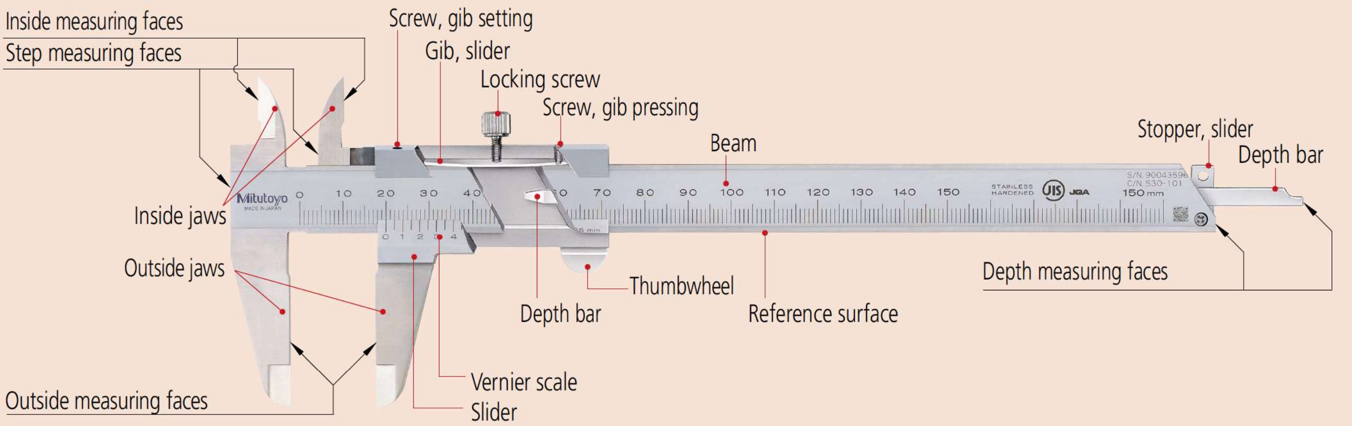
Quick Guide to Precision Measuring Instruments

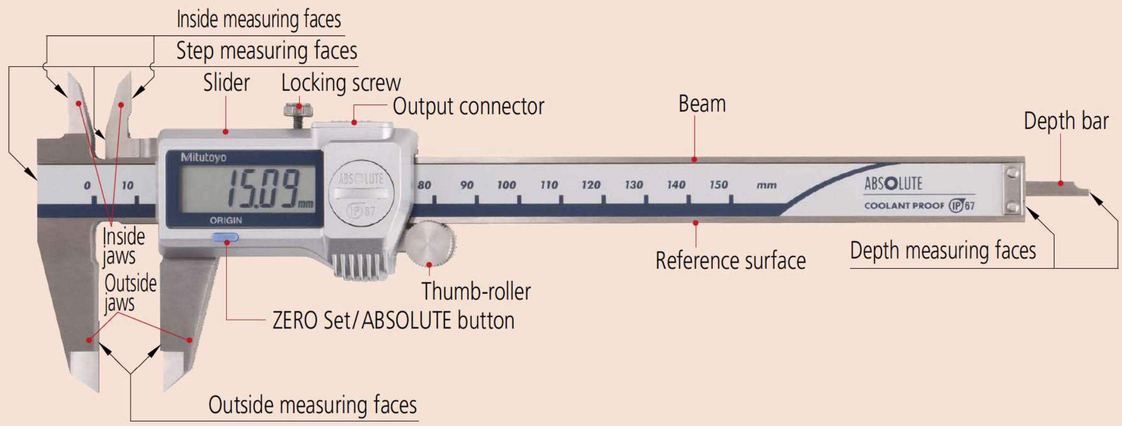
Calipers

Nomenclature

Vernier Caliper

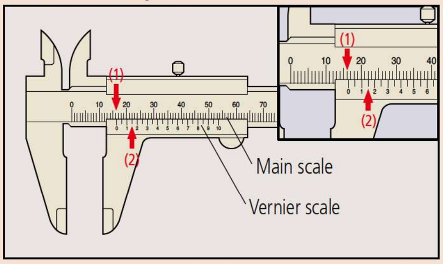


ABSOLUTE Digimatic Caliper



How to Read the Scale

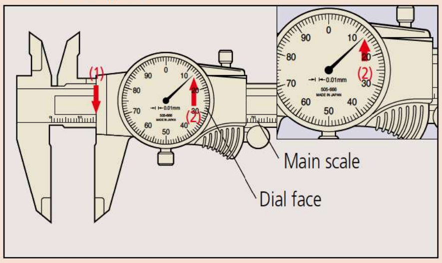
• Vernier Calipers



Graduation 0.05 mm

(1) Main scale	16 mm
(2) Vernier scale	0.15 mm
Reading	16.15 mm

• Dial Calipers



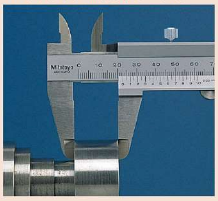
Graduation 0.01 mm

(1) Main scale	16 mm
(2) Dial face	0.13 mm
Reading	16.13 mm

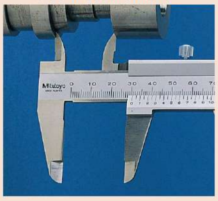
Note: Above left, 0.15 mm (2) is read at the position where a main scale graduation line corresponds with a vernier graduation line.

Measurement examples

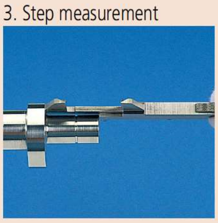
1. Outside measurement



2. Inside measurement



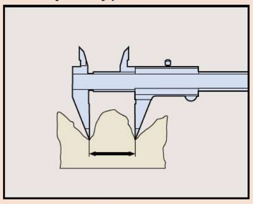
3. Step measurement



4. Depth measurement

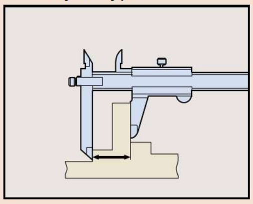
Special Purpose Caliper Applications

Point jaw type



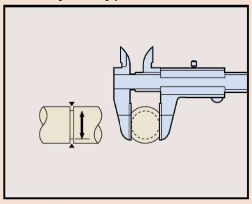
For uneven surface measurement

Offset jaw type



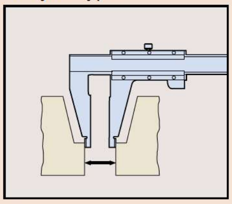
For stepped feature measurement

Blade jaw type



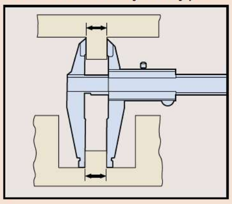
For diameter of narrow groove measurement

Nib jaw type



For outside measurement and inside measurement of a stepped hole

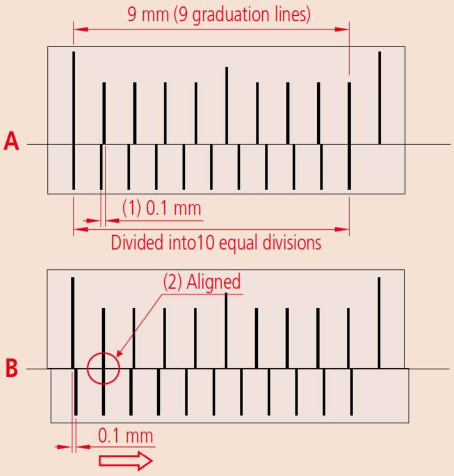
Nib/Standard jaw type



For outside measurement and measurement of a stepped hole

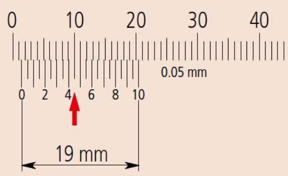
Vernier scale

This is a short auxiliary scale that enables accurate interpolation between the divisions of a longer scale without using mechanical magnification. The principle of operation is that each vernier scale division is slightly smaller than a main scale division, so that successive vernier graduations successively coincide with main scale graduations as one is moved relative to the other. Specifically, n divisions on a vernier scale are the same length as n-1 divisions on the main scale it works with, and n defines the division (or interpolation) ratio. Although n may be any number, in practice it is typically 10, 20, 25, etc., so that the division is a useful decimal fraction. The example below is for n = 10. The main scale is graduated in mm, and so the vernier scale is 9 mm (10 divisions) long, the same as 9 mm (9 divisions) on the main scale. This produces a difference in length of 0.1 mm (1) as shown in figure A (the 1st vernier graduation is aligned with the first main scale graduation). If the vernier scale is slid 0.1 mm to the right as shown in figure B, the 2nd graduation line on the vernier scale moves into alignment with the 2nd line on the main scale (2), and so enables easy reading of the 0.1 mm displacement.



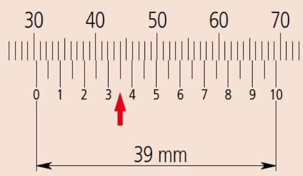
Some early calipers divided 19 divisions on the main scale by 20 vernier divisions to provide 0.05 mm resolution. However, the closely spaced lines proved difficult to read and so, since the 1970s, a long vernier scale that uses 39 main scale divisions to spread the lines is generally used instead, as shown below.

- 19 mm Vernier scale



Scale reading 1.45 mm

- 39 mm vernier scale (long vernier scale)

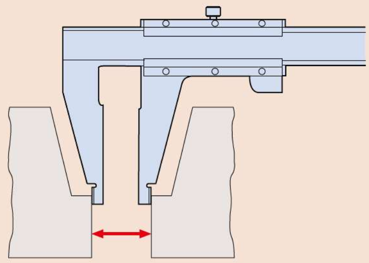


Scale reading 30.35 mm

Calipers were made that gave an even finer resolution of 0.02 mm. These required a 49-division vernier scale dividing 50 main scale divisions. However, they were difficult to read and are now hard to find since Digital calipers with an easily read display and resolution of 0.01 mm appeared.

Long Calipers

Steel rules are commonly used to roughly measure large workpieces but if a little more accuracy is needed then a long caliper is suitable for the job. A long caliper is very convenient for its user friendliness but does require some care in use. In the first place it is important to realize there is no relationship between resolution and accuracy. For details, refer to the values in our catalog. 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.



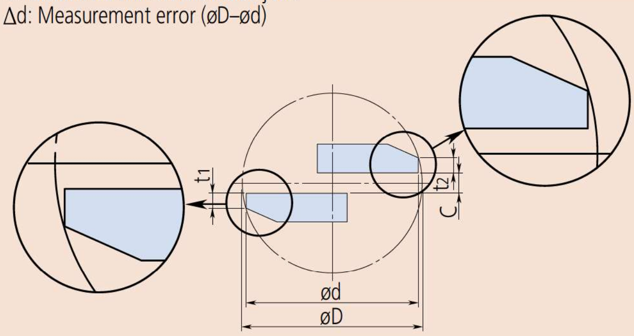
Small hole measurement with a standard type caliper

A structural error d occurs when you measure the internal diameter of a small hole.

øD: True internal diameter
ød: Measured diameter
t_1, t_2: Thickness of the inside jaw
C: Distance between the inside jaws
Δd: Measurement error (øD–ød)

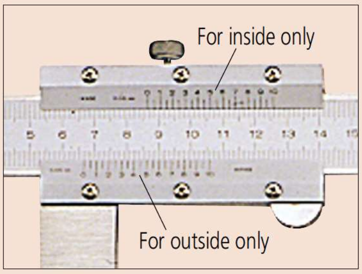
True internal diameter (øD: 5 mm) Unit: mm

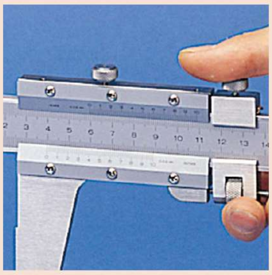
t_1+t_2+C	0.3	0.5	0.7
Δd	0.009	0.026	0.047



Inside Measurement with a caliper with Nib Style Jaws and Fine Adjustment

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

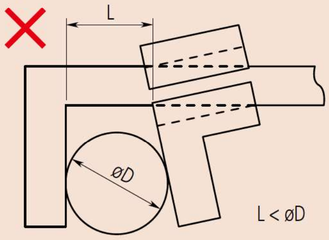


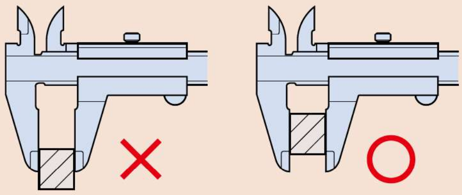


General notes on use of the caliper

1. Potential causes of error

A variety of factors can cause errors when measuring with a caliper. Major factors include parallax effects, excessive measuring force due to the fact that a caliper does not conform to Abbe's Principle, differential thermal expansion due to a temperature difference between the caliper and workpiece, and the effect of the thickness of the knife-edge jaws and the clearance between these jaws during measurement of the diameter of a small hole. Although there are also other error factors such as graduation accuracy, reference edge straightness, main scale flatness on the main blade, and squareness of the jaws, these factors are included within the *E*MPE error tolerances. Therefore, these factors do not cause problems as long as the caliper satisfies the *E*MPE error tolerances. Handling notes have been added to the JIS so that consumers can appreciate the error factors caused by the structure of the caliper before use. These notes relate to the measuring force and stipulate that "as the caliper does not have a constant-force device, you must measure a workpiece with an appropriate even measuring force. Take extra care when you measure it with the root or tip of the jaw because a large error could occur in such cases."





2. Inside measurement

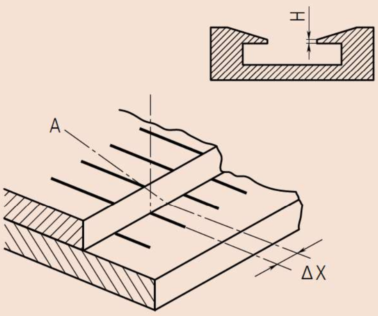
Insert the inside jaw as deeply as possible before measurement.
Read the maximum indicated value during inside measurement.
Read the minimum indicated value during groove width measurement.

3. Depth measurement

Read the minimum indicated value during depth measurement.

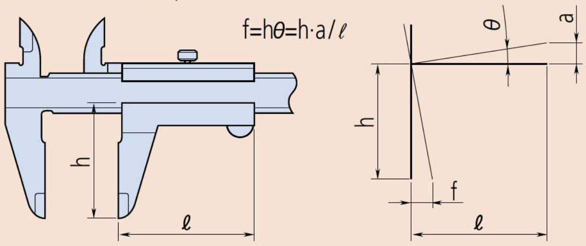
4. Parallax error when reading the scales

Look straight at the vernier graduation line when checking the alignment of vernier graduation lines to the main scale graduation lines.
If you look at a vernier graduation line from an oblique direction (A), the apparent alignment position is distorted by ΔX as shown in the figure below due to a parallax effect caused by the step height (H) between the planes of the vernier graduations and the main scale graduations, resulting in a reading error of the measured value. To avoid this error, the JIS stipulates that the step height should be no more than 0.3 mm.



5. Moving Jaw Tilt Error

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



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

6. Relationship between measurement and temperature

The main scale of a caliper is engraved (or mounted on) stainless steel, and although the linear thermal expansion coefficient is equal to that of the most common workpiece material, steel, i.e. $(10.2\pm1)\times10^{-6}$/K, note that other workpiece materials, the room temperature and the workpiece temperature may affect measurement accuracy.

7. Handling

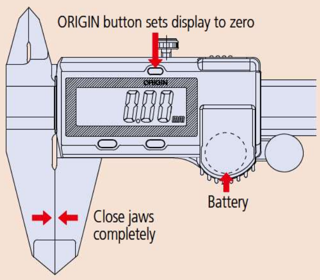
Caliper jaws are sharp, and therefore the instrument must be handled with care to avoid personal injury.
Avoid damaging the scale of a digital caliper and do not engrave an identification number or other information on it with an electric marker pen.
Avoid damaging a caliper by subjecting it to impact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

8. Maintenance of beam sliding surfaces and measuring faces

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

9. Checking and setting the origin before use

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



10. Handling after use

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

11. Notes on storage

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

Performance evaluation method for the caliper

As a result of the revision in 2016 to JIS B 7507:2016, indication errors of callipers specified by JIS B 7507 (the Japanese Industrial Standard of callipers) have been changed from "instrumental errors" specified by JIS B 7507:1993 or earlier to "Maximum permissible errors (MPEs) of indication".
The acceptance criterion adopted for "instrumental errors" in JIS B7507:1993 or earlier regards the specification range (precision specifications) to be the same as the acceptance range and does not take into account measurement uncertainty in pass/fail judgement. (**Fig. 1**)
For "Maximum permissible errors (MPEs) of indication" adopted by JIS B 7507:2016, the basic principle of pass/fail judgement that takes into account uncertainty specified by the ISO standard (ISO 14253-1) is used.
The verification of conformity and nonconformity to the specifications is clearly stipulated to use the internationally recognized acceptance criteria (simple acceptance) when the specification range equals the acceptance range, and it is accepted that the specification range equals the acceptance range if a given condition considering uncertainty is met.
In this case, the internationally recognized acceptance criterion is ISO/TR 14253-6: 2012. (**Fig. 2**)
The following describes the standard inspection method including the revised content of JIS 2016.

Fig. 1 Instrumental error
JIS B 7507: 1993 or earlier

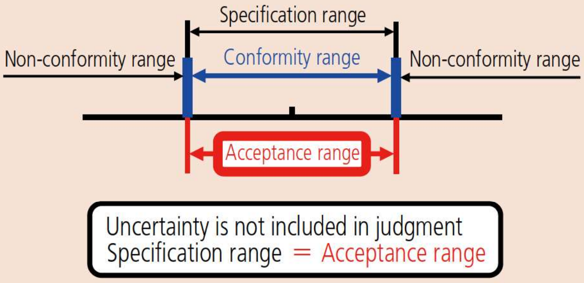
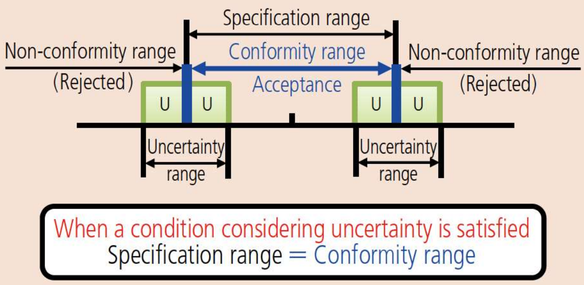


Fig. 2 Maximum permissible error (MPE)
JIS B 7507: 2016 (ISO/TR 14253-6: 2012)



Maximum permissible error of partial measuring surface contact error *E*MPE [JIS B 7507: 2016]

The partial measuring surface contact error of a caliper is an indication error applied to outside measurement.
Table 1 shows the Maximum permissible error *E*MPE for various measuring ranges and graduation/resolution of a caliper.
The value can be obtained by inserting a gauge block (or an equivalent standard) between the outside measuring surfaces (**Fig. 3**), measuring it at arbitrary positions between the jaws and then subtracting the dimension of the gage from the maximum or minimum indicated value.

Scale Shift Error *S*MPE [JIS B 7507: 2016]

The scale shift error in a caliper is an indication error of the inside measurement, depth measurement, etc., if measuring surfaces other than the outside measuring surfaces are used.
The Maximum permissible error *S*MPE of the indication value for inside measurement is given in **Table 1**. The Maximum permissible error *S*MPE of depth measurement is obtained by adding 0.02 mm to a value in **Table 1**.
The indication error for inside measurement can be obtained by using gauge blocks (or equivalent standards) and standard jaws from an accessory set to form accurate inside dimensions for calibration (**Fig. 4**), with the error being given by the indicated value minus the gauge block size.

Table 1: Maximum permissible error *E*MPE of partial measuring surface contact error in a conventional caliper

Unit: mm

Measurement range	Scale interval, graduation or resolution	
	0.05	0.02
50 or less	±0.05	±0.02
Over 50, 100 or less	±0.06	±0.03
Over 100, 200 or less	±0.07	
Over 200, 300 or less	±0.08	±0.04

Note: *E*MPE includes the measurement error arising from the straightness, flatness and parallelism of the measuring surfaces.

Fig. 3: Determining partial measuring surface contact error

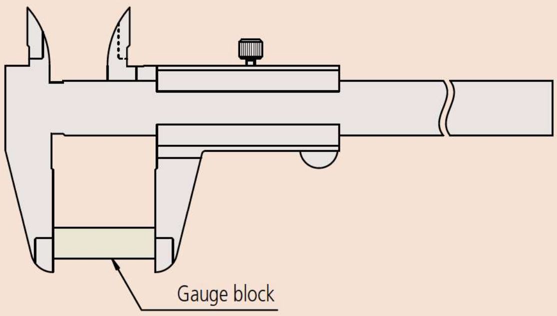
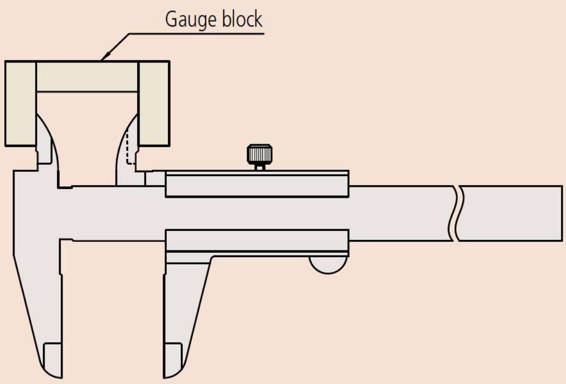


Fig. 4: Determining scale shift error



The "Instrumental error" indicating the indication error of JIS has been changed to "Maximum permissible error (MPE) of indication" for the following three models:

- **Vernier Caliper SERIES 530 — Standard model** described on page 04-8 (**530-101 530-108 530-109**)
- **Vernier Caliper SERIES 532 — with fine adjustment** described on page 04-10 (All models)
- **Vernier Caliper SERIES 531 — with thumb grip** described on page 04-11 (All models)

Compliance with ISO 13385-1:2019 and JIS B 7507:2022

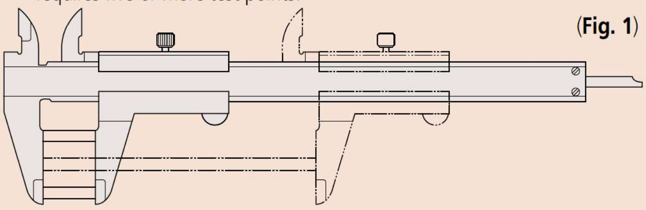
ISO 13385-1 (the ISO standard of callipers) was revised and published as ISO 13385-1:2019 in August 2019, and accordingly based on ISO 13385-1:2019, JIS B 7507 (the Japanese Industrial Standard of callipers) was revised and published as JIS B 7507:2022 in May 2022. One of the major points of these revisions is that specific numerical values have been provided for indication and inspection methods regarding the accuracy of callipers. This quantification does not affect the quality of callipers manufactured in the past, as they were measured and inspected in an agreed, standardized way in line with certain methods and criteria. The following paragraphs explain points and changes in the revised ISO 13385-1:2019 and JIS B 7507:2022.

Partial surface contact error $E_{(MPE)}$ [ISO 13385-1:2019, JIS B 7507:2022]

The partial surface contact error of a caliper is an indication error applied to outside measurement.
The ISO 13385-1:2019 and JIS B 7507:2022 standard quantifies for each measuring range the testing method and criteria, such as test points, number of tests, and testing arrangement that were previously left to the manufacturers' own criteria.
(**Fig. 1**, **Table 1**)

Ex.) For a caliper with a measuring range of 150 mm, the revised standard requires five or more test points.

(**Fig. 1**)



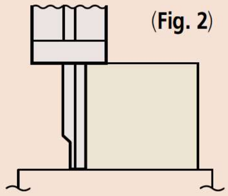
Number of partial surface contact error test points (**Table 1**)

Measuring range (mm)	Minimum number of test points
150	5
300	6
1000	7
1000 or more	8

Furthermore, the revised standards require testing in 90% or more points within the product measuring range as well as testing at the root and tip of the jaw at the maximum/minimum point. Therefore, it is important to conduct tests following the newly defined standard.
The following is an example of measurement for a 150 mm caliper. To comply with the ISO 13385-1:2019 and JIS B 7507:2022 standard, the minimum number of test points is five for a 150 mm caliper. (**Table 1**)
Five or more test points are necessary to comply with the ISO 13385-1:2019 and JIS B 7507:2022 standard. These include testing at the maximum and minimum point, as well as at the root and tip of the measuring unit. These test points must add up to a total of five.

ISO 13385-1:2019 and JIS B 7507:2022

The Shift Error for calipers is the error of indication for areas other than the outside measuring face. In the ISO 13385-1:2019 and JIS B 7507:2022 standard, all measurement errors (inside, depth, step, and I.D. measurement error) other than the outside measurement error (E_{MPE}) are Scale Shift Errors (S_{MPE}). Test points and their number were newly quantified as the type of errors included in the Scale Shift Error were better specified. (**Fig. 2**, **3**, **Table 3**)



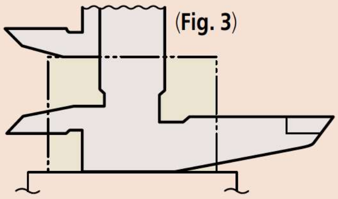
(**Fig. 2**)

Scale Shift Error measurement example-depth measurement

Ex.) Step and depth measurement

[ISO 13385-1:2019] (**Table 3**)

Test numbering	Test point	Reference standard
1	Less than 50 mm	Gauge block



(**Fig. 3**)

Scale Shift Error measurement example-step measurement

For example, for depth measurement or step measurement, the standard specifically requires one or more test points at less than 50 mm and a testing arrangement using gauge blocks.
(See **Table 3**)

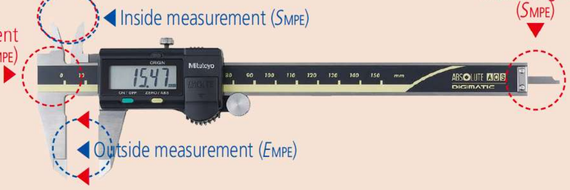
Accuracy notation change (Regarding MPE notation)

The "instrumental error" used until now will change to "MPE (E_{MPE}/ S_{MPE})". Scale Shift Error (S_{MPE}) will describe the permissible error including those for depth and step.(**Table 4**)

Standards	E_{MPE} Outside measurement	S_{MPE} Inside measurement	Depth measurement	Step measurement	I.D. measurement
ISO13385-1:2019	Accuracy notation for outside measurement	Permissible values including those for all measurements: inside, depth, step, etc.			
ISO13385-1:2011 (JISB7507:2016)	Accuracy notation for outside measurement	Inside measurement = E_{MPE}	Depth, step, = E_{MPE} + 0.02 mm		

Maximum permissible error includes the repeatability and quantizing error.

Test points and MPE notation



Ex.) 200 mm caliper (**Table 4-1**)

Accuracy ±0.02 mm (conventional notation)

Breakdown	Outside measurement	±0.02
	Inside measurement	±0.02

For depth and step measurement, add 0.02 mm to the outside measurement value.

S_{MPE} is described for measurements other than the outside measurement, but the maximum permissible error for inside measurement remains the same as before.
The permissible values for measurements other than the outside measurement (inside, depth, step, and inside diameter measurement) must be described as S_{MPE} in line with the ISO 13385-1:2019 and JIS B 7507:2022 standard. Since the permissible values for depth and step measurement are larger than those for inside measurement, this could give an impression that accuracy has suffered. However, this is simply due to the change of notation in accordance with the ISO 13385-1:2019 and JIS B 7507:2022 standard; neither has the accuracy of the inside measurement deteriorated nor has the product performance changed. (**Table 6-1**, **6-2**)

(**Table 6-1**) Unit: mm

Measured length	Scale interval, graduation or resolution 0.05	0.02 or 0.01
50 or less	±0.05	±0.02
Over 50, 100 or less	±0.06	±0.03
Over 100, 200 or less	±0.07	
Over 200, 300 or less	±0.08	±0.04

Note: E_{MPE} includes the measurement error arising from straightness, flatness and parallelism of the measuring surface.

Maximum permissible error E_{MPE} of Partial surface contact error in JIS B 7507

➡

Ex.) Permissible values for a 200 mm caliper

(**Table 6-2**)

Measured length (mm)	Maximum permissible error (MPE) E_{MPE} (mm)	S_{MPE} (mm)
0 ≤ L ≤ 50	±0.02	±0.04
50 ≤ L ≤ 100		
100 ≤ L ≤ 150		
150 ≤ L ≤ 200		

Ex.) Breakdown of S_{MPE}

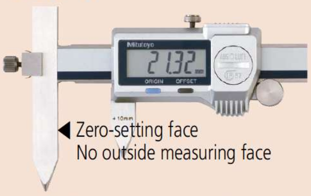
Inside measurement	Step measurement	Depth measurement	I.D. measurement
±0.02	±0.04	±0.04	+0.01 −0.03

Accuracy notation change (for custom products)

The ISO 13385-1:2019 and JIS B 7507:2022 standard stipulates the accuracy notation for compliant products. However, nothing is stipulated for custom products that are not compliant with said standard (such as calipers with dedicated measuring faces), so for these products the notation of accuracy is left to the discretion of each manufacturer.
Mitutoyo, with many custom calipers, describes MPE for all of its calipers based on the following line of thinking. For example, MPE is "Scale Shift Error (S_{MPE})" for "calipers whose measuring face is other than the zero-setting face = calipers with exclusive measuring method" such as centerline calipers, inside calipers, etc. (**Fig. 5, Table 7**)
Accuracy is described using S_{MPE} measured not using the number of test points stipulated in the ISO 13385-1:2019 and JIS B 7507:2022 standard, but rather with the same number of test points and testing method as before.

(**Fig. 5**) Non-ISO model (Ex.)

573-605-20



(**Table 7-1**)

Maximum permissible error (MPE) E_{MPE} (mm)	S_{MPE} (mm)
—	±0.04

Number of test points: 3

573-646-20

(**Table 7-2**)

Maximum permissible error (MPE) E_{MPE} (mm)	S_{MPE} (mm)
—	±0.03

Number of test points: 3

Appendix: List of maximum permissible errors (MPE) for typical products

The following list shows MPE for ISO-compliant models. (Table 8)

Series 500

Measured length	Maximum permissible errors	
	E_{MPE} (mm)	S_{MPE} (mm)
0 ≤ L ≤ 50	±0.02	±0.04
50 < L ≤ 100	±0.02	±0.04
100 < L ≤ 150	±0.02	±0.04
150 < L ≤ 200	±0.02	±0.04
200 < L ≤ 300	±0.03	±0.05
300 < L ≤ 400	±0.04	±0.06
400 < L ≤ 500	±0.05	±0.07
500 < L ≤ 600	±0.05	±0.07
600 < L ≤ 700	±0.06	±0.08
700 < L ≤ 800	±0.06	±0.08
800 < L ≤ 900	±0.07	±0.09
900 < L ≤ 1000	±0.07	±0.09

Series 505
(0.01 mm)

Measured length	Maximum permissible errors	
	E_{MPE} (mm)	S_{MPE} (mm)
0 ≤ L ≤ 50	±0.02	±0.04
50 < L ≤ 100	±0.02	±0.04
100 < L ≤ 150	±0.02	±0.04
150 < L ≤ 200	±0.03	±0.05
200 < L ≤ 300	—	—
300 < L ≤ 400	—	—
400 < L ≤ 500	—	—
500 < L ≤ 600	—	—
600 < L ≤ 700	—	—
700 < L ≤ 800	—	—
800 < L ≤ 900	—	—
900 < L ≤ 1000	—	—

Series 505
(0.02 mm)

Measured length	Maximum permissible errors	
	E_{MPE} (mm)	S_{MPE} (mm)
0 ≤ L ≤ 50	±0.02	±0.04
50 < L ≤ 100	±0.03	±0.05
100 < L ≤ 150	±0.03	±0.05
150 < L ≤ 200	±0.03	±0.05
200 < L ≤ 300	±0.04	±0.06
300 < L ≤ 400	—	—
400 < L ≤ 500	—	—
500 < L ≤ 600	—	—
600 < L ≤ 700	—	—
700 < L ≤ 800	—	—
800 < L ≤ 900	—	—
900 < L ≤ 1000	—	—

Note: The reference point (0) is at 10.1 mm for **Series 550** and **551**.

Series 550

Measured length	Maximum permissible errors	
	E_{MPE} (mm)	S_{MPE} (mm)
0 ≤ L ≤ 50*1	±0.02	±0.02
0 ≤ L ≤ 50*2	±0.03	±0.03
50 < L ≤ 100	±0.03	±0.03
100 < L ≤ 200	±0.03	±0.03
200 < L ≤ 300	±0.04	±0.04
300 < L ≤ 400	±0.04	±0.04
400 < L ≤ 450	±0.05	±0.05
450 < L ≤ 500	±0.05	±0.05
500 < L ≤ 600	±0.05	±0.05
600 < L ≤ 700	±0.06	±0.06
700 < L ≤ 800	±0.06	±0.06
800 < L ≤ 900	±0.07	±0.07
900 < L ≤ 1000	±0.07	±0.07

*1 **550-301-20** and **550-331-20**
*2 **550-203-10**, **550-205-10** and **550-207-10**
Note: The minimum inside measurement size is 20.1 mm for **550-203**, **205** and **207**.

Series 551

Measured length	Maximum permissible errors	
	E_{MPE} (mm)	S_{MPE} (mm)
0 ≤ L ≤ 50*1	±0.02	±0.02
0 ≤ L ≤ 50*2	±0.03	±0.03
50 < L ≤ 100	±0.03	±0.03
100 < L ≤ 200	±0.03	±0.03
200 < L ≤ 300	±0.04	±0.04
300 < L ≤ 400	±0.04	±0.04
400 < L ≤ 500	±0.06	±0.06
500 < L ≤ 600	±0.06	±0.06
600 < L ≤ 700	±0.06	±0.06
700 < L ≤ 750	±0.06	±0.06
750 < L ≤ 800	±0.06	±0.06
800 < L ≤ 900	±0.07	±0.07
900 < L ≤ 1000	±0.07	±0.07

*1 **551-301-20** and **551-331-20**
*2 **551-204-10**, **551-206-10** and **551-207-10**
Note: The minimum inside measurement size is 20.1 mm for **551-204**, **206** and **207**.

Series 530

Measured length	Maximum permissible errors	
	E_{MPE} (mm)	S_{MPE} (mm)
0 ≤ L ≤ 50	±0.05	±0.07
50 < L ≤ 100	±0.05	±0.07
100 < L ≤ 150	±0.05	±0.07
150 < L ≤ 200	±0.05	±0.07
200 < L ≤ 300	±0.08	±0.10
300 < L ≤ 400	±0.09	±0.11
400 < L ≤ 500	±0.10	±0.12
500 < L ≤ 600	±0.10	±0.12
600 < L ≤ 700	±0.12	±0.14
700 < L ≤ 800	±0.13	±0.15
800 < L ≤ 900	±0.14	±0.16
900 < L ≤ 1000	±0.15	±0.17