained from the primary profile using a phase-correct band-pass filter with cutoff values of lc and ls.

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



Symbol	Used profile
RzJIS82	Surface profile as measured
RzJIS94	Roughness profile derived from the primary profile using a phase-correct high-pass filter

Arithmetic mean deviation of the profile Ra_{75}

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

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

Sampling Length for Surface Roughness Parameters

JIS B 0633: 2001 (ISO 4288: 1996)

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

Ra µm	Sampling length lr mm	Evaluation length ln mm
(0.006) <Ra≤0.02	0.08	0.08
0.02 <Ra≤0.1	0.25	0.25
0.1) <Ra≤2	0.8	0.8
2 <Ra≤10	2.5	2.5
10 <Ra≤80	8	8

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

Rz Rz1max µm	Sampling length lr mm	Evaluation length ln mm
(0.025) <Rz, Rz1max≤0.1	0.08	0.08
0.1 <Rz, Rz1max≤0.5	0.25	0.25
0.5) <Rz, Rz1max≤10	0.8	0.8
10 <Rz, Rz1max≤50	2.5	2.5
50 <Rz, Rz1max≤200	8	8

1) Rz is used for measurement of Rz, Rv, Rp, Rc, and Rt.
2) Rzlmax only used for measurement of Rzlmax, Rvlmax, Rplmax, and Rclmax.

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

Rsm µm	Sampling length lr mm	Evaluation length ln mm
0.013 <Rsm≤0.04	0.08	0.08
0.04 <Rsm≤0.13	0.25	0.25
0.13) <Rsm≤0.4	0.8	0.8
0.4 <Rsm≤1.3	2.5	2.5
1.3 <Rsm≤4	8	8

Procedure for determining a sampling length if it is not specified

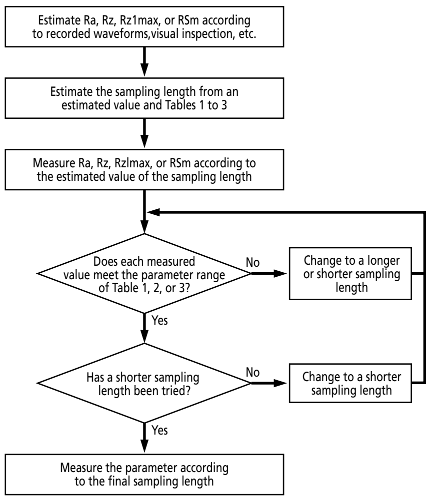


Fig.1 Procedure for determining the sampling length of an aperiodic profile if it is not specified

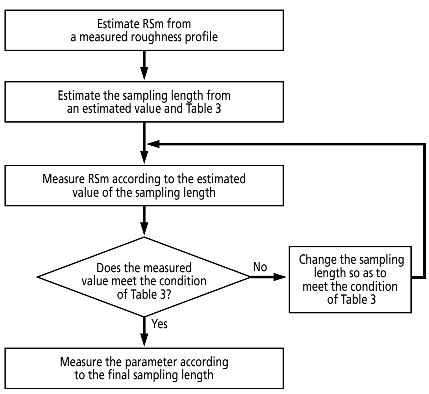
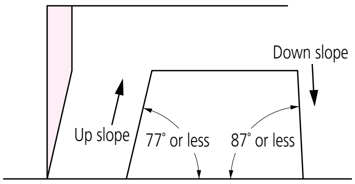


Fig.2 Procedure for determining the sampling length of a periodic profile if it is not specified

Contracer (Contour Measuring Instruments)

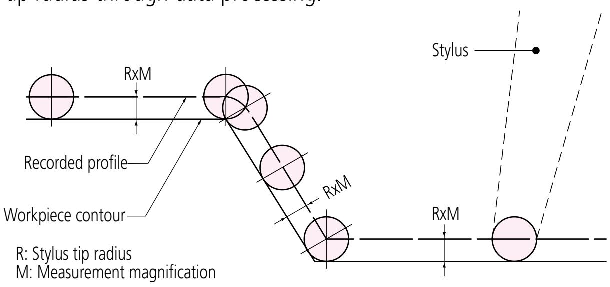
Traceable Angle



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

Compensating for Stylus Tip Radius

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

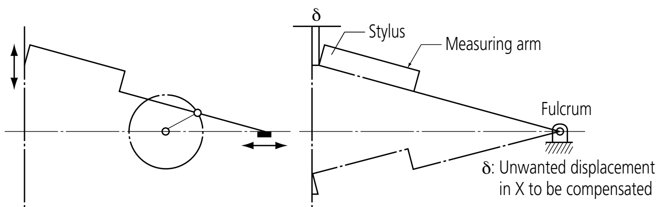


If a profile is read from the recorder through a template or scale, it is necessary to compensate for the stylus tip radius beforehand according to the applied measurement magnification.

Compensating for Arm Rotation

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

1: Mechanical compensation
2: Electrical compensation



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

Overload Safety Cutout

If an excessive force (overload) is exerted on the stylus tip due, perhaps, to the tip encountering a too-steep slope on a workpiece feature, or a burr, etc., a safety device automatically stops operation and sounds an alarm buzzer. This type of instrument is commonly equipped with separate safety devices for the tracing direction (X axis) load and vertical direction (Y axis) load.

Simple or Complex Arm Guidance

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

Z-axis Measurement Methods

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

Surface Profile Analysis Method

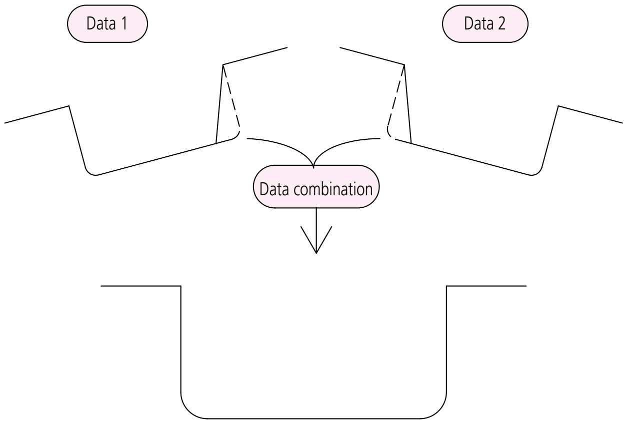
The following two methods are available as a means of analyzing a surface profile after the measurement operation has been completed.

1: Recorder
There are two methods by which the dimensions of a measured surface profile can be obtained from a recorded profile. The first is by reading a dimension with a scale applied to the recorded profile and dividing the result by the measurement magnification. The second method is by performing comparative measurement with a template [(actual dimension ± tolerance) x measurement magnification] that has been created with a CAD package, etc., applied to the recorded profile. In both methods stylus tip radius compensation must be considered at the time of measurement, and template creation, and the fact that reading error or human error may be significant.

2: Data processing unit and analysis program
In this method, the measured surface profile is fed to a data processing unit in real-time and analysis of the profile is performed by a dedicated analysis program controlled from a mouse and/or keyboard. The data processing unit displays angle, radius, step height, pitch, etc., directly in numeric values and also allows straightforward analysis in combination with a coordinate system. The recorded profile is subjected to stylus tip radius compensation and then output to a plotter or a laser printer.

Data Combination

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

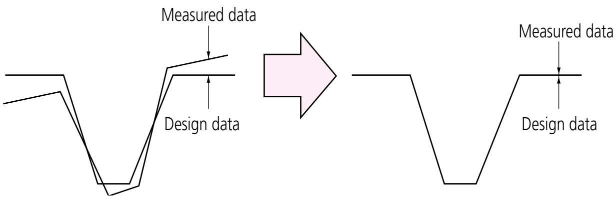


Tolerancing with Design Data

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

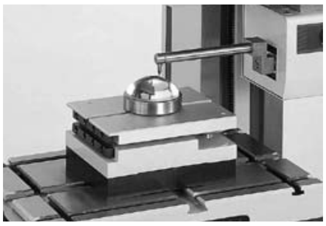
Best-fitting

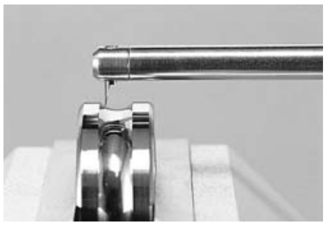
If there is a standard for measured surface profile data, tolerancing with design data is performed according to the standard. If there is no standard, or if tolerancing only with shape is desired, best-fitting between design data and measured data can be performed.

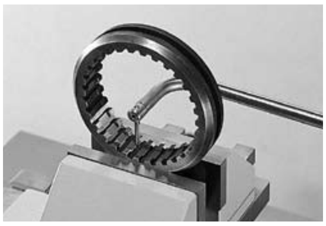


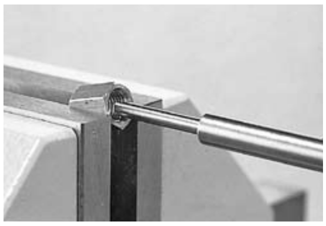
The best-fit processing algorithm searches for deviations between both sets of data and derives a coordinate system in which the sum of squares of the deviations is a minimum when the measured data is overlaid on the design data.

Measurement Examples

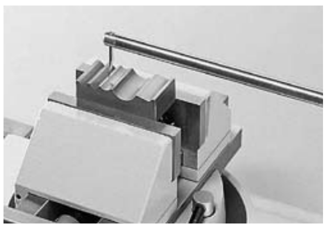

Aspheric lens contour


Inner/outer ring contour of a bearing


Internal gear teeth


Female thread form


Male thread form

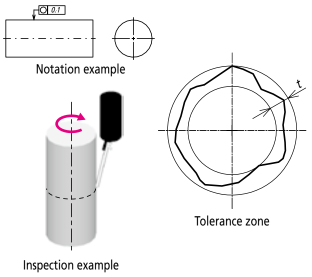

Gage contour

Roundtest (Roundform Measuring Instruments)

■ JIS B 7451-1997: Roundness measuring instruments
■ JIS B 0621-1984: Definition and notation of geometric deviations
■ JIS B 0021-1998: Geometric property specifications (GPS) of products – Geometric tolerance

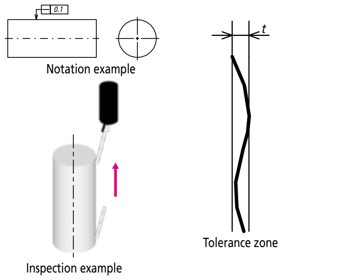
○ Roundness

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



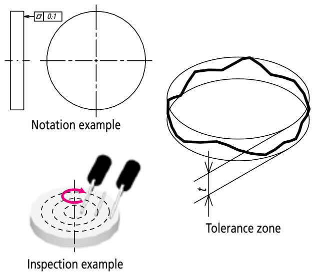
— Straightness

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



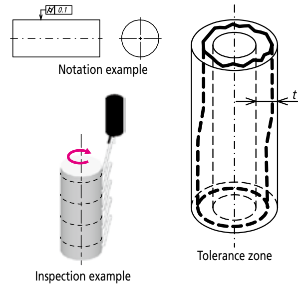
▱ Flatness

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



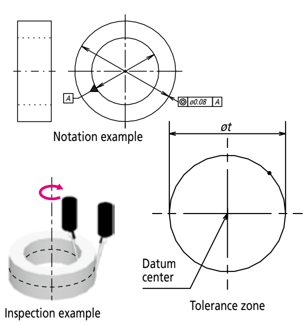
Cylindricity

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



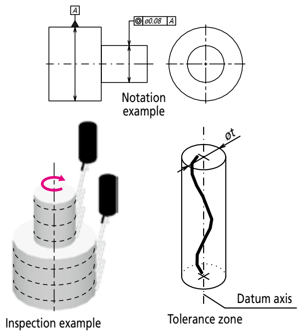
◎ Concentricity

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



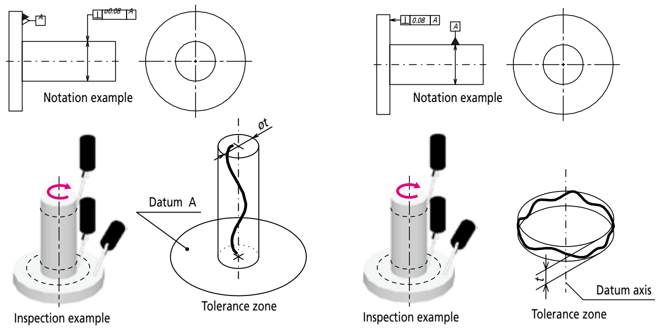
◎ Coaxiality

The axis must be contained within the tolerance zone formed by a cylinder of diameter t concentric with the datum



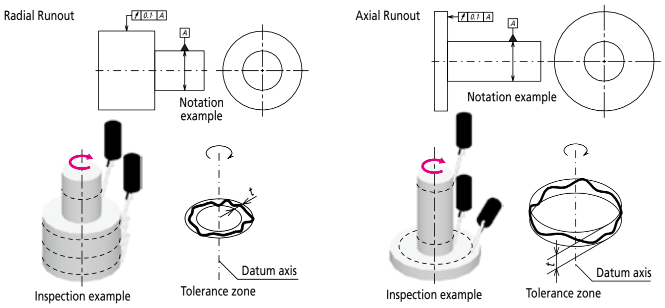
⊥ Perpendicularity

The line or surface must be contained within the tolerance zone formed between two planes a distance t apart and perpendicular to the datum



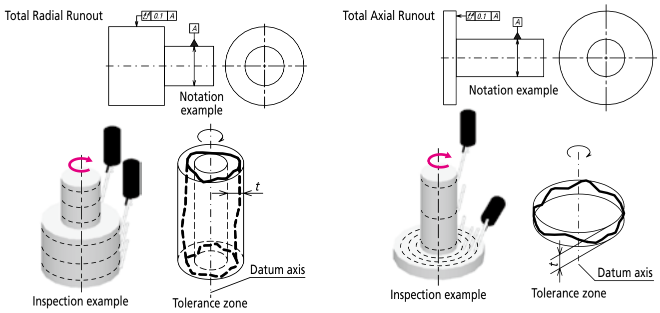
↗ Circular Runout

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



⌰ Total Runout

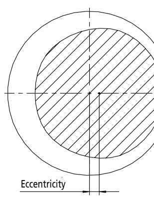
The surface must be contained within the tolerance zone formed between two coaxial cylinders with a difference in radii of t, or planes a distance t apart, concentric with or perpendicular to the datum



■ Adjustment prior to Measurement

Centering

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



Effect of eccentricity compensation function

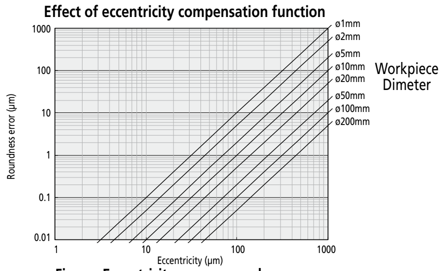
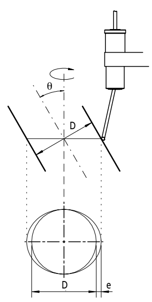


Figure: Eccentricity versus roundness error

Leveling

Any inclination of the axis of a workpiece with respect to the rotational axis of the measuring instrument will cause an elliptic error. Leveling must be performed so that these axes are sufficiently parallel.



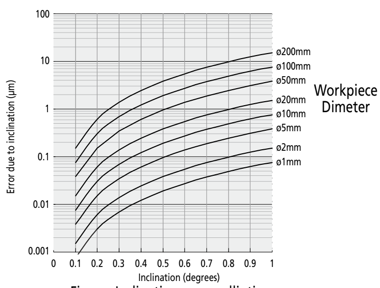
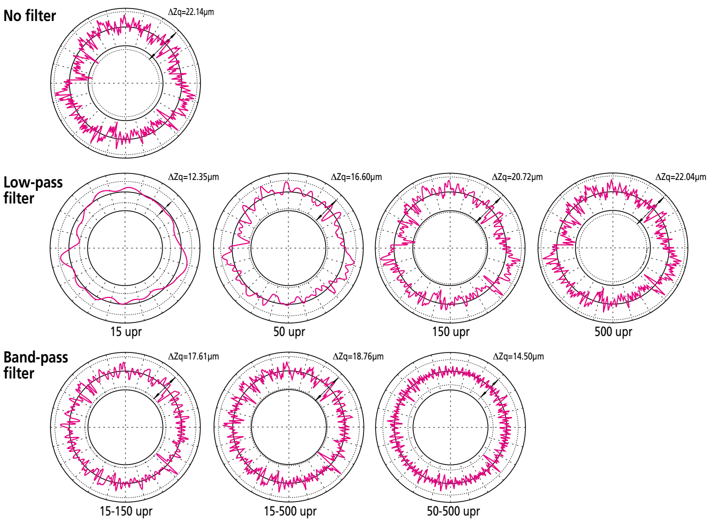


Figure: Inclination versus elliptic error

Roundness Testing

Effect of Filter Settings on the Measured Profile

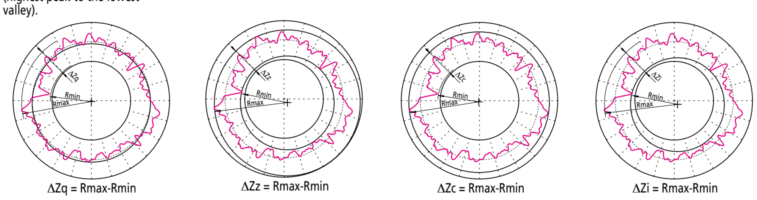
Roundness values as measured are greatly affected by variation of filter cutoff value. It is necessary to set the filter appropriately for the evaluation required.



Evaluating the Measured Profile Roundness

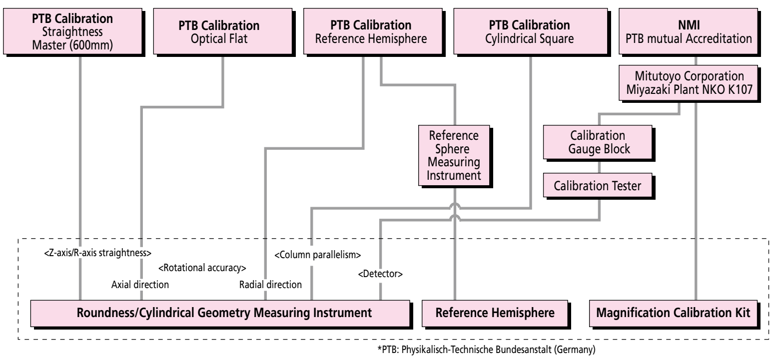
Roundness testers use the measurement data to generate reference circles whose dimensions define the roundness value. There are four methods of generating these circles, as shown below, and each method has individual characteristics so the method that best matches the function of the workpiece should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

Least Square Circle (LSC) Method	Minimum Zone Circles (MZC) Method	Minimum Circumscribed Circle (MCC) Method	Maximum inscribed Circle (MIC) Method
A circle is fitted to the measured profile such that the sum of the squares of the departure of the profile data from this circle is a minimum. The roundness figure is then defined as the difference between the maximum departures of the profile from this circle (highest peak to the lowest valley).	Two concentric circles are positioned to enclose the measured profile such that their radial difference is a minimum. The roundness figure is then defined as the radial separation of these two circles.	The smallest circle that can enclose the measured profile is created. The roundness figure is then defined as the maximum departure of the profile from this circle. This circle is sometimes referred to as the 'ring gage' circle.	The largest circle that can be enclosed by the profile data is created. The roundness figure is then defined as the maximum departure of the profile from this circle. This circle is sometimes referred to as the `plug gage' circle.



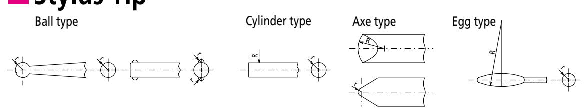
Traceability System for Roundform Measuring Instruments

(Traceability to PTB*)



*PTB: Physikalisch-Technische Bundesanstalt (Germany)

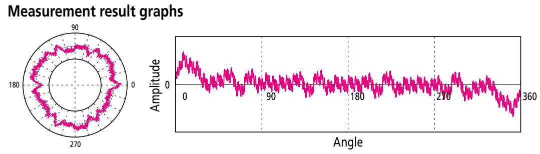
Stylus Tip



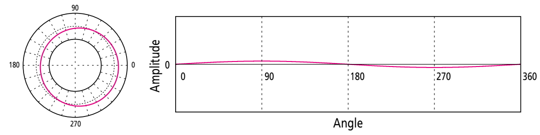
Tip shape: Ball, axe, cylinder, and egg
Tip radius : 0.25mm, 0.8mm, 2.5mm, 8mm, 25mm (tolerance: 30% of the nominal value)
Measuring force: 250mN or less

Undulations Per Revolution (UPR) data in the roundness graphs

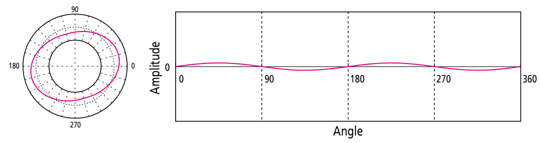
Measurement result graphs



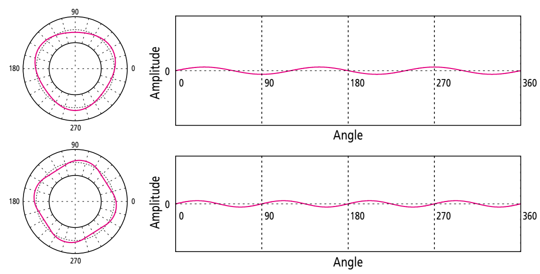
A 1 UPR condition indicates eccentricity of the workpiece relative to the rotational axis of the measuring instrument. The amplitude of undulation components depends on the leveling adjustment.



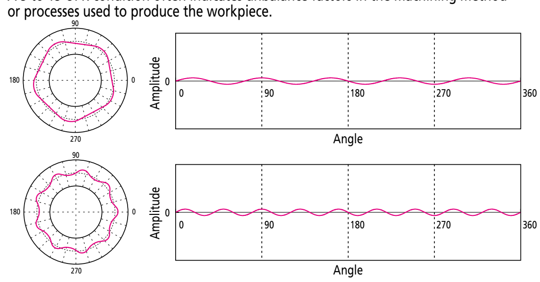
A 2 UPR condition may indicate: (1) insufficient leveling adjustment on the measuring instrument; (2) circular runout due to incorrect mounting of the workpiece on the machine tool that created its shape; (3) the form of the workpiece is elliptical by design as in, for example, an IC-engine piston.



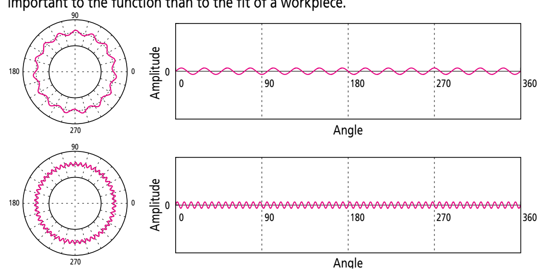
A 3 to 5 UPR condition may indicate: (1) Deformation due to over-tightening of the holding chuck on the measuring instrument; (2) Relaxation deformation due to stress release after unloading from the holding chuck on the machine tool that created its shape.



A 5 to 15 UPR condition often indicates unbalance factors in the machining method or processes used to produce the workpiece.



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



Hardness Testing Machines

Hardness Test Methods and Guidelines for Selection of a Hardness Testing Machine

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

* ●: Well-suited ▲: Reasonably suited

Methods of Hardness Measurement

(1) Vickers

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

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

F:N
d:mm

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

$$\frac{\Delta HV}{HV} \fallingdotseq \frac{\Delta F}{F} -2\frac{\Delta d_1}{d} -2\frac{\Delta d_2}{d} - \frac{a^2}{d^2}\,3.5\times10^{-3}\Delta\theta$$

(2) Knoop

As shown in the following formula, Knoop hardness is a value obtained by dividing test force by the projected area A (mm2) of an indentation, which is calculated from the longer diagonal length d (mm) of the indentation formed by an indenter after pressing a diamond square pyramid (its cross section is rhomboidal with opposing edge angles of 172°30' and 130°) into a specimen with test force F applied. Knoop hardness can also be measured by replacing the Vickers indenter of a microhardness testing machine with a Knoop indenter.

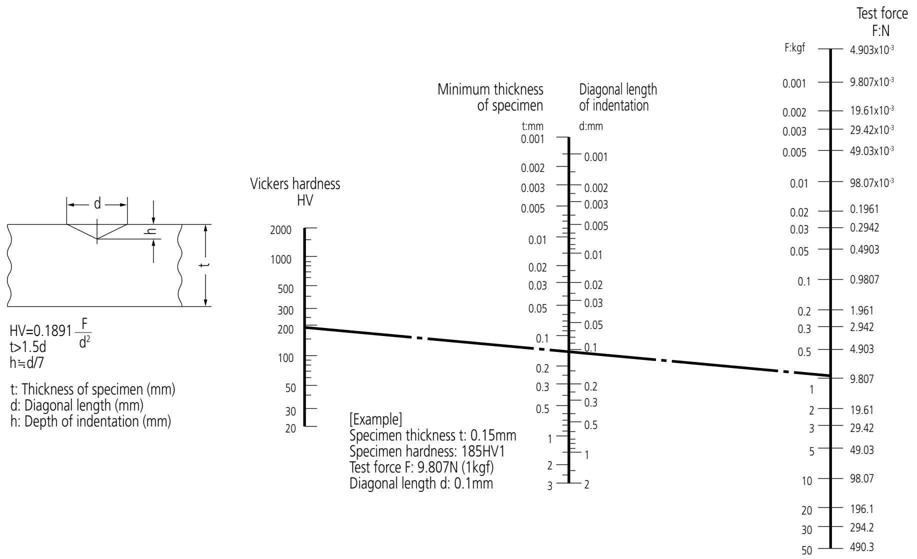
$$HK=k\frac{F}{A}=0.102\frac{F}{A}=0.102\frac{F}{cd^2}=1.451\frac{F}{d^2}$$

F:N
d:mm
c:Constant

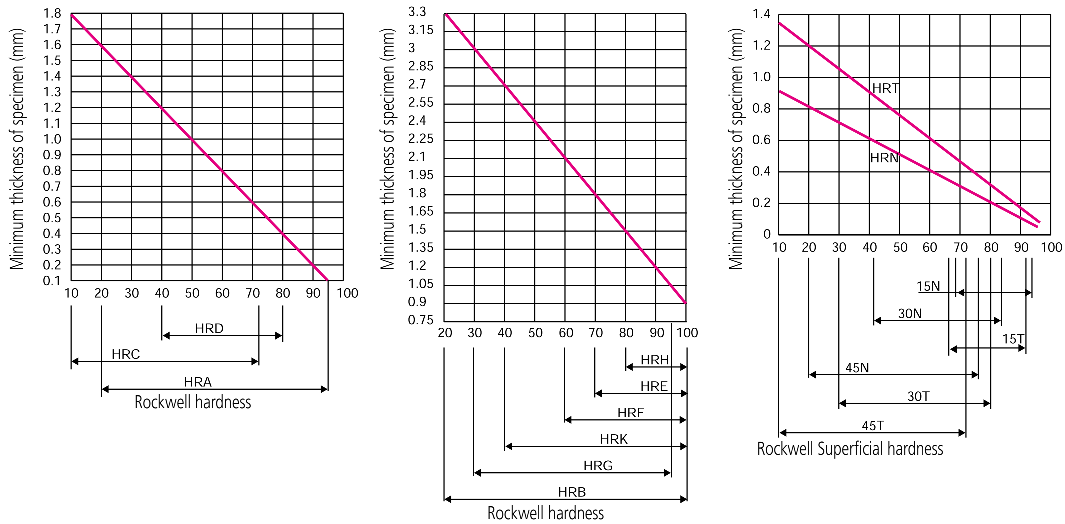
(3) Rockwell and Rockwell Superficial

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

Relationship between Vickers Hardness and the Minimum Thickness of a Specimen



Relationship between Rockwell/Rockwell Superficial Hardness and the Minimum Thickness of a Specimen



Rockwell Hardness Scales

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

Rockwell Superficial Hardness Scales

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

Vibration Measuring Instruments

Vibration Terminology

Important parameters relating to vibration pickups/vibrometers are described below:

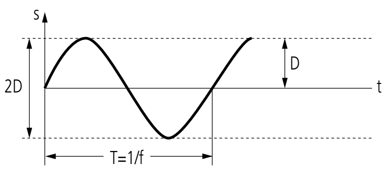
(1)Vibration frequency Unit: Hz (Hertz) Symbol: f

Refers to the number of times a vibrating object vibrates per second. The inverse of a vibration frequency is referred to as the period (T), T=1/f. Incidentally, vibration frequency is also referred to as frequency, and the motion is assumed to be sinusoidal.

When discussing vibration of a rotating object, the relation between the number of rotations (rpm: revolutions per minute) and the frequency is as follows, where rpm is a non-SI unit (SI unit: min^{-1}).

Example: 1200rpm/60s=20Hz

Frequency of an object rotating at 1200 revolutions per minute is 20Hz.



Example of notation in the catalog:
0.001 - 19.99mm_{p-p}

(2)Displacement Unit: m, mm, µm Symbol: D, s

Refers to the distance a vibrating object is displaced from a reference position (normally, the stationary position).

s = D sin wt

"D" is implied when displacement is simply referred to as amplitude. However, "2D" is customarily used in many cases to refer to the peak-to-peak amplitude.

Half-amplitude D, 0-p (zero-to-peak)

Full-amplitude 2D, p-p (peak-to-peak)

(3)Velocity Unit: m/s, cm/s, mm/s Symbol: V, v

Refers to the maximum speed reached by a vibrating object during the vibration cycle in the direction of motion. Defined by the rate of change in displacement per unit time. Velocity may be measured directly but is often derived from a measurement of acceleration, and may also be derived from measuring displacement with respect to time, as below.

$$v = ds/dt = d\,(D \sin \omega t) / dt$$

Example of notation in the catalog:
0.001 - 19.99cm/s_{o-p}

● Merit of velocity measurement

Velocity is a parameter widely used for equipment diagnosis and closely related to the fatigue failure of equipment structures. It is discussed in ISO standards as a parameter for specifying the severity of vibration.

(4)Acceleration Unit: m/s2, cm/s2, mm/s2 Symbol: A, a

Refers to the rate at which the velocity of an object changes per unit time. Acceleration is often measured directly and may also be derived from measuring velocity, or displacement (with respect to time) as below.

$$a = dv/dt = d^2s/dt^2 = d^2\,(D \sin \omega t) / dt^2$$

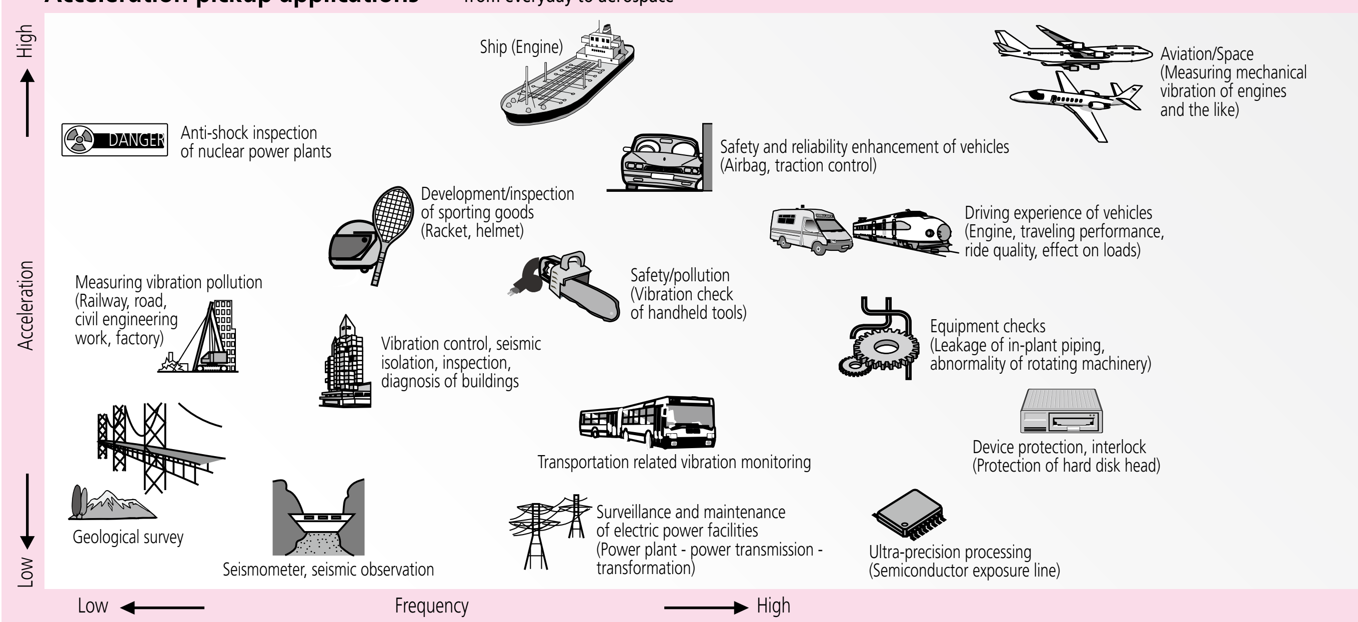
Example of notation in the catalog:
0.01-199.9 $cm/s^2{}_{o-p}$

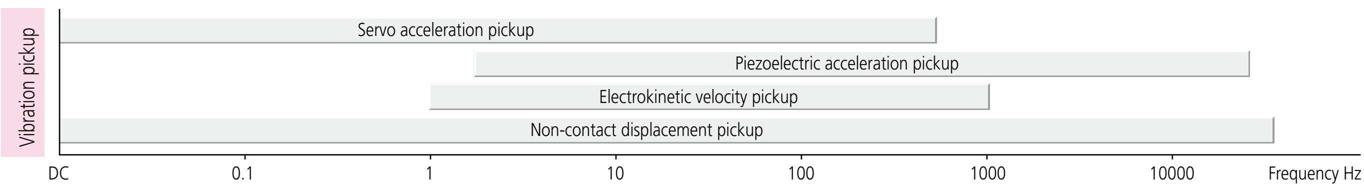
● Merit of acceleration measurement

Acceleration is regarded as a parameter effective for assessing the likelihood of dynamic fracture, and is widely used as a means of handling the fracture or breakdown especially of an object rotating at high speed.

Selection Guide to Vibration Transducers (Pickups)

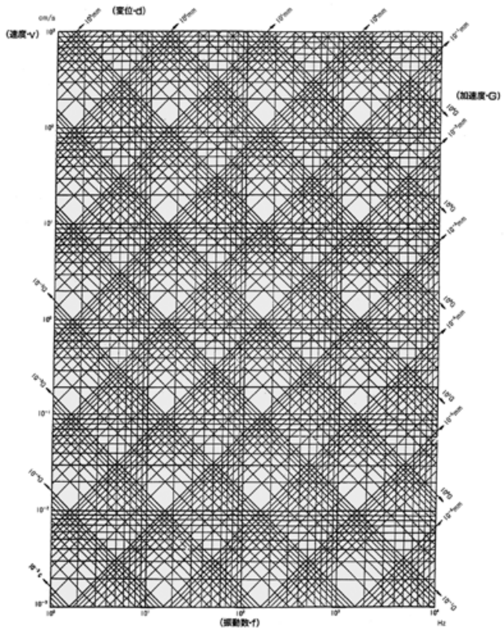
Acceleration pickup applications — from everyday to aerospace —





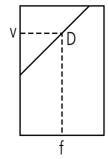
Seismogram Chart

Illustration of usage

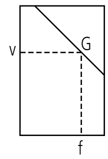


D: Displacement (mm) at half amplitude
v: Velocity (cm/s)
g: Acceleration (stated as a fraction of g_o, the 'standard acceleration of gravity' at the Earth's surface)
f: Frequency (Hz)
ft: Frequency (Hz) determined by a given displacement and acceleration

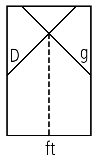
● Relation between v-f-D



● Relation between v-f-g



● Relation between D-g-ft



* The seismogram chart allows the magnitude of any one parameter to be determined from the magnitudes of two other parameters.

Selection Guide to Vibration Pickups and Model of Vibrometers

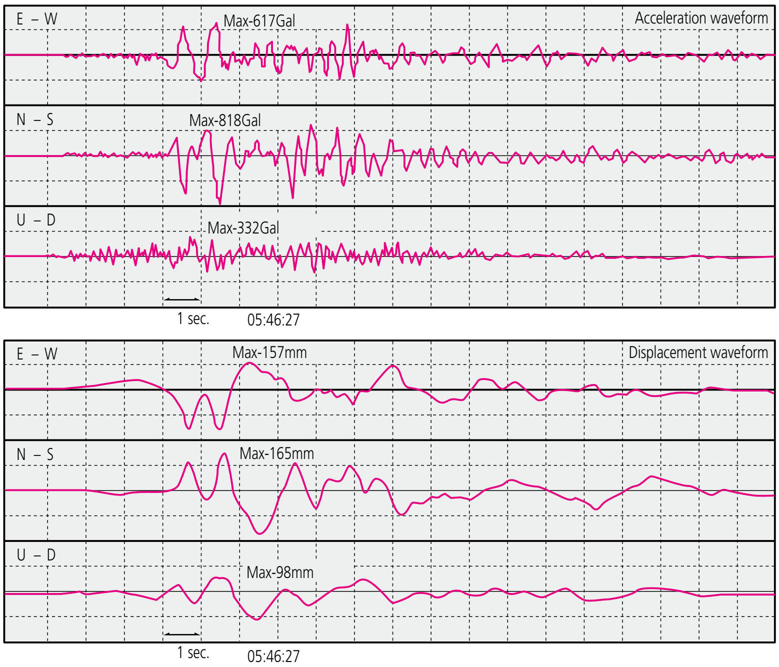
Field of application	Purpose	Specification requirements	Recommended type
Industrial machinery Machine tools	Operating conditions monitoring abnormality Vibration observation Equipment diagnosis Evaluation of bearings	For measuring the vibration induced by rotating/reciprocating motions through the use of gears and rolling bearings and its wide vibration range of harmonics. A vibration pickup is required of a size that does not affect the frequency characteristics of an object to be measured. High frequency characteristics (10 kHz) are required.	Piezoelectric acceleration pickup/vibrometer
High-speed rotating machinery Internal combustion engines		For measuring the unbalance and coupling abnormality resulting from the rotating motion through the use of a sliding bearing.	Electrokinetic velocity pickup/vibrometer
Power plant turbine Generator peripherals/accessories	Abnormal vibration observation	For monitoring vibrations in the normal state. For non-contact measurement of rotating shafts. For measuring vibrations of a casing. For measuring relatively low frequency in terms of velocity and displacement.	Non-contact displacement pickup/vibrometer
			Mainly electrokinetic velocity pickup/ vibrometer
Transportation machinery Automobile/ship/aircraft	Safety evaluation Riding quality evaluation	For measuring low-velocity vibrations.	Servo acceleration pickup/vibrometer
			Electrokinetic velocity pickup (compact type)/ vibrometer
		For measuring high frequencies and noise levels.	Piezoelectric acceleration pickup (extra compact type)/vibrometer
Large-scale structures	Dynamic stiffness evaluation Anti-earthquake design data	For measuring in a low frequency range while putting the priority to the sensitivity over the magnitude of the output.	Servo acceleration pickup/vibrometer
Building structures	Environmental measurement Seismic diagnosis (earthquake resistance diagnosis)		
Ground disturbance	Seismic observation Vibration pollution research Machinery foundation research	For measuring mainly in the low frequency range below 50Hz where precision measurement of vibration levels to lower than a few Gals is required. (m/s^2=100Gal)	Electrokinetic velocity pickup/vibrometer
			Servo acceleration pickup/vibrometer
Various vibration testing	Research and development Dynamic stiffness/frequency characteristics evaluation	If a pickup for the entire range of frequency is required, select multiple pickups according to the purpose. For the purpose of motion control of equipment.	Piezoelectric acceleration pickup/vibrometer
			Electrokinetic velocity pickup/vibrometer
			Servo acceleration pickup/vibrometer

	Pickup	Portable vibrometer (Ground noise meter)	Vibration monitoring machine
Servo	V405, 407	AVT-103/104	AVR-145L
Piezoelectric	V311TE, TB, SB, TF, V301SS, TA, TB, SB, TC, TD, V331TB	AVT-CZ, AVT-3000DZ, AHV-1000AZ	AVR-145Z
Electrokinetic	V238J, V231, V233, V237L, V240V, V242T, U1-FH, U1-FH-S, U1-FMA, V235B, V241 251M, 2516, V251GV (H), (L1), (L2)	AVT-B2, AHV-1000BU, AHV-11A	AVR-145, 150
Non-contact	V462B-8, MX	—	AVR-145X

Seismic Observation Equipment

Basic Facts About Earthquakes

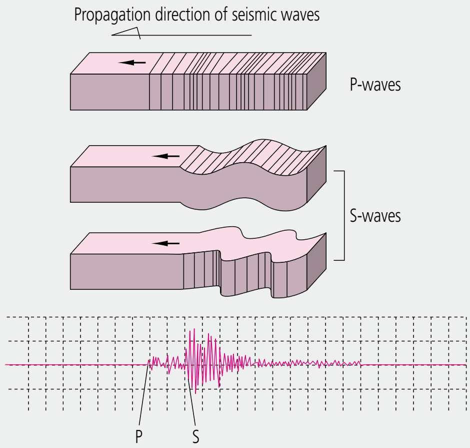
An earthquake is a phenomenon in which a release of energy, caused by slippage at the boundaries of tectonic plates just below the earth's crust, causes waves to travel along the ground, making it vibrate violently.
The vibrations caused by earthquakes include longitudinal (or compression) waves (P-waves: Primary waves) that propagate through rock mass in all directions from the earthquake source, vibrating in the same direction of propagation and transverse (or shear) waves (S-waves: Secondary waves) that vibrate perpendicular to the direction of propagation.
Due to the characteristics of the waves, the P-wave propagates faster than the S-wave and since the S-wave is generally larger than the P-wave in amplitude, it is thought that the S-wave is the one that causes the most destruction.
As shown in the figure below, for example, the smaller-amplitude waves for the first two or three seconds represents the P-waves and the next section from the point of sudden increase in amplitude indicates the arrival of the S-waves.



Waveforms in the Southern Hyogo Prefecture Earthquake (1995)

Seismic Terminology

Gal	Unit of acceleration (cm/s^2) named after Galileo Galilei
Seismic intensity	A measure of the intensity of earthquake motion at a given place. The Meteorological Agency of Japan sets forth a measure of the strength of seismic motion in ten classes from zero to seven. Conventionally, the intensity was determined by means of human perception. Now, it is determined by measuring using seismometers. Even if the magnitude is small, the seismic intensity is large near the earthquake source.
SMAC type strong-motion seismometer	Typical acceleration seismometer used in Japan for strong motion observation. It was named after the acronym of the Strong Motion Accelerometer Committee.
Magnitude	A scale to quantitatively indicate the size (magnitude) of an earthquake but there are multiple definitions used for it. The magnitude (M) announced by the Meteorological Agency of Japan for shallow earthquakes near Japan is defined as $M=\log A+\log\Delta-0.83$. Where, A is the maximum seismic motion amplitude [mm] and Δ is determined by a formula based on the epicentral distance [km] at the observatory point. Seismic intensity is small at a point far from the seismic source even though the magnitude may be large.



Model of P- and S-waves

*If the product specification identifies the Z direction as the sensitivity direction, the product concerned is suitable for the detection of P-waves. Similarly, identification of the X and Y directions as the sensitivity directions indicates that the product is suitable for the detection of S-waves.

Selection by Application and Performance

Application	Control-type seismometer	Display-type seismometer	Instrumental seismic intensity meter	Strong-motion seismometer
Emergency shutdown of plant facilities	●			
Emergency shutdown of water storage tank	●			
Emergency shutdown of high pressure gas and/or fuels tanks	●			
Shutdown of power source and electric power transmission of power plants	●			
Triggering the protection circuit of memory devices of office automation equipment	●			
Triggering the protection circuit of transformers	●			
Warning and emergency stop of railways	●			
Monitoring skyscrapers for earthquake and wind effects				●
Monitoring earthquake disaster prevention at dams, bridges, and river levees.				●
Local disaster prevention by an autonomous body			●	
Evacuation and guidance from collective facilities		●	●	
Coordination with the security/maintenance manual		●	●	
Seismic observation network in small/medium areas				
Function				
Maximum acceleration indication		●	●	●
Maximum velocity indication			●	
Corresponding seismic intensity indication		●		
Instrumental seismic intensity indication			●	●
SI value indication			●	●
Seismic waveform recording			●	●
Alarm output			●	●
Control output	●			
Sensitivity direction	Horizontal/perpendicular (varies with the model)	All horizontal directions	Orthogonal three directions	Orthogonal three directions

Table of Comparison of "Old and New" Seismic Intensity Scale of the Meteorological Agency

Reference acceleration

<table>
<tr><th>Instrumental seismic intensity
(t: 1sec.)</th><th>Seismic intensity scale</th><th colspan="2">Old seismic intensity scale
(human perception)</th><th>Acceleration
(Gal)</th></tr>
<tr><td>0.54</td><td>0</td><td rowspan="2">0</td><td></td><td>0.6</td></tr>
<tr><td>0.7</td><td rowspan="2">1</td><td></td><td>0.8</td></tr>
<tr><td>0.9</td><td rowspan="3">1</td><td></td><td>1</td></tr>
<tr><td>1.5</td><td rowspan="3">2</td><td></td><td>2</td></tr>
<tr><td>1.7</td><td rowspan="3">2</td><td>2.5</td></tr>
<tr><td>2.3</td><td></td><td>5</td></tr>
<tr><td>2.7</td><td rowspan="2">3</td><td rowspan="4">3</td><td>8</td></tr>
<tr><td>3.2</td><td></td><td>15</td></tr>
<tr><td>3.5</td><td rowspan="4">4</td><td></td><td>20</td></tr>
<tr><td>3.7</td><td rowspan="4">4</td><td>25</td></tr>
<tr><td>4.3</td><td></td><td>50</td></tr>
<tr><td>4.4</td><td></td><td>60</td></tr>
<tr><td>4.7</td><td rowspan="2">5 lower</td><td rowspan="6">5</td><td>80</td></tr>
<tr><td>4.9</td><td></td><td>100</td></tr>
<tr><td>5.0</td><td rowspan="3">5 upper</td><td></td><td>110</td></tr>
<tr><td>5.4</td><td></td><td>180</td></tr>
<tr><td>5.4</td><td></td><td>190</td></tr>
<tr><td>5.7</td><td rowspan="2">6 lower</td><td rowspan="4">6</td><td>250</td></tr>
<tr><td>5.9</td><td></td><td>320</td></tr>
<tr><td>6.0</td><td rowspan="5">6 upper</td><td></td><td>340</td></tr>
<tr><td>6.1</td><td></td><td>380</td></tr>
<tr><td>6.1</td><td rowspan="4">7</td><td rowspan="4">Ex post facto judgment from the aftermath of destruction for the magnitude 6 and over</td><td>400</td></tr>
<tr><td>6.4</td><td>580</td></tr>
<tr><td>6.4</td><td>600</td></tr>
<tr><td>6.9</td><td>7</td><td>1,000</td></tr>
</table>

Remarks: Instrumental seismic intensity differs slightly from the actual earthquake intensity since it varies with the frequencies and duration of the seismic waves. As to the relation between the acceleration and instrumental seismic intensity, there is no direct correspondence between them and should be taken for reference.

Coordinate Measuring Machines

■ Performance Assessment Method of Coordinate Measuring Machines

Regarding the performance assessment method of coordinate measuring machines, JIS was revised in 2003. In the revised JIS, the standards for scanning measurement and rotary tables have been added to the conventional test items. Also, the concept of "uncertainty" has been incorporated into the latest JIS. At that point in 2003 the four items in Table 1 were standardized.

Table 1 JIS B 7440 (2003) Series

	Item	JIS Standard No.	Year of issue
1	Terms	JIS B 7440-1 (2003)	2003/4
2	Dimensional measurement	JIS B 7440-2 (2003)	2003/4
3	Rotary table-equipped CMM	JIS B 7440-3 (2003)	2003/4
4	Scanning measurement	JIS B 7440-4 (2003)	2003/4

■ Maximum Permissible Measuring Error MPE_E [JIS B 7440-2 (2003)]

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

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

$MPE_E = A + L/K \le B$
$MPE_E = A + L/K$
$MPE_E = B$

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

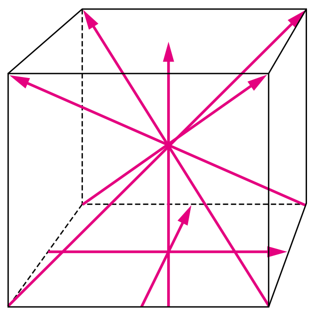


Figure 1 Typical test measurement directions within the CMM measuring volume

■ Maximum Permissible Probing Error MPE_P [JIS B 7440-2 (2003)]

The test procedure under this standard is that a probe is used to measure defined target points on a standard sphere (25 points, as in Figure 2) and the result used to calculate the position of the sphere center by a least squares method. Then the distance R from the sphere center for each of the 25 measurement points is calculated, and the radius difference Rmax - Rmin is computed. An extended uncertainty that combines the uncertainty of the stylus tip shape and that of the standard test sphere is added to the radius difference. If this final calculated value is equal to or less than the specified value, the probe has passed the test.

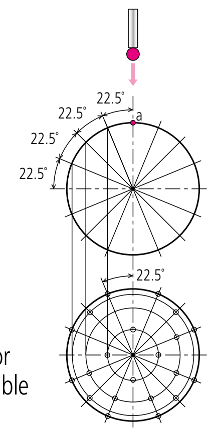


Figure 2 Target points on standard sphere for determining the Maximum Permissible Probing Error

Maximum Permissible Scanning Probing Error MPE_{THP} [JIS B 7440-4 (2003)]

This is the accuracy standard for a CMM if equipped with a scanning probe. Scanning probing error was standardized in JIS B 7440-2 (2003) for the first time. The test procedure under this standard is to perform a scanning measurement of 4 planes on the standard sphere and then, for the least squares sphere center calculated using all the measurement points, calculate the range (dimension 'A' in Figure 3) in which all measurement points exist. Based on the least squares sphere center calculated above, calculate the distance between the calibrated standard sphere radius and the maximum measurement point or minimum measurement point, and take the larger distance (dimension 'B' in Figure 3). Add an extended uncertainty that combines the uncertainty of the stylus tip shape and the uncertainty of the standard test sphere shape to each A and B dimension. If both calculated values are less than the specified values, this scanning probe test is passed.

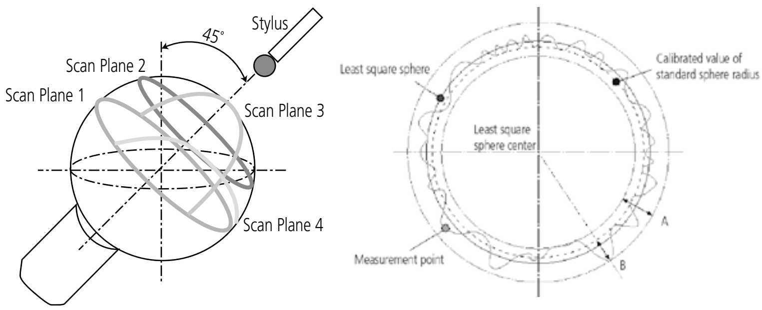


Figure 3 Target measurement planes for the maximum permissible scanning probing error and its evaluation concept

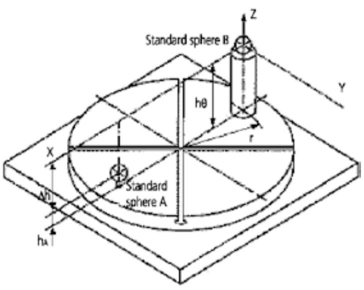


Figure 4 Evaluation of a CMM with a rotary table

Maximum Permissible Rotation Axis Radial-Direction Error MPE_{FR}, Maximum Permissible Rotation Axis Connecting-Direction Error MPE_{FT}, and Maximum Permissible Rotation Axis Axial-Direction Error MPE_{FA} [JIS B 7440-3 (2003)]

The test procedure under this standard is to place two standard spheres on the rotary table as shown in Figure 4. Rotate the rotary table to a total of 15 positions including 0˚, 7 positions in the plus (+) direction, and 7 positions in the minus (-) direction and measure the center coordinates of the two spheres in each position. Then, add the uncertainty of the standard sphere shape to each variation (range) of radial direction elements, connecting direction elements, and rotational axis direction elements of the two standard sphere center coordinates. If these calculated values are less than the specified values, the evaluation test is passed.

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