TEXTBOOK NO. 7008

Calipers, Height Gages and Depth Gages

TEXTBOOK

Mitutoyo

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VERNIER CALIPERS

1. INTRODUCTION

A vernier caliper is a type of measuring tool that incorporates a vernier scale and a pair of calipers. It is said that the vernier scale was invented by Petrus Nonius (1492-1577), a Portuguese mathematician. Its present sliding scale design bears the name of its developer, Frenchman Pierre Vernier (1580-1637). Before vernier calipers were introduced, parts were measured with simple types of calipers (outside calipers, inside calipers, hermaphrodite calipers, etc) and steel rules. For example, when measuring an outside diameter, the part is put between the two legs of the calipers, and then the calipers are set to a rule to transfer the reading. In another application the legs of outside calipers are separated by a specific distance by using a rule and parts are machined until the legs of the calipers just manage to fit outside the machined surface. **Figs. 1.1** and **1.2** show an example of outside measurement using outside calipers. **Figs. 1.3** and **1.4** show an example of inside measurement using inside calipers.

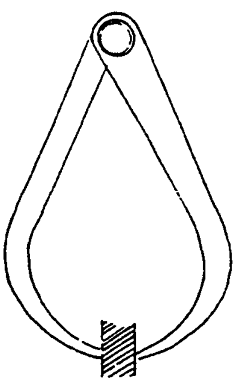


Fig. 1.1 Measuring with outside calipers

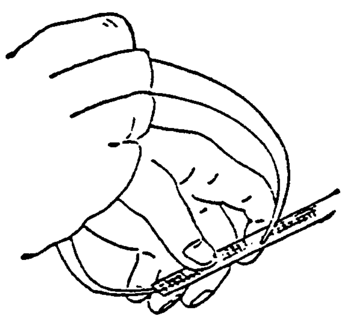


Fig. 1.2 Reading the measurement with a rule

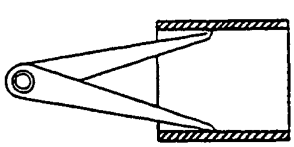


Fig. 1.3 Measuring with inside calipers

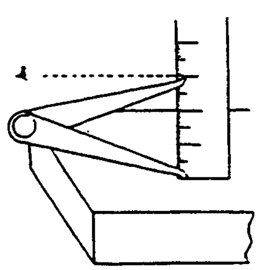


Fig. 1.4 Reading the measurement with a rule

These indirect-reading calipers require a great deal of expertise in each measurement step. The vernier caliper was developed to meet the need for a direct-reading tool that can take a measurement easily in a single operation. The typical slide caliper can take three types of measurements; outside, inside and depth measurements. Mitutoyo vernier calipers have an additional function for taking step measurements.

Newer types of calipers employ different types of readouts; a dial for the least count readout and electronic digital readouts. (The Mitutoyo digital readout calipers are named *Digimatic Calipers.*) The digital readout caliper is the newest development and is becoming more popular these days. Typical discriminations, or resolutions, are 0.05mm and 0.02mm for vernier calipers, and 0.01mm for dial calipers and digital calipers.

2. VERNIER

2.1 Types of Verniers

The vernier is an auxiliary scale that slides along the main scale to permit accurate fractional reading of the least division of the main scale.

There are two kinds of verniers:

(1) Direct vernier

A vernier graduated into n equal divisions in the same length as $n - 1$ divisions on the main scale. Both the main scale and vernier scale are marked off in the same direction. A fraction of $1/n$ of the smallest division of the main scale may be read. (See **Fig. 2.1.**)

Verniers on the standard metric calipers have either 20 divisions that occupy 19 divisions on the main scale graduated in 1mm increments, or 25 divisions that occupy 24 divisions on the main scale graduated in 0.5mm increments, providing discriminations of 0.05mm and 0.02mm, respectively.

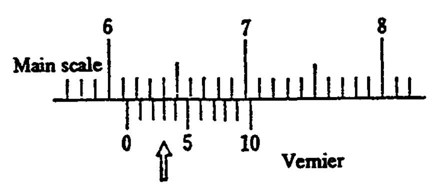


Fig. 2.1 Direct vernier

(2) Retrograde vernier

A vernier graduated into *n* equal divisions in the same length as $n + 1$ divisions on the main scale. The main scale and the vernier scale are marked off in opposite directions. A fraction of $1/n$ of the smallest division of the main scale may be read. (See **Fig. 2.2.**) The retrograde vernier is rarely used in practical applications.

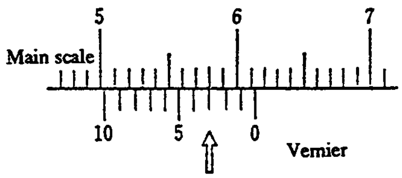


Fig. 2.2 Retrograde vernier

2.1.1 Rows of main scale graduations

The main scale is graduated on one or two sides as shown in **Table 2.1.** The M-type vernier calipers usually have graduations on the lower side only. The CM-type has graduations on both upper and lower sides for outside and inside measurements. The M-type, which is designed for both metric and inch measurements, has two rows of graduations on the upper and lower sides. One is a metric scale and the other is an inch scale.

Table 2.1 Rows of main scale graduations

Type	Number of rows	Unit/type of measurement
M-type caliper	1	Either mm or inch
M-type caliper	2	Both mm and inch
CM-type caliper	2	Outside and inside measurements

2.1.2 Graduations on main scale and vernier

Table 2.2 shows different types of graduations on the main and vernier scales. There are five types of graduations for the main scale and eight types for the vernier scale, including the metric and inch systems.

2.1.3 Graduations on dial calipers

Table 2.3 shows different types of graduations on dial calipers. There are five types of graduations, including the metric and inch systems.

Table 2.2 Graduations of main and vernier scales

Metric		Vernier reading	Inch		Vernier reading
Main scale division	Vernier graduations		Main scale division	Vernier graduations	
0.5mm	25 divisions in 12mm	0.02mm	1/16in.	8 divisions in 7/16in.	1/128in.
	25 divisions in 24.5mm	0.02mm			
1mm	50 divisions in 49mm	0.02mm	1/40in.	25 divisions in 1.225in.	1/1000in.
	20 divisions in 19mm	0.05mm	1/20in.	50 divisions in 2.45in.	1/1000in.
	20 divisions in 39mm	0.05mm			

Table 2.3 Dial caliper graduations

Type	Metric			Inch		
	Division	Dial graduations	Displacement/revolution	Division	Dial graduations	Displacement/revolution
D-type	0.05mm	100 divisions around circumference	5mm/rev.	0.001in.	100 divisions around circumference	0.1 in./rev.
DT-type	0.02mm	100 divisions around circumference	2mm/rev.	0.001in.	200 divisions around circumference	0.2 in./rev.
DE-type	0.01mm	100 divisions around circumference	1mm/rev.			

2.2 How to Take Readings on Vernier Scales

Direct verniers are classified into two types, the standard vernier and the long vernier.

2.2.1 Standard vernier

This is the most commonly used vernier, which has n equal divisions that occupy the same length as $n - 1$ divisions on the main scale. In **Fig. 2.3**, let

S: Value of one main scale division

V: Value of one vernier division

C: Discrimination of vernier

then, the value C is obtained as follows:

$$(n-1)S = nV$$

$$V = \frac{n-1}{n} S$$

$$C = S - V = S - \frac{n-1}{n} S = \frac{S}{n}$$

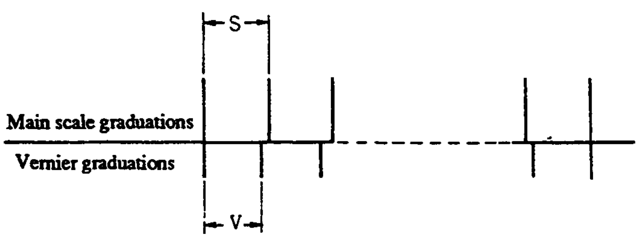


Fig. 2.3 Relationship between main scale and vernier graduations

Thus, each division on the vernier is smaller than one main scale division by S/n. The fraction between the main scale graduation immediately to the left of the vernier zero index and the next graduation is represented by a multiple of S/n (the difference between one main scale division and one vernier scale division); this is determined by finding the graduation on the vernier scale that is most accurately aligned with a graduation on the main scale.

Fig. 2.4 shows an example of reading a main scale graduated in 1mm increments with a vernier that has 20 equal divisions in 19mm.

The difference between one main scale division and one vernier scale division is as follows:

$$C = S - V = \frac{S}{n} = \frac{1}{20} \text{ mm}$$

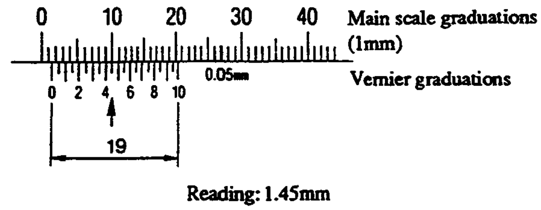


Fig. 2.4 Vernier having 20 divisions in 19mm on the main scale

As shown in **Fig. 2.4**, the fourth graduation (numbered 2) after the zero index on the vernier scale is aligned with a graduation on the main scale. Thus, the distance between the 73mm graduation on the main scale and the vernier zero index is:

$$\frac{1}{20} \text{ mm} \times 4 = 0.20\text{mm}$$

The total reading is:

73mm + 0.20mm = 73.20mm

2.2.2 Long vernier

The long vernier is designed to make adjacent vernier graduations more distinguishable. For example, a long vernier that has 20 equal divisions in 39mm provides a discrimination of 1/20mm, which is the same as in the standard vernier example in **2.2.1**. Because this vernier has 20 divisions that occupy 39mm on the main scale, the difference between two divisions on the main scale and one division on the vernier is given as:

$$C = 2\text{mm} - \frac{39}{20} \text{ mm} = \frac{1}{20} \text{ mm}$$

As shown in **Fig. 2.5**, the ninth graduation (next to the graduation numbered *4*) after the zero index on the vernier coincides with a main scale graduation. Thus, the distance between the 12mm graduation on the main scale and the vernier zero index is:

$$\frac{1}{20} \text{ mm} \times 9 = 0.45\text{mm}$$

The total reading is:

12mm + 0.45mm = 12.45mm

One division on the long verniers can be expressed as:

$$\frac{(an-1)}{n}$$

where, a is a positive integer (1, 2, 3,...)

The discrimination of a long vernier that has *n* equal divisions in the same length as *an - 1* divisions on the main scale is *1/n* of one main scale division, as shown below:

Let

S: Value of one main scale division

V: Value of one vernier division

C: Discrimination of vernier

a: Positive integer (1, 2, 3, ...)

then, the value *C* is obtained as follows:

$$(an-1)S = nV$$

$$V = \frac{(an-1)}{n} S$$

$$C = aS - V = \frac{naS - naS + S}{n} = \frac{S}{n}$$

Thus, each division on the vernier is smaller than *a* times one main scale division by *S/n*.

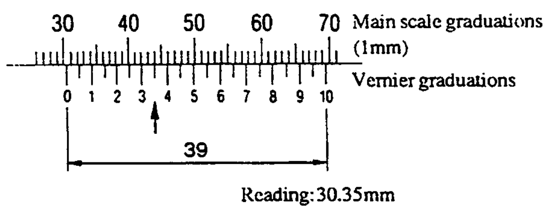


Fig. 2.5 Vernier having 20 divisions in 39mm on the main scale

2.2.3 Inch verniers

In **Fig. 2.6**, the vernier zero index is between the second and third graduations after the 1in. graduation on the main scale. The vernier is graduated in eight equal divisions that occupy seven divisions on the main scale. Therefore the difference between one main scale division and one vernier scale division is given as:

$$C = S - V = \frac{S}{n} = \frac{1}{16} \text{ in} \times \frac{1}{8} = \frac{1}{128} \text{ in}$$

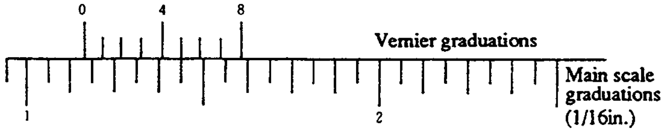


Fig. 2.6 Vernier having 8 divisions in 7/16in. on the main scale

Fig. 2.6 shows that the fifth graduation after the zero index on the vernier graduation coincides with a main scale graduation. Thus the fraction is calculated as:

$$\frac{1}{128} \text{ in} \times 5 = \frac{5}{128} \text{ in.}$$

The total reading is:

$$1 \text{ in} + \frac{2}{16} \text{ in} + \frac{5}{128} \text{ in} = 1\frac{21}{128} \text{ in.}$$

3. CLASSIFICATION OF CALIPERS BY SIZE AND TYPE

3.1 Small and Large Calipers

Calipers are available in many different sizes, with measuring ranges from 100mm to 3m (4in. to 120in. for inch calipers). Generally, calipers that have a measuring range of 300mm (12 in.) or less are classified as small calipers, and ones with larger ranges are classified as large calipers.

3.2 Standard Type Vernier Calipers

JIS B 7505 specifies two types of standard vernier calipers, the M-type (**Fig. 3.1**) and the CM-type (**Fig. 3.2**).

3.2.1 M-type vernier calipers

Fig. 3.1 shows a Mauser type vernier caliper (first manufactured by Mauser, a German company). JIS refers to this type of caliper as the M-type vernier caliper (called the depth-bar caliper). The M-type caliper has a grooved slider and jaws for inside measurement. A depth bar is provided for calipers that have a measuring range of 300mm or less. Large calipers, such as ones with 600mm and 1000mm measuring ranges, have no depth bar. The vernier is graduated into 20 divisions in 39mm for the 0.05mm reading type, or into 50 divisions in 49mm for the 0.02mm reading type. The Mitutoyo M-type vernier calipers (**Fig. 3.3**) are designed to allow easy step measurement; the inside jaws are close to the main scale beam head as compared with the M-type vernier calipers from other manufacturers and the end of the slider is flush with the main scale beam head when the jaws are completely closed.

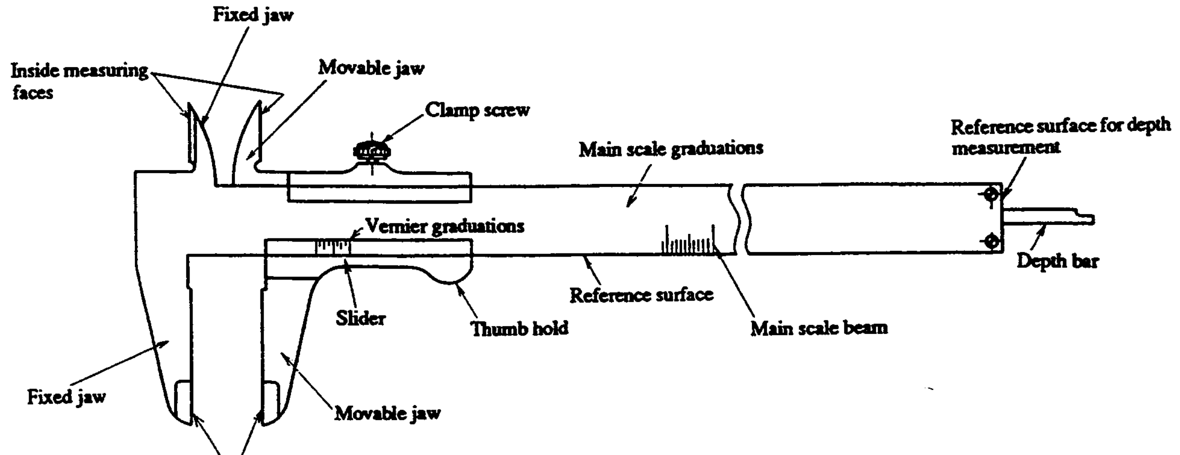


Fig. 3.1 M-type vernier caliper

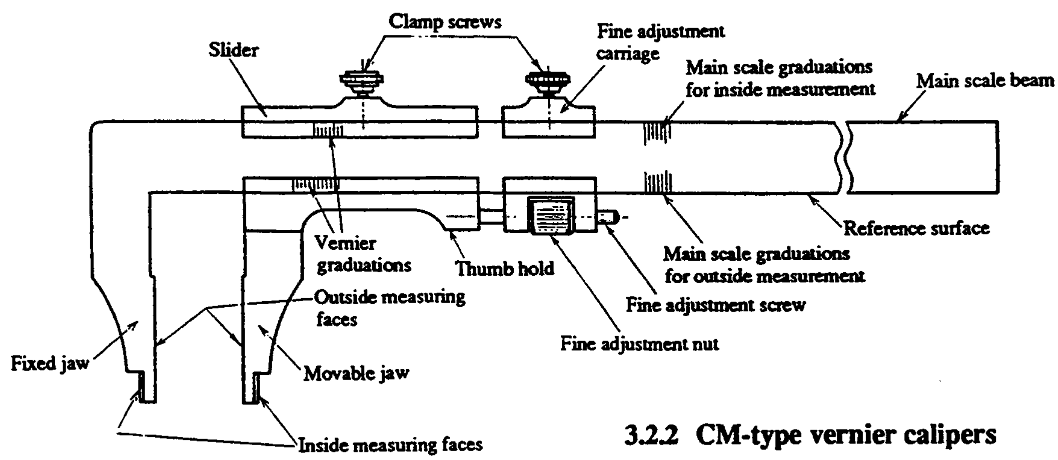


Fig. 3.2 CM-type vernier caliper

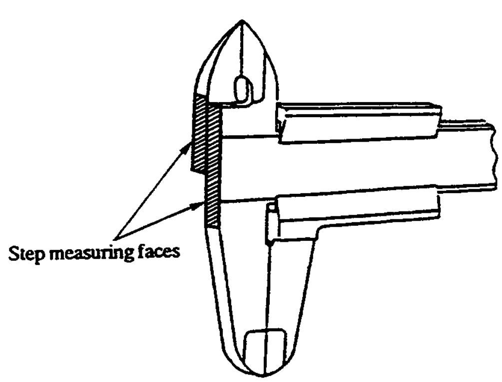


Fig. 3.3 Head of M-type vernier caliper

3.2.2 CM-type vernier calipers

Fig. 3.2 shows a CM-type vernier caliper (first manufactured by Mauser). This type is also called the Mauser type or German type vernier caliper. As shown in the figure, the CM-type caliper has a slider that consists of a box and is designed in such a way that the tips of the outside jaws can be used for inside measurement. This type is usually provided with fine adjustment for vernier movement. Unlike the M-type calipers, the inside measuring faces of the CM-type are not sharp-edged, so they have superior resistance to wear and damage. The C-type caliper, which is a simplified version of the CM-type, has no fine adjustment mechanism, and a discrimination of 0.05mm.

3.3 Other Types of Vernier Calipers

The vernier calipers described above are standard types and most widely used. There are, however demands for special-purpose calipers and calipers that are easy to handle and read. The following types were developed for such demands.

3.3.1 M-type vernier calipers with fine adjustment

The M-type vernier caliper that incorporates the fine adjustment mechanism of the CM-type is useful for measuring small inside dimensions. Mitutoyo offers three sizes of M-type vernier calipers with measuring ranges of 130mm, 180mm, and 280mm. All three have a vernier discrimination of 0.02mm.

3.3.2 M-type vernier calipers with a thumb clamp

The standard M-type vernier calipers have the main scale's reference surface (for guiding the slider) on the side of the outside jaw, and a leaf spring and a slider clamp screw on the side of the inside jaw of the slider. The M-type vernier calipers with a thumb clamp (auto-stopper) have the main scale's reference surface on the side of the inside jaw. The spring-loaded thumb clamp on the slider is used to clamp the slider. By pushing the knurled thumb hold on the thumb clamp to close the jaw, the slider is unclamped and can be moved smoothly. This eliminates the need for tightening and loosening the clamp screw, thus improving the measuring efficiency.

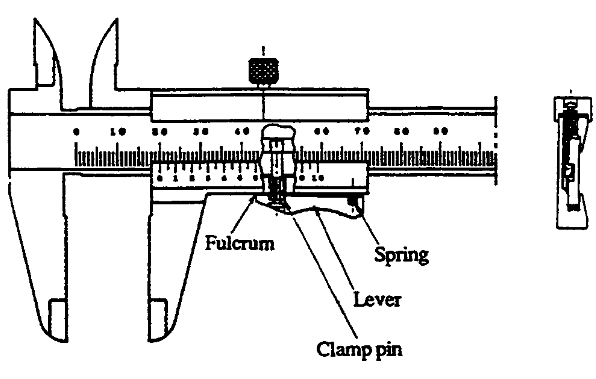


Fig. 3.4 M-type vernier caliper with thumb clamp

3.3.3 Dial calipers

Dial calipers are now used extensively because they provide easy and error-free readings when compared with vernier calipers. The dial caliper uses the amplification mechanism of the dial gage. Measurements are taken by adding the reading on the dial, which indicates the fraction of the main scale reading with a pointer, to the reading on the main scale. Since parallax errors are not involved when taking readings from a dial, the dial caliper allows quick and accurate measurement without special skill. As shown in **Fig. 3.5**, the dial caliper consists of a main scale to which a rack is attached, and a slider to which the dial is attached. Since the meshing of the rack and pinion mechanism is of critical importance, the depth bar is covered to protect the rack teeth from dust, cutting chips and oil. Mitutoyo offers dial calipers in eight different sizes with measuring ranges of 100mm, 150mm, 200mm, 300mm for the metric models, and 4in., 6in., 8in., and 12in. for the inch models. They are classified into three types, the D-type (dial reading to 0.05mm or 0.001in.), the DT-type (dial reading to 0.02mm or 0.001in.), and the DF-type (dial reading to 0.01mm, metric type only).

3.3.4 Digimatic Caliper CD

The Digimatic Caliper CD (Mitutoyo digital caliper, **Fig. 3.6**) uses a capacitance type detector, which is a new displacement detection system. It is almost the same size and weight as conventional vernier calipers of the same measuring range. The Digimatic Calipers are now used extensively because of their advantages – easy reading and operation and enhanced functionality – that were made possible by the digital system.

1) Sizes and types of Digimatic Calipers

Digimatic Calipers are available in a wide variety of sizes with measuring ranges of 100mm, 150mm, 200mm, 300mm, 450mm, 600mm, and 1000mm. Some small Digimatic Calipers have carbide-tipped jaws. The Digimatic Calipers are divided into three types; the M-type, the C-type, and the CN-type. There are also Digimatic Calipers for special purposes (NTD series). Standard Digimatic Calipers are provided with a data output connector.

2) Features

The main features of the Digimatic Calipers are shown below.

① Easy-to-read

Measured values are displayed on a five-digit LCD (resolution: 0.01mm) which is easy to read and free from reading errors.

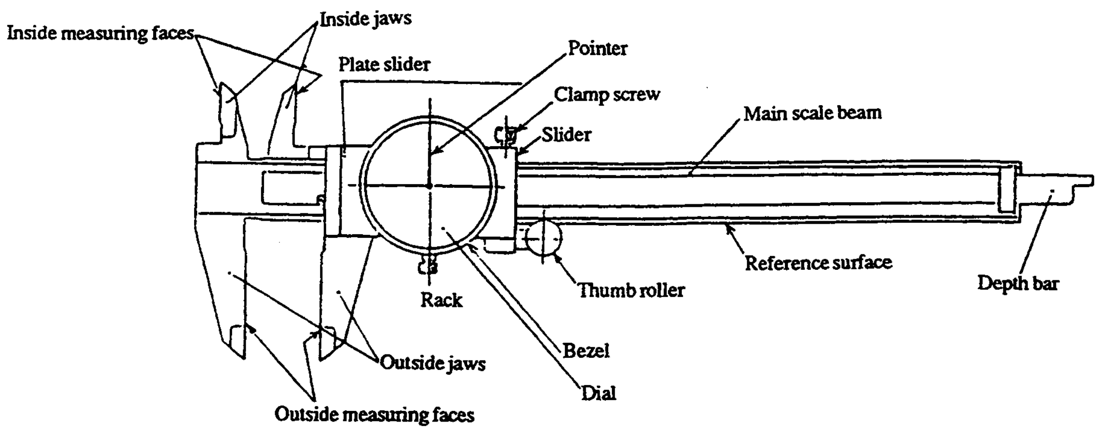


Fig. 3.5 Dial caliper

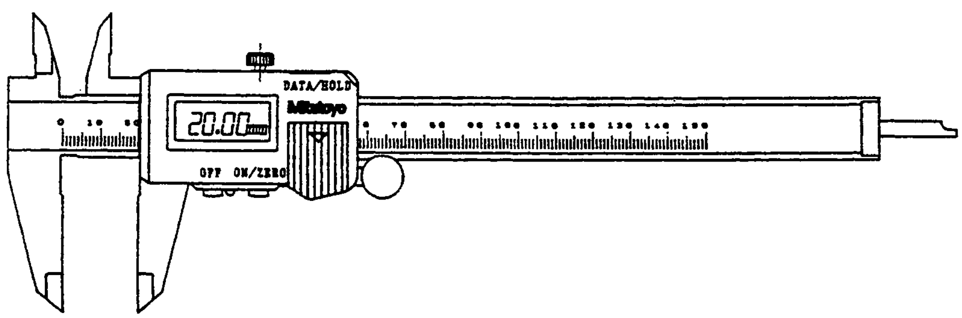


Fig. 3.6 Digimatic Caliper CD

② Compact, light weight, and low power consumption

The Digimatic Calipers are as compact and light weight as conventional vernier calipers. This was achieved by adopting a capacitance type detector which is made compact with a low-power, miniaturized circuit and does not require substantial changes from the conventional caliper structure. Since Digimatic Calipers consume little power, long hours of service are provided by a small battery. (Battery life is about two years under normal operating conditions.)

Reference data:

Weight: 170g (150mm measuring range)
200g (200mm measuring range)

Power source: Silver oxide battery (SR-44) x 1

③ Zero-setting function

This function zeroes the display at any desired position, allowing comparative measurement and other types of measurements according to the workpeice type.

④ Quick response speed

The detector's response speed is high enough for normal measuring speeds. (The maximum response speeds are 6000mm/s when opening the jaw and 1600mm/s when closing the jaw.)

⑤ Data output function

Digimatic Calipers can be connected to an external data processing device, such as a Digimatic processor or personal computer. They can also be integrated into an M-SPC (Mitutoyo Statistical Process Control) system.

The data output button has two functions. It serves as a data output switch when an external device is connected, and as a data holding switch when no external device is connected.

Reference data:

Operating temperature range: 0°C to 40°C

Storage temperature range: -10°C to 60°C

3) Structure

The Digimatic Caliper consists of a main scale and a slider, as in conventional vernier calipers, and a displacement scale unit and a reading unit. **Fig. 3.7** shows the structure of the Digimatic Caliper.

The displacement scale unit incorporates an accurately aligned array of electrodes to provide a reference for the sensor position. The reading unit consists of a sensor electrode that faces the electrodes of the displacement scale unit, circuitry to process the signal from the sensor into a displacement value, and operation buttons.

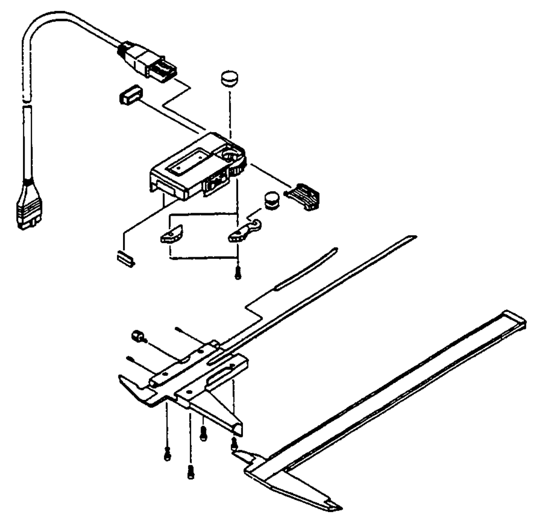


Fig. 3.7 Exploded drawing of Digimatic Caliper

4) Sensor performance requirements

The following are performance requirements for a sensor to determine displacements in digital calipers:

- Low power consumption
- High resolution and large measuring range
- Must not respond to linear or angular displacement in directions other than the measuring direction
- No wiring to the main scale
- Small size and low cost

The capacitance type sensor satisfies these requirements and is employed in Digimatic Calipers.

5) Detecting principle of Digimatic Calipers

The displacement sensor of Digimatic Calipers uses a capacitance type linear encoder that detects displacements based on the phase difference of induced electric current. As shown in **Fig. 3.8**, each sensor unit consists of parallel-plate capacitors C_1 and C_2, sender plates P_1 and P_2, and receiver plate R. When sine-wave voltages V_1 (= *sin wt*) and V_2 ('= *cos wt*) are applied to sender plates P_1 and P_2, respectively, the phase of the electric current generated by the charge *QR* on plate R is shifted from that of V_1, in proportion to the displacement of the sender plates. By detecting the phase difference, the displacement, or measured value, is determined.

As shown in **Fig. 3.9**, the displacement sensor of a Digimatic Caliper contains six sets of eight sender plates (providing eight different phases), or 48 sender plates in all.

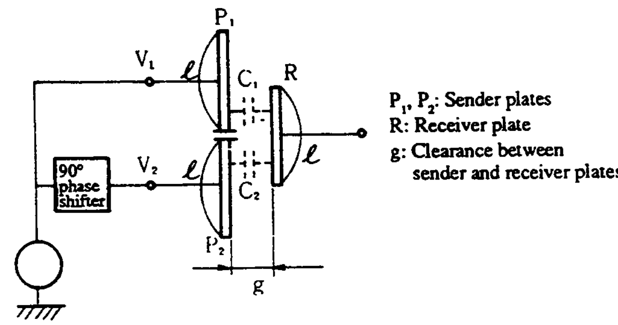


Fig. 3.8 Displacement detecting principle of Digimatic Caliper

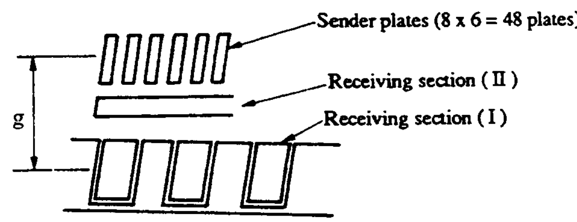


Fig. 3.9 Displacement sensor in Digimatic Caliper

3.3.5 Digimatic Mini-processor

1) M-SPC (Mitutoyo Statistical Process Control) system

a) The M-SPC system is a comprehensive process control system that integrates a wide variety of measuring tools. It consists of Digimatic Mini-processors that process data from Digimatic measuring tools on shop floors, and a variety of data transmission units that send measurement data to a host computer for centralized data management and storage. The desired system can be configured to best suit the manufacturer's particular production system.

b) Many powerful pieces of software are available, including the M-STAT program for creating histograms and $\overline{X}$-R charts, and making process capability analyses.

2) Digimatic Mini-processors and examples of data processing

Figs. 3.10, 3.11, and **3.12** show the DP-1HS, DP-2DX, and DP-30, respectively. **Fig. 3.13** shows data processing examples.

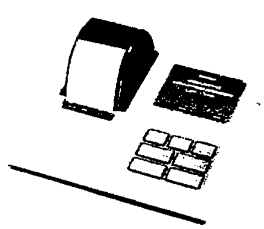


Fig. 3.10 DP-1HS

Fig. 3.11 DP-2DX

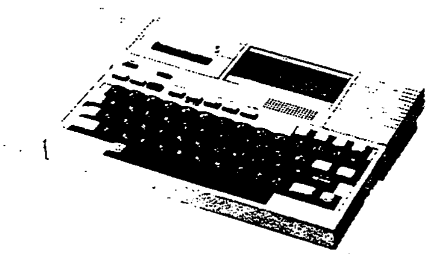


Fig. 3.12 DP-30

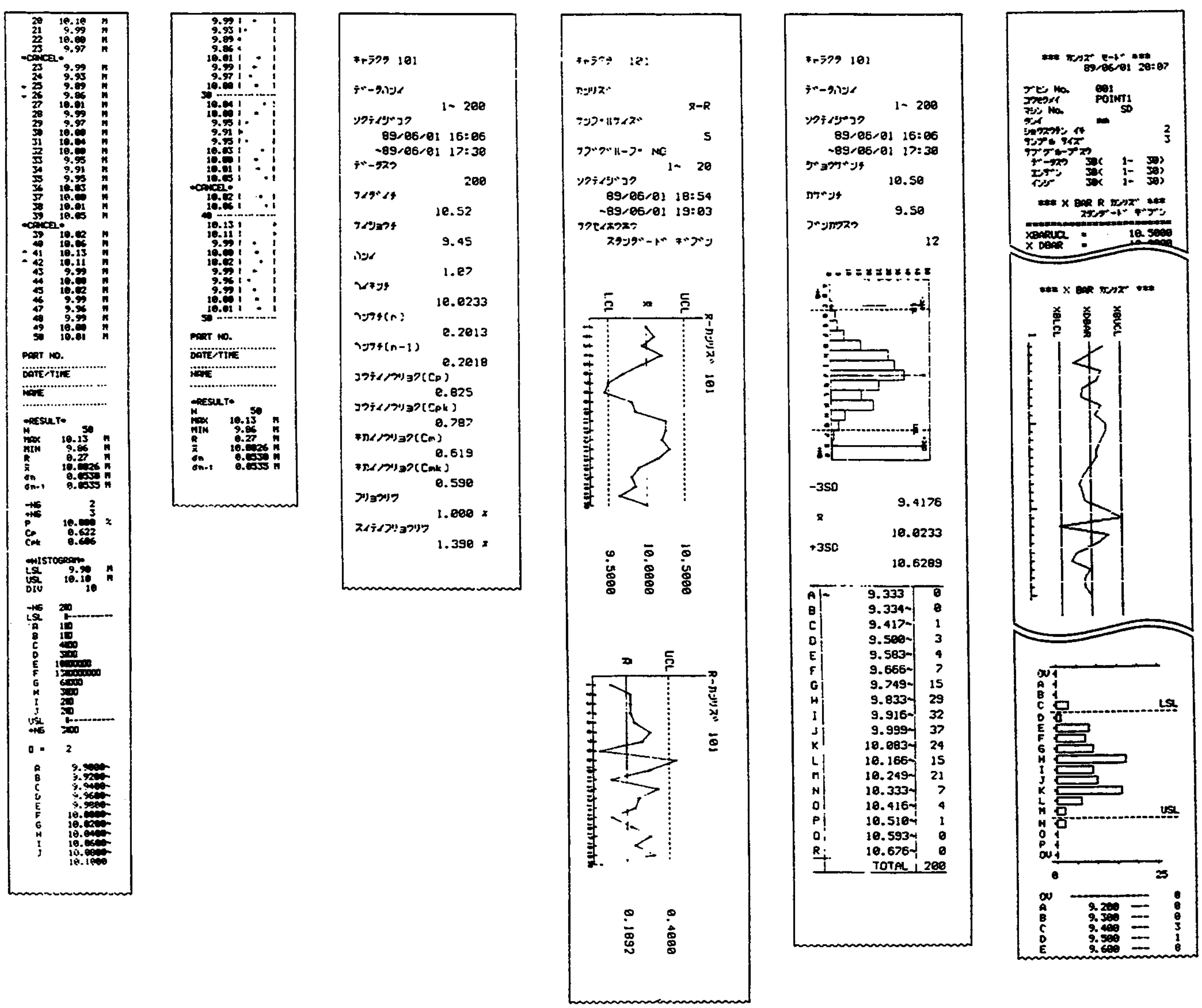


Fig. 3.13 Data processing examples

3.4 Special-purpose Calipers

As mentioned above, calipers have a wide range of applications. Some workpieces, however, have a complex shape that is difficult to measure with standard types of calipers. Many special-purpose calipers have been developed to solve these measuring problems. Descriptions of the principal types of special-purpose calipers follow.

3.4.1 Calipers with carbide measuring faces

The measuring faces of calipers are subject to wear. In order to increase abrasion resistance, some of the Mitutoyo M- and CM-type calipers have carbide-tipped inside and outside jaws. These types are suitable for measuring workpieces with rough surfaces, castings, and grinding stones.

3.4.2 Offset calipers

This type of caliper permits the jaw on the head end of the main scale to be vertically adjusted by loosening the clamp screw (**Fig. 3.14**). This makes it possible to measure dimensions on stepped workpieces, which cannot be measured with standard types of calipers.

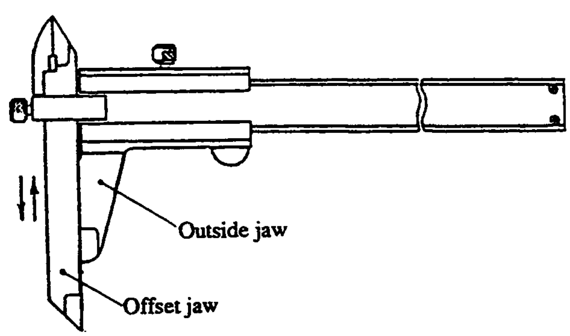


Fig. 3.14 Offset caliper

3.4.3 Swivel-jaw calipers

This type has a slider jaw that can be rotated by ±90° about an axis that is parallel with the line of measurement (**Fig. 3.15**). It can measure stepped workpieces and shafts having off-centered sections that cannot be measured with standard types of calipers.

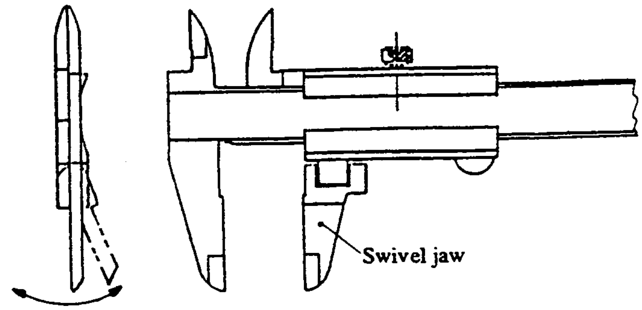


Fig. 3.15 Swivel-jaw caliper

3.4.4 Long-jaw calipers

This type is a modified design of the C- and CM-type calipers and has longer main scale and slider jaws than standard types of calipers (**Fig. 3.16**). It can measure inside diameters of deep holes and large outside diameters that cannot be measured with standard types of calipers. The standard jaw lengths of this type are 90mm for a measuring range of 300mm, and 200mm for a measuring range over 500mm.

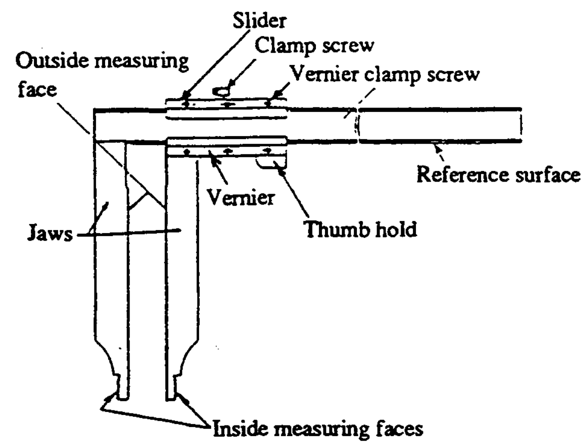


Fig. 3.16 Long-jaw caliper

3.4.5 Constant-force dial calipers

Plastic materials are now extensively used for machine parts and require accurate dimensional measurement. Because these materials are soft, they can be deformed by the measuring force of ordinary calipers and micrometers, resulting in inaccurate measurements. Constant-force dial calipers have been developed to measure materials that are easily deformed. **Fig. 3.17** shows a constant-force dial caliper.

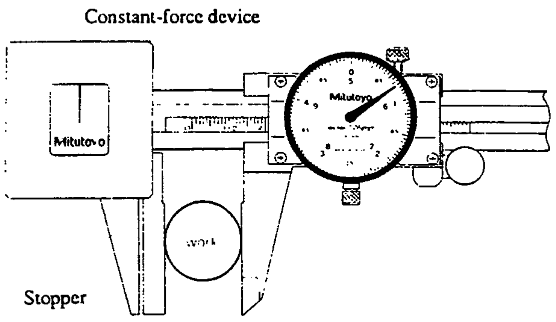


Fig. 3.17 Constant-force dial caliper

As shown in **Fig. 3.18**, the constant-force dial caliper is designed such that the main scale jaw and the main scale beam are not one piece; the main jaw is attached to the beam via parallel leaf springs, which apply a constant measuring force to the workpiece being measured. The main scale jaw is held by one end of the parallel springs, the other end of which is fixed to the main scale beam. When the workpiece touches the main scale jaw, it displaces the jaw by a small amount. The movement of the jaw is conveyed via the connecting pin, which is attached to the jaw, to the sector gear which rotates the pinion. When the pointer, which is attached to the pinion, points to the index line on the dial, a predetermined constant measuring force is applied to the workpiece to measure it accurately.

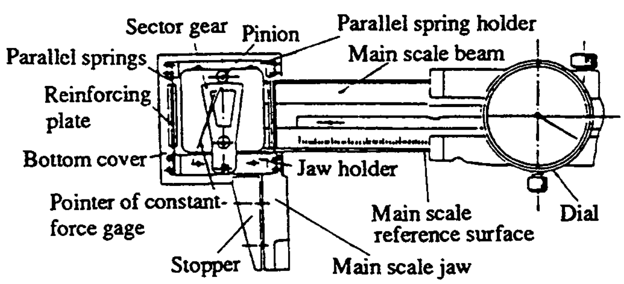


Fig. 3.18 Mechanism of constant-force dial caliper

The measuring operation is as follows:
Finely feed the slider by turning the thumb roller, the same way as for ordinary dial calipers. Bring the jaws into contact with the workpiece, and continue to turn the thumb roller until the pointer of the constant-pressure gage points to the index line. Then read the measurement.
Table 3.1 shows the specifications of the constant-force dial caliper.

Table 3.1 Specifications of constant-force dial caliper

Measuring range	0 – 180mm
Dial reading	0.05mm
Readout method	Dial
Measuring force (50 - 100gf)	0.5N – 1N
Maximum displacement of main scale jaw	0.2mm
Slider movement	By roller

3.4.6 Offset calipers for hole distance measurement

This type has cone-shaped jaws (cone angle: 40°) to measure the centerline distances between holes with the same or different diameters, between holes on different surfaces on a stepped workpiece, and the distance from a datum face to the center of a hole (**Fig. 3.19**).
Both the vernier and dial types are available. The measuring ranges are 10 - 150mm, 10 - 200mm, and 10 - 300mm.

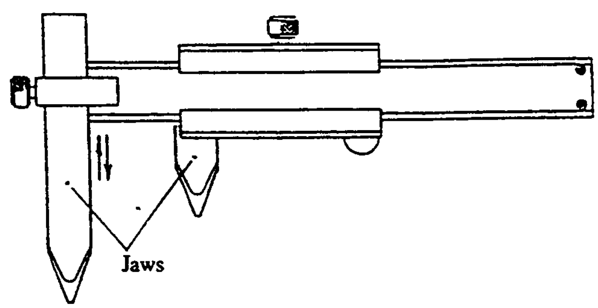


Fig. 3.19 Offset caliper for hole distance measurement

3.5 Construction of Main Scale and Vernier

Measurements on a vernier caliper are read by finding the vernier graduation that is aligned with a main scale graduation. However, the alignment position may vary depending on the viewing angle (parallax error). If a caliper is used in an adverse environment where the graduated face is exposed to cutting chips and dust, the graduations may become hard to read due to scratches or stains. Slider movement may become uneven also. In order to cope with these problems, many different types of main scale - vernier construction are available, as shown in **Figs. 3.20 - 3.25**.

3.5.1 Standard construction

This is the most common type of construction. As shown in **Fig. 3.20**, the edge of the graduated face of the vernier is in contact with the graduated face of the main scale. Parallax error is minimal, but the drawback of this construction is that the graduated face of the main scale is subject to damage caused by the movement of the slider.

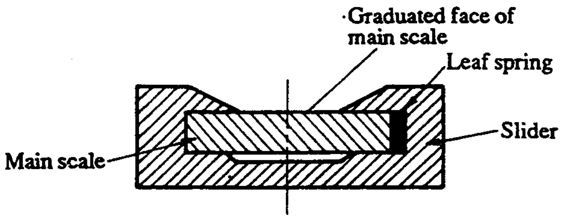


Fig. 3.20 Standard construction

3.5.2 Grooved construction

The graduated face of the main scale has grooves, as shown in **Fig. 3.21**. This construction allows smooth movement of the slider by reducing the friction between the main scale and the slider, and allows dust inside the slider to be collected in the grooves. A modified version of this type has a thin vernier graduation plate, which has a graduated face that is parallel with the graduated face of the main scale to minimize parallax errors (**Fig. 3.22**).

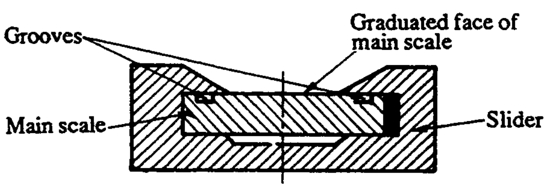


Fig. 3.21 Grooved construction

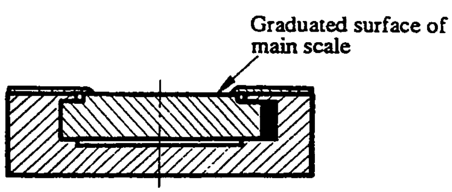


Fig. 3.22 Parallel graduated faces

3.5.3 Recessed construction

As shown in **Fig. 3.23**, the graduated face of the main scale is recessed by about 0.05mm. In this construction the edges of the vernier will not come into contact with the graduated face of the main scale, thus minimizing damage to the graduated face of the main scale. (This type has measuring ranges of up to 1000mm.)

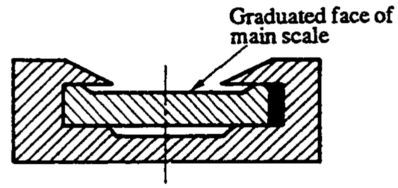


Fig. 3.23 Recessed construction

3.5.4 Flush-fit construction (Parallax-free graduated faces)

As shown in **Figs. 3.24** and **3.25**, the graduated faces of the main scale and vernier are flush with each other. The graduations of the two surfaces face each other. This construction eliminates parallax errors. The flush type 2 (**Fig. 3.25**) is sometimes referred to as the diamond type because of its cross-sectional shape.

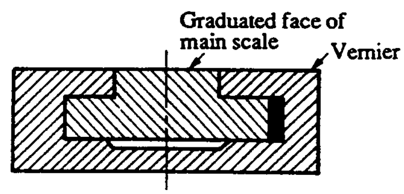


Fig. 3.24 Flush type (1)

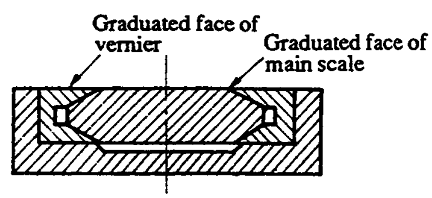


Fig. 3.25 Flush type (2) (Diamond type)

4. MATERIALS OF CALIPERS

Two major quality requirements for the caliper material are; (a) abrasion resistance on the measuring and sliding faces, and (b) corrosion resistance.
To satisfy these two requirements, the caliper is made from hardened stainless steel. Because hardened, high carbon stainless steel is superior in hardness but inferior in corrosion resistance to ordinary stainless steel, the material generally used to construct calipers is chromium13-based stainless steel with a 0.25 - 0.40% carbon content. For the main scale and the slider, materials such as SUS 420 J2 of JIS G 4303 and SK6 of JIS G 4401 or materials with equal or superior performance are used.

5. JIS SPECIFICATIONS FOR CALIPERS

5.1 Hardness

The measuring faces of calipers should have a hardness of not less than Hv 550, when stainless steel is used, or Hv 700, when another material is used. The hardness is measured either on the measuring face or on a side face within 2mm of the measuring face.

5.2 Graduation Lines

The graduation lines on vernier calipers should have the widths specified in **Table 5.1**. The width of all graduation lines on the main scale and vernier scale should not differ by more than 30μm.

Table 5.1 Width of graduation lines

Discrimination	Width of graduation line
0.05mm	80 – 200μm
0.02mm	80 – 150μm

5.3 Instrumental Errors

Table 5.2 shows the permissible instrumental errors.

5.4 Straightness of Measuring Faces

The straightness of both the outside and inside measuring faces of calipers should be within 0.01mm per 100mm of the measuring face.

Table 5.2 Permissible instrumental errors of vernier calipers

Unit: mm

Measuring range \ Discrimination	0.1	0.05	0.02
0	±0.05	±0.05	±0.02
Over 0 to 100 incl.			±0.03
Over 100 to 200 incl.			
Over 200 to 300 incl.		±0.08	±0.04
Over 300 to 400 incl.	±0.10		
Over 400 to 500 incl.		±0.10	±0.05
Over 500 to 600 incl.			
Over 600 to 700 incl.	±0.15	±0.12	±0.06
Over 700 to 800 incl.			
Over 800 to 900 incl.		±0.15	±0.07
Over 900 to 1000 incl.			

Values specified in this table are for a temperature of 20°C.

5.5 Gap Between Measuring Faces

When the jaws are closed and the two outside measuring faces touch each other, the gap between the faces should not exceed 5μm (a gap that can be determined by recognizing the interference color caused by the diffraction of light).

5.6 Overall Errors of Calipers

The overall error takes every possible individual error into account. It is defined as the estimated error (uncertainty in measurements) when a workpiece made of metal or an equivalent material is measured under conditions that are close to standard conditions, with a caliper that has an instrumental error within a specified tolerance. In other words, the overall error is the maximum error when dimensions close to the maximum measuring range are measured. The overall errors of calipers should not be greater than the values given in **Table 5.3**.

Table 5.3 Overall errors

Unit: mm

Measuring range \ Discrimination	0.1	0.05	0.02
150	±0.1	±0.08	±0.05
200	±0.1	±0.08	±0.05
300	±0.1	±0.10	±0.06
600	±0.15	±0.13	±0.08
1000	±0.20	±0.18	±0.11

5.7 Zero Point Error of Depth Bar

In calipers with a depth bar, the error at the zero point should not exceed 0.02mm.

5.8 Step Between Graduated Faces

The distance (step) between the graduated face of the main scale and the bevelled edge of the graduated face of the vernier should not exceed 0.3mm.

5.9 Construction and Functions

(1) The maximum peak-to-valley height (Rmax) of the surface roughness of the measuring face should not exceed 1.6μm.

(2) The parallelism between the outside and inside measuring faces should be within the absolute value of the permissible instrumental error, and should not affect practical use.

(3) The distance between the planes of the outside jaw of the main scale beam and the outside jaw of the slider should not affect practical use.

(4) The slider should slide smoothly, free from looseness, over the entire range of operation.

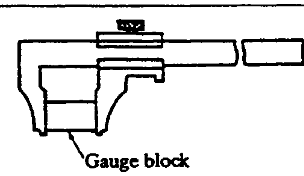
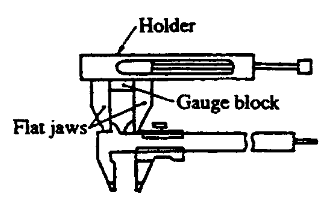
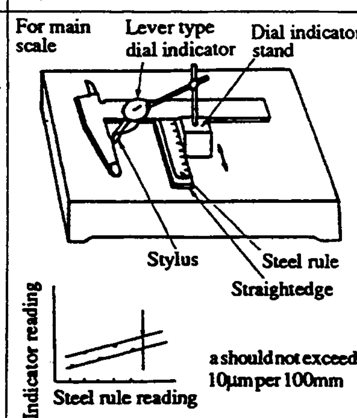
(5) It should be possible to securely clamp the slider and fine feed device to the main scale beam with the clamping device.

(6) The fine feed screw should operate smoothly. The play felt in the screw should not affect practical use.

6. MEASURING METHODS TO EVALUATE CALIPER PERFORMANCE

The performance of a caliper is checked according to the procedures in **Table 6.1**.

Table 6.1 Measuring methods to evaluate caliper performance

No.	Item	Measuring method		Measuring instrument
1	Instrumental error of outside measurement	Insert a gauge block between the two outside measuring faces. Measure it at the root and tip of the measuring faces. Determine the instrumental error by reducing the dimension of the gauge block from the reading on the caliper.		Grade 1 gauge block specified in JIS B 7506
2	Instrumental error of inside measurement	Measure the internal dimension which has been set using a gauge block and accessories by the inside measuring faces. Determine the instrumental error by reducing the dimension of the gauge block from the reading on the caliper.		Grade 1 gauge block specified in JIS B7506 Holder and Type A flat jaws are accessories of the gauge block and are given in the Appendix of JIS B7506
3	Straightness of inside and outside measuring faces	Set a lever type dial indicator on a surface plate so that its contact point can move in parallel with the outside and inside measuring faces of the caliper. Measure the straightness of the outside measuring faces by sliding the dial indicator stand. Measure the straightness of the inside measuring faces in the same manner.		Steel rule specified in JIS B 7515 Grade 1 precision surface plate specified in JIS B 7513 Lever type dial indicator specified in JIS B 7533 (Graduation: 0.002mm) Grade A (or higher grade) straightedge specified in JIS B 7514 Dial indicator stand
4	Clearance between measuring faces	Visual test		

7. MEASUREMENT ERRORS OF CALIPERS

The following factors affect the measuring accuracy of calipers:

(1) Errors inherent to the construction of the caliper
(2) Parallax error
(3) Environmental conditions and measuring force

7.1 Errors Inherent to the Construction of Calipers

7.1.1 Abbe's error

In 1890, Ernst Abbe formalized what is now known as Abbe's principle, which states: "maximum accuracy may be obtained only when the standard is in line with the axis of the object being measured." The construction of calipers does not conform to Abbe's principle. **Fig. 7.1** shows a case where the graduations of the main scale are on the extension of the line of measurement. The diameter, *L*, of the workpiece is measured as *R*, on the caliper. If the axis of the spindle makes angle θ with the line of the measurement, the error in this measurement is calculated as follows:

$$L - R = -\delta$$
$$L = R\cos\theta$$
$$R = \frac{L}{\cos\theta} \approx L\left(1 + \frac{\theta^2}{2}\right)$$
$$\therefore \delta = -L + L\left(1 + \frac{\theta^2}{2}\right) = \frac{1}{2}L\theta^2$$

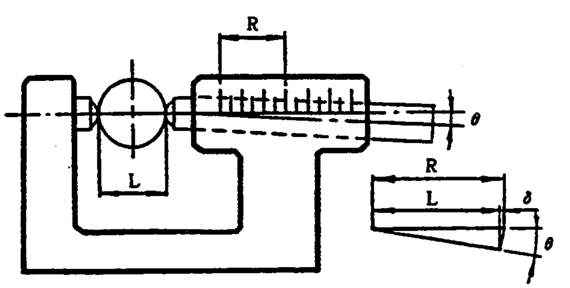


Fig. 7.1 Abbe's principle

Thus, as long as Abbe's principle is satisfied, the measurement error, d, is negligible in many cases because the value θ^2 is small enough.

Fig. 7.2 shows measurement using a caliper. The workpiece is placed between the jaws on a line at a distance, *h*, from main scale *A*. Suppose that jaw *B* is tilted by angle θ due to the fitting clearance between the slider and the main scale and that the diameter, *L*. of the workpiece is read as *R* on the main scale. Note that the value *R* includes an additional error, δ_2, that arises because jaw *B* touches the workpiece at a point that is a distance *h'* below the diameter to be measured. Thus, the error in this measurement is calculated as follows:

$$L = R + \delta_1 + \delta_2$$

where,

$$\delta_1 = (h - h')\tan\theta = (h - h')\theta$$
$$h' = L\theta$$
$$\delta_2 = L(1 - \cos\theta) = L\frac{\theta^2}{2}$$
$$\therefore L = R + (h - L\theta)\theta + \frac{1}{2}L\theta^2$$
$$L - R = h\theta - \frac{1}{2}L\theta^2$$

As the value θ is small, the value θ^2 may be ignored. Therefore, the measurement error can approximately be expressed as:

$$L - R \approx h\theta$$

This means that in order to increase accuracy in caliper measurement, (1) the fitting clearance between the slider and the main scale should be minimized to make the angle θ small, and (2) the workpiece should be measured in a position as close to the main scale as possible.

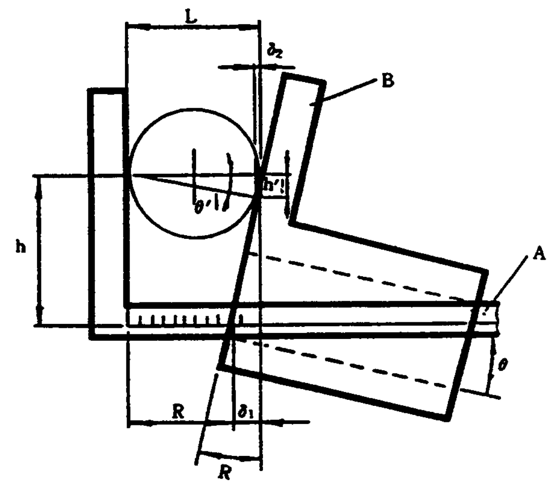


Fig. 7.2 Abbe's error for calipers

7.1.2 Error caused by flexure of the main scale beam

The main scale of vernier calipers may bend in two directions, both of which affect measuring accuracy.
(1) Bends along the reference face
(2) Bends along the graduated face

7.1.2.1 Bends along the reference face

As shown in **Fig. 7.3**, a measurement error will result if the main scale's reference face (the side face that serves as the reference to guide the slider) is bent. This error can be expressed by the formula to determine Abbe's error, as follows:

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

Example: If the straightness error of the slider motion, caused by a bent reference face, is 0.010mm/50mm and a dimension of 50mm is measured by the tips of 40mm-long outside measuring jaws, the resultant error, f, is obtained as follows:

$$f = 40\text{mm} \times 0.01 \div 50 = 0.008\text{mm}$$

Thus, a bent reference face caused by careless handling or improper use as well as wear on the reference face significantly affects the measuring accuracy. Measuring with a large-size caliper or long-jaw caliper requires special consideration in supporting the caliper (e.g., calipers should be supported as close to Bessel points as possible).

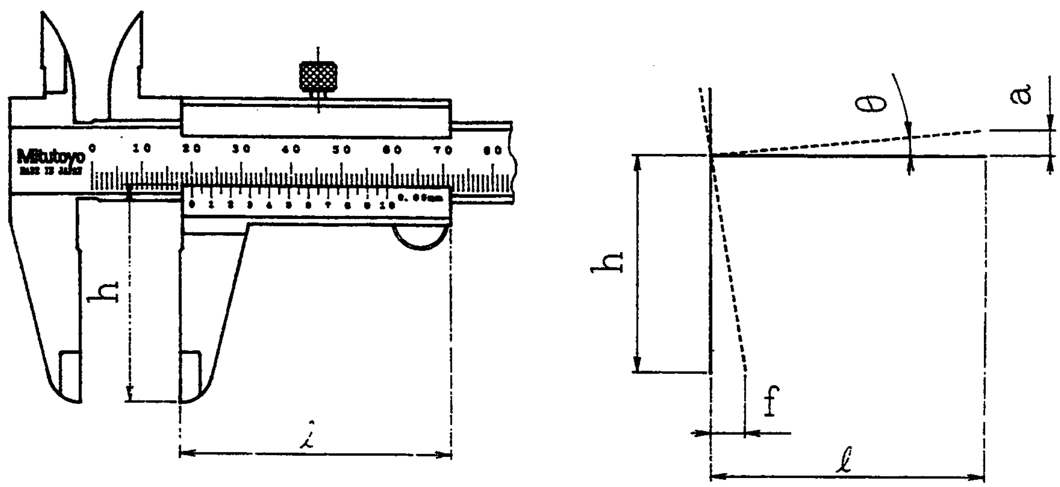


Fig. 7.3 Error due to bent reference face on main scale

7.1.2.2 Bends along the graduated face

Bent graduated faces of the main scale also cause measurement errors. In this case, arc length, l_2, is obtained, instead of the required linear length, L, as shown in **Fig. 7.4**. The resultant error, E, is given as:

$$E = l_2 - L$$
$$(R_1 - d)\tan\frac{\theta}{2} = \frac{L}{2}$$
$$R_1 = \frac{d^2 + (L/2)^2}{2d}$$
$$R_2 = R_1 + t$$
$$l_2 = R_2\theta = (R_1 + t)\theta$$

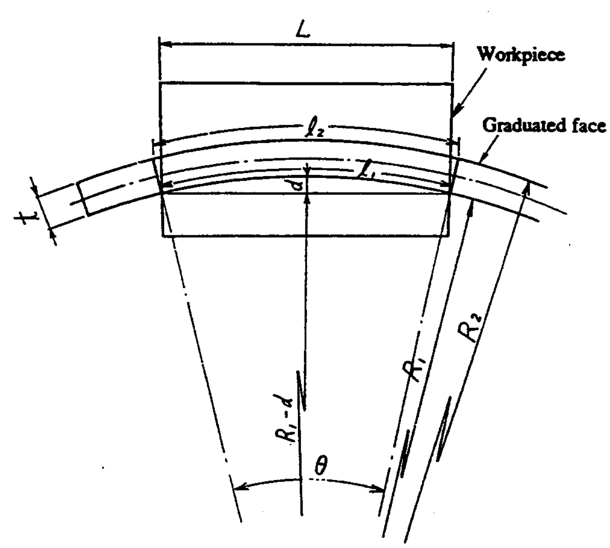


Fig. 7.4 Error due to bent graduated face on main scale

Example: If the bend along the graduated face is 0.05mm/50mm and a dimension of 50mm is measured with a caliper that has a 3mm thick main scale, the resultant error, E, is obtained as follows:

(L = 50mm d = 0.05mm t = 3mm)
R_1 = 6250mm R_2 = 6253mm θ = 0.008 (RAD)
l_2 = 50.024mm
$\therefore E = l_2 - L = 0.024$mm

When the formulas are applied to the neutral surface of the beam, the error is calculated to be 0.012mm.
The calculation shows that a bent graduation face is less significant, and indeed less likely to cause measurement errors than a bent reference face. However, sufficient care should be taken because the main scale is more liable to be bent or deformed along the graduated face due to careless handling.

7.1.3 Wear on the jaws

Because the tip of the jaws on the M-type calipers are thin (for measuring narrow grooves), they are subject to greater wear. In order to minimize wear, use the portion of the jaws that is closest to the main scale whenever possible.

7.1.4 Errors in inside diameter measurement

Measurements made with M-type vernier calipers, which measure inside diameters with the inside jaws, involve measurement errors that are inherent to the design of the jaws. These errors are more significant when measuring small holes. In this measurement, dimension d_1 is obtained instead of the actual dimension, d, as shown in **Fig. 7.5**. In this case, thicknesses t_1 and t_2 of the inside measuring faces, and the clearance C between the main scale jaw and the slider jaw greatly affect the measuring accuracy. **Table 7.1** shows the errors calculated for different values of B (= t_1 + t_2 + C) between 0.3mm and 0.7mm in 0.1mm increments. **Graph 7.1** shows an error curve when B is constant (0.7mm).
As shown above, when measuring inside diameters, especially those of small holes, it is necessary to take these errors into consideration and make necessary compensations.
Graph 7.2 shows error curves with reference to different jaw clearances and thicknesses when a hole diameter of 10mm is measured.

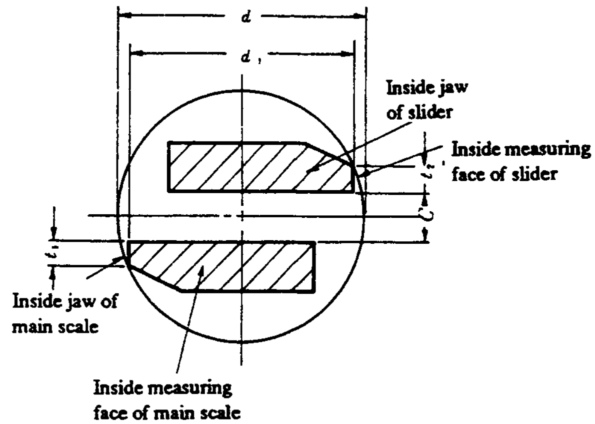


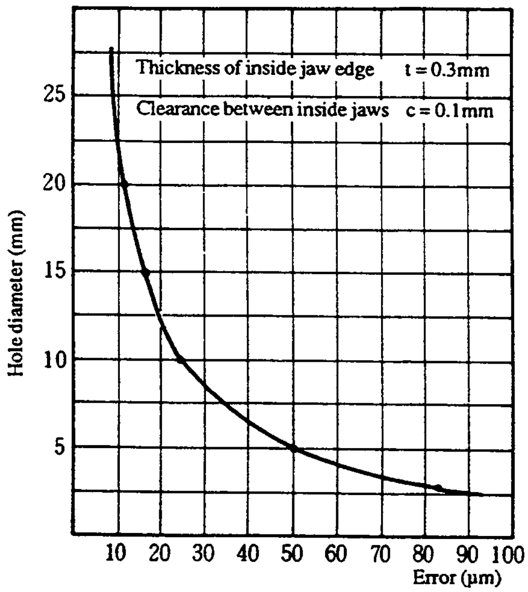
Fig. 7.5 ID measurement using inside jaws of M-type caliper

Table 7.1 Small hole measurement errors
(Relative to offset of measured points from hole center line)

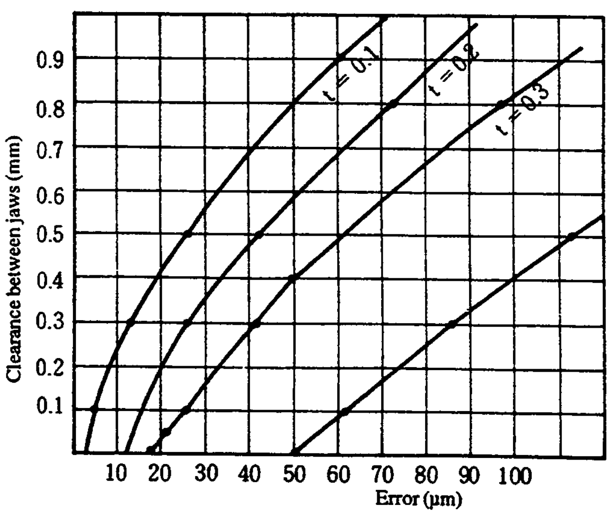
Unit: mm

Hole diameter	Offset from hole center line B (B = t_1 + t_2 + C)				
	0.3	0.4	0.5	0.6	0.7
1.5	0.030	0.050	0.090	0.12	0.17
2	0.023	0.041	0.060	0.09	0.13
2.5	0.018	0.032	0.050	0.07	0.10
3	0.015	0.027	0.042	0.06	0.08
3.5	0.013	0.023	0.036	0.05	0.07
4	0.011	0.020	0.031	0.045	0.06
4.5	0.010	0.017	0.028	0.038	0.05
5	0.009	0.014	0.026	0.033	0.047
6	0.008	0.013	0.021	0.029	0.041
7	0.007	0.011	0.018	0.026	0.036
8	0.007	0.010	0.016	0.023	0.033
9	0.006	0.009	0.013	0.020	0.028
10	0.005	0.008	0.012	0.017	0.023

Graph 7.1 Hole diameter vs. measurement error



Graph 7.2 Clearance between inside jaws vs. measurement error when measuring a hole dia. of 10mm (t: Thickness of inside jaw edge)



7.2 Vernier Reading and Parallax

The following factors can produce errors in vernier scale readings:

(1) Graduation error (one type of instrumental error)

(2) The eye's ability to recognize the alignment of two graduations

(3) Parallax

7.2.1 The eye's ability to recognize the alignment of two graduations

The scale of vernier calipers must be read by the human eye. There are three aspects that affect the eye's ability to read scales: recognizing power, visual acuity, and resolving power (resolution).

Recognizing power: The ability to recognize the shape of an object. (Multiple visual cells are stimulated)

Visual acuity: The ability to perceive existence of an object without shape recognition. (A single visual cell is stimulated.)

Resolving power: The ability to distinguish two proximate objects as two separate objects. (This is most closely related to measurement.)

(1) Resolving power of the eye

The lens of the eye focuses unconsciously. When an object is brought into focus at the distance of distinct vision (250mm), the distance from the lens to the retina is about 15.5mm (Fig. 7.6).

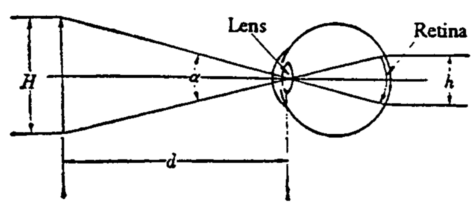


Fig. 7.6 Structure of eye

As mentioned above, the ability of the eye to distinguish two separate points or lines close to each other is called the resolving power. E. Hering, a German physiologist and psychologist, explained the resolving power of the human eye from the structure of the eye. In order for the eye to distinguish separate points, the two points must be far enough apart that between the stimulated visual cells that sense the points, there is at least one cell that is not stimulated. To meet this condition, the distance, h, in **Fig. 7.7** is required. The average size of the cells located near the center of the retina is about 5μm. This corresponds to a visual angle of 1', which is equivalent to 0.06mm at the distance of distinct vision.

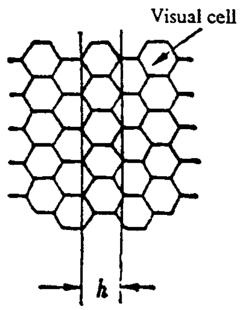


Fig. 7.7 Resolving power

Measurements on a caliper are taken by finding a main scale graduation that is aligned with a vernier graduation. The ability to recognize whether or not two proximate lines align with each other is called the recognition power of two-line alignment. The relationship between distance *h'*, in **Fig. 7.8**, and distance *h*, mentioned in section **7.1.2**, is $h = 2\sqrt{3}\,h'$. Hence distance *h'*, is calculated to lie between 0.012mm and 0.017mm for objects that are at the distance of distinct vision. This explains why vernier instruments permit a reading of 0.02mm. Thus the recognition power of two-line alignment, or vernier acuity, is much superior to the resolving power of the eye.

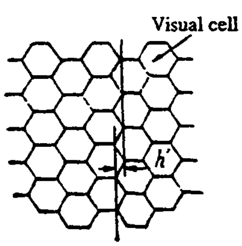
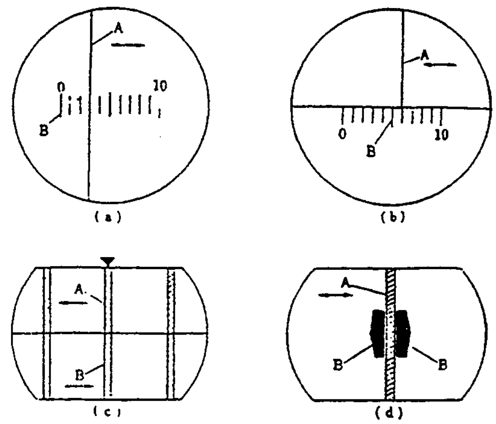


Fig. 7.8 Recognition power of two-line alignment

(2) Experimental data on recognition power of two-line alignment

In 1960, W. Moser verified in his report contributed to *Microtechnic* that a simple alignment of two lines (as in a vernier reading) can be recognized to an accuracy of 0.02mm (**Fig. 7.9** and **Table 7.2**).



(a) Simple superposition (b) Simple alignment
(c) Double alignment (d) Symmetrical division

Fig. 7.9 Types of alignment

Table 7.2 Alignment recognition power (by W. Moser)

	Fig. 7.9	Alignment recognition power at distance of distinct vision		Required amplification for specific measuring accuracies	
		sec	Length (μm)	0.001mm	0.01mm
Simple superposition	a	±63	±80	80	8
Simple alignment	b	±16	±20	20	2
Double alignment	c	± 8	±10	10	1
Symmetrical division	d	± 5	±6.5	6.5	0.65

7.2.2 Parallax error

Because the graduated faces of the main scale and vernier of a caliper are usually not on the same plane, parallax can cause errors in finding the graduations that are aligned with each other.

In **Fig. 7.9**, we consider the parallax error when there is a height difference, *h*, between the graduated face of the main scale and the graduated edge of the vernier. If the eyes are at position *A"*, which is right above the matching graduations, no parallax error will occur.

However, the eye position is usually shifted, to the left or right, when taking a measurement with one eye closed. In addition, most people have different visual acuities between the left and right eyes. For these reasons, a parallax error tends to occur. Referring to **Fig. 7.10**, the parallax error, ΔS, is given by the following formula:

$$\Delta S = \frac{bh}{a}$$

This indicates that the smaller the value h, the smaller the parallax is. However, the value h is limited by the construction of the caliper. It is also difficult to position the eyes right above the matching graduations. If the graduations are seen at the distance of distinct vision (250mm), assuming that the distance between the left eye and right eye is 60mm, and the difference in height between the vernier and main scale is 0.2mm, then the parallax error is calculated as follows:

$(b = 30mm \quad h = 0.2mm \quad a = 250mm)$

$\Delta S = 0.024mm$

The above calculation supposes that the face is positioned directly above the caliper. The parallax error will be greater when the face is shifted in either direction. Parallax errors can be minimized through experience.

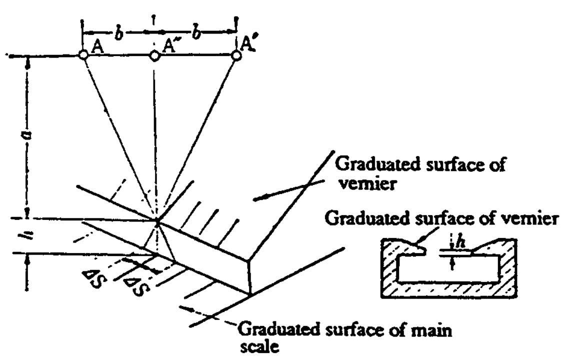


Fig. 7.10 Parallax error of caliper

7.3 Environmental Conditions and Measuring Force

In addition to the causes of error mentioned above, there are many other factors that can cause significant errors, such as the environmental conditions and the method of use. The major factors are discussed below.

7.3.1 Thermal expansion

Objects will expand or contract with temperature changes. Lengths of objects are determined at the internationally adopted standard temperature of 20°C. If the thermal expansion coefficients and temperatures of the workpiece and the measuring tool are the same, a measurement error will not result even if the measurement is taken at a temperature other than 20°C.

If there is a temperature difference, Δt, between the caliper and the workpiece, the measurement error, f, is given by the following formula:

$$f = \Delta t \times \alpha \times L$$

where

α: Thermal expansion coefficient (/°C)

L: Measured length

If the thermal expansion coefficients of the caliper and the workpiece are different and there is no temperature difference between the two, the following formula applies:

$$f = (t - 20°C)(\alpha_1 - \alpha_2) L$$

where

t: Temperature (°C)

α_1: Thermal expansion coefficient of workpiece

α_2: Thermal coefficient of caliper

If both the expansion coefficients and the temperatures are different, the following formula applies:

$$f = \{(t_1 - 20°C)\alpha_1 - (t_2 - 20°C)\alpha_2\} L$$

where

t_1: Workpiece temperature

t_2: Caliper temperature

Example: Consider the case where a brass part is measured on a shop floor where the temperature is very high, and assume that the temperatures of the caliper and the workpiece are the same.

Letting

$t = 35°C$, $\alpha_1 = 18.5 \times 10^{-6}/°C$, $\alpha_2 = 11.5 \times 10^{-6}/°C$, $L = 380mm$

Then,

$$f = 15 \times (18.5 - 11.5) \times 10^{-6} \times 380mm = 0.04mm$$

This example shows that the temperature seldom presents a serious problem in ordinary measurement. Normal considerations will be sufficient; e.g. minimize the temperature difference between the caliper and the workpiece, and avoid extremely high or low temperatures when measuring non-ferrous, metal workpieces.

7.3.2 Measuring force

Unlike micrometers, vernier calipers are not provided with a mechanism that ensures a constant measuring force. Therefore, the measuring force will vary each time a measurement is made (especially with different users).

The degree of smoothness of the vernier motion along the main scale greatly affects the measuring force of a caliper. When measuring a workpiece using a caliper, the workpiece is held between the jaws of the main scale and the slider with a certain force. The user's fingers hold the vernier with force, Q, which is the sum of forces, P and R, which are the force exerted on workpiece by the jaws and the frictional force that exists between the main scale and the vernier, respectively ($Q = P + R$).

There is a clearance between the sliding faces of the main scale and the vernier where a leaf spring (typically made of phosphor bronze) is installed. If an excessive force is applied to the workpiece by the jaws, the leaf spring will bend, causing the slider jaw to tilt and thus resulting in a measurement error. To minimize errors, the following precautions must be observed:

(1) The slider must move smoothly.
(2) Do not apply an excessive measuring force.
(3) Measure the workpiece using the portion of the jaws that are closest to the main scale.

8. MAINTENANCE OF CALIPERS

Although calipers are often used under hostile environments, their maintenance tends to be overlooked because of the simple construction and low accuracy requirements. In order to obtain the best possible performance from calipers and to ensure economical use, it is essential to implement effective maintenance control. As with other types of measuring instruments, calipers should have standardized rules that govern purchasing, training, handling, storage, maintenance, and periodic inspection.

8.1 Purchase

An effective method of maintenance control for measuring tools, such as calipers, that are frequently used on the shop floor, is to limit the number of tools in the tool room and on the shop floor. Although calipers are not very expensive, they are not consumables and should not be treated as such. When purchasing a caliper, its service life should be considered. The type, size and accuracy of the caliper should be selected according to your specific application. For example, if an application requires a discrimination of 0.05mm, and a vernier caliper with a discrimination of 0.02mm is purchased, it is uneconomical and increases the inspection time. On the other hand, inspection procedures must be standardized when the caliper is purchased.

8.2 Storage

Observe the following precautions when storing calipers:

(1) Select a place where the calipers will not be subjected to dust, high humidity, or extreme temperature fluctuations.
(2) When storing large-size calipers, which are not frequently used, apply a rust preventive to the sliding and measuring faces and separate the two measuring faces.
(3) At least once a month, check the storage condition and sliding movement of calipers that are seldom used and kept in storage.
(4) Prevent vapors from chemicals such as hydrochloric acid or sulfuric acid, from permeating storage rooms where calipers are stored.
(5) Lay calipers so that the main scale beam will not bend and the vernier will not be damaged.
(6) Keep a record of calipers that are stored and lent-out to the shop floor with check-out slips.
(7) Put a person in charge of calipers that are stored in tool boxes and on racks that are on the shop floor.

8.3 Periodic Inspection

Periodic inspections of calipers should be carried out once or twice a year, depending on the frequency of use. Inventory control methods should be implemented to prevent inadvertent use of calipers in need of repair and those to be disposed of. There are two systems of making periodic inspections; one is to inspect the calipers at each work site, the other is to collect all the calipers, at certain intervals, and inspect them all at once. All personnel who use calipers in the work place should be informed of the inspection system.

9. PRECAUTIONS WHEN MEASURING WITH A CALIPER

Observe the following precautions when measuring with a caliper:

(1) Before taking measurement, remove cutting chips, dust, burrs, etc. from the workpiece.

(2) When measuring, slowly move the slider while lightly pressing the finger hold against the main scale.

(3) Measure the workpiece using the portion of the jaw that is closest to the main scale.

(4) Do not use an excessive measuring force when making inside measurements with CB- and CM-type vernier calipers, which use the jaw tips for inside measurement.

(5) Never attempt to measure a rotating workpiece.

(6) After using a caliper, wipe it clean and store it with the outside jaws slightly opened.

– MEMO –

HEIGHT GAGE

1. OUTLINE

The height gage, as its name may indicate, is a device for measuring the height of a workpiece. It is also used as a scribing tool. As the vernier caliper was developed by combining a pair of calipers and a scale with a vernier for quick and accurate measurement, the height gage was developed by combining a rule, a rule stand and a surface gage. The vernier height gage incorporates a vernier to provide accurate readings.

2. SCALE GRADUATIONS

The standard graduations of vernier height gages are shown in **Table 2.1** and **Fig. 2.1.** There is also a type which has a main scale that is graduated in 0.5mm increments, which is rarely used nowadays. The most common vernier graduations of height gages are 0.02mm for the metric system, and 0.001" for the inch system. Some height gages have both metric and inch graduations.

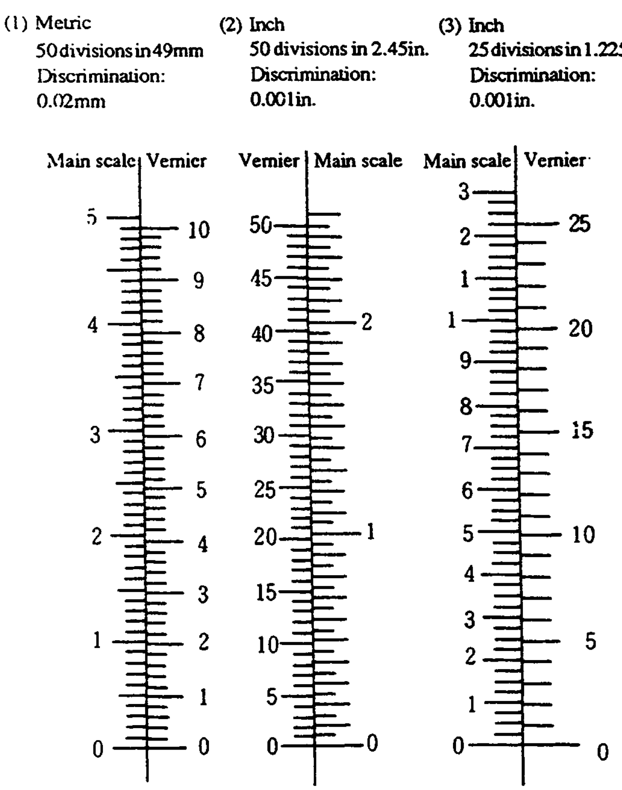


Fig. 2.1 Graduation types

Table 2.1 Height gage scale graduations

	Graduation		Discrimination
	Main scale	Vernier	
Metric	1.0mm	50 divisions in 49mm	0.02mm
	1.0mm	20 divisions in 19mm	0.05mm
	1.0mm	20 divisions in 39mm	0.05mm
Inch	0.025in.	25 divisions in 1.225in.	0.001in.
	0.05in.	50 divisions in 2.45in.	0.001in.

3. TYPES OF HEIGHT GAGES

Height gages are classified into the following types, according to the readout system:

- Vernier type
- Dial type
- Dial type with counter
- Digital type

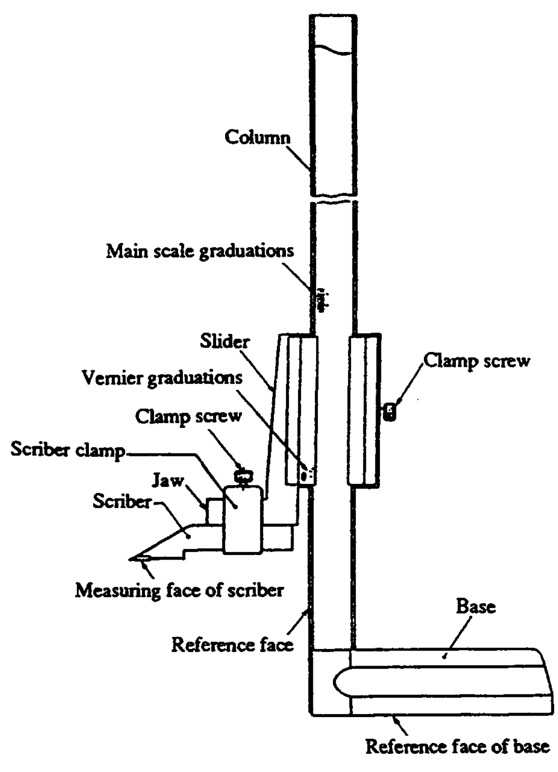


Fig. 4.1 Vernier height gage

4. CONSTRUCTION

4.1 Vernier Height Gage

Fig. 4.1 shows the basic construction of the vernier height gage. It has a mechanism (**Fig. 4.2**) for vertically feeding the scale and a fine feed mechanism (**Fig. 4.3**) for the slider.

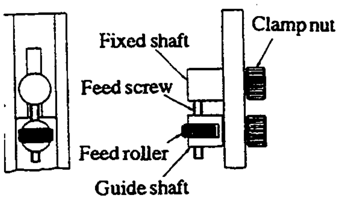


Fig. 4.2(a) Scale feed mechanism

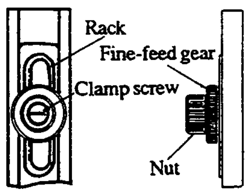


Fig. 4.2(b) New Scale feed mechanism*

* Utility model (pending)

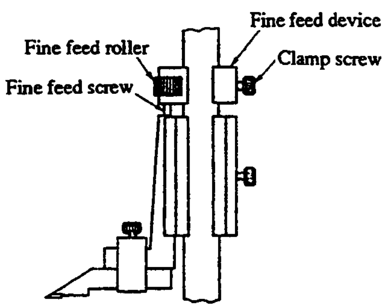


Fig. 4.3 Fine feed mechanism

4.2 Dial Height Gage

The main disadvantages of the vernier height gage are that readings take time and involve parallax errors because measurements are taken by finding a graduation on the main scale that is aligned with a graduation on the vernier scale. The dial height gage (**Figs. 4.4** and **4.5**) solves these problems by incorporating the amplification mechanism of the dial indicator into the height gage. Dial height gage measurements are taken by adding the reading on the main scale graduation to the reading on the dial, which indicates the fraction of the main scale reading with a pointer. This minimizes parallax errors and allows quick and accurate measurements. **Fig. 4.6** shows the amplification mechanism of the dial height gage (one rotation of the pointer corresponds to a 2mm displacement).

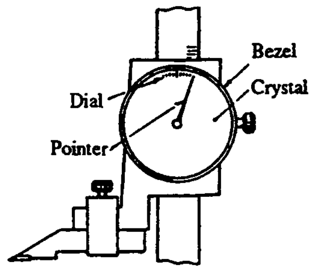


Fig. 4.4 Dial height gage

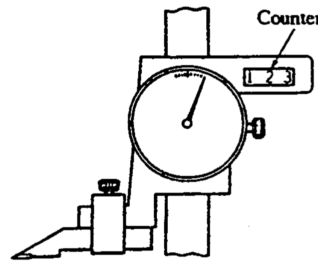


Fig. 4.5 Dial Indicator with counter

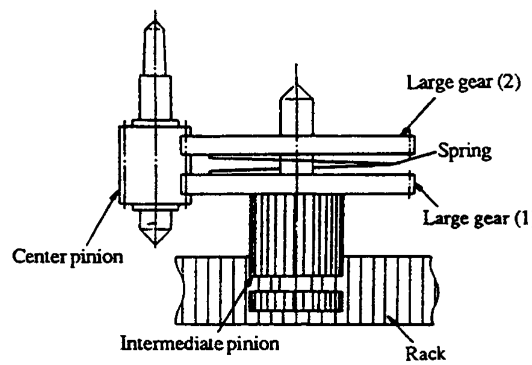


Fig. 4.6 Amplification mechanism

4.3 Digimatic Height Gage

Like other Digimatic measuring tools, such as Digimatic Calipers and Micrometers, many types of Digimatic Height Gages (Mitutoyo digital height gage series) have been developed and marketed. The Digimatic Height Gages are broadly classified into two types. One type (the HD and HDM series) uses a rotary encoder for displacement detection and has a double column, and the other type (the HDS and HDF series) uses the capacitance type displacement detector – the same system adopted by Digimatic Calipers – and has a single square column.

4.3.1 Rotary encoder type

4.3.1.1 Series names and outline

There are two types; the HD series (standard type) and the high-performance HDM series.

(1) HD series

The HD series, which was the first Digimatic Height Gage series to be developed, is the standard and most popular type. Gages in this series have all the basic functions, including zero setting, display holding, presetting (for the uppermost digit), miscount error indication, and battery check.

(2) HDM type

The HDM series Digimatic Height Gages are equipped with many advanced functions, including data output and ABS (origin restoration) functions. The data output function allows printing, go/nogo judgments, statistical analyses, and histogram generation when connected to a data processor such as a DP-1DX or a DP-2DX, thus greatly increasing the efficiency of data processing and recording. The ABS function permits the absolute origin to be restored so that the distance from the origin can be determined, even after zeroing the display at any scriber position. For example, after zeroing the display for a step measurement, the height from the reference face can be instantly determined, which greatly improves the measuring efficiency.

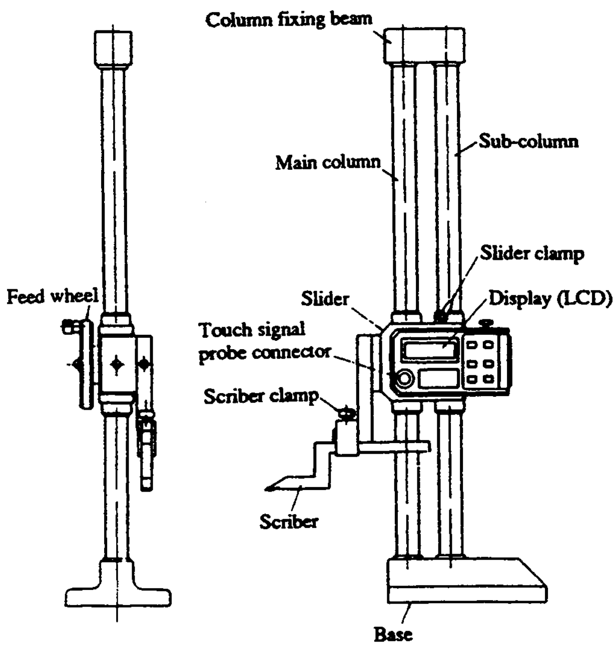


Fig. 4.7 Digimatic Height Gage HDM

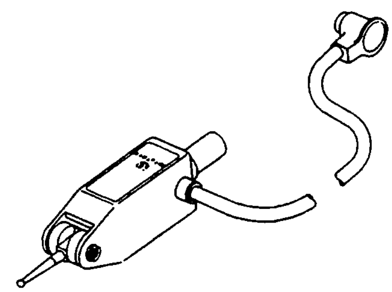


Fig. 4.8 Two-directional touch signal probe

4.3.1.2 Specifications

The table below shows the specifications of the HD and HDM series Digimatic Height Gages.

Table 4.1 Digimatic Height Gage specifications (HD and HDM series)

Order No.	Code No.	Measuring range (mm)	Resolution (mm)	Zero setting	Presetting	Data hold	Two-directional touch signal probe	Data output	ABS function	Error indication	Battery check	Power source	Battery life (at 20°C)
192-601	HD-30	0–300	0.01	O	O(1 digit)	O				O	O	LR6x3	500 (h)
192-603	HD-60	0–600	0.01	O	O(1 digit)	O				O	O	LR6x3	500 (h)
192-604	HD-100	0–1000	0.01	O	O(1 digit)	O				O	O	LR6x3	500 (h)
192-621	HHD-30	0–300	0.01	O	O(All digits)	O	O			O	O	LR6x3	900 (h)
192-651	HDM-30	0–300	0.01	O	O(All digits)	O	O	O	O	O	O	LR6x3	900 (h)
192-653	HDM-60	0–600	0.01	O	O(All digits)	O	O	O	O	O	O	LR6x3	900 (h)
192-654	HDM-100	0–1000	0.01	O	O(All digits)	O	O	O	O	O	O	LR6x3	900 (h)

4.3.1.3 Nomenclature

Refer to Fig. 4.7 for the nomenclature of the Digimatic Height Gage.

4.3.1.4 Features

The HD and HDM series Digimatic Height Gages have many features which vary depending on the model. The following features are common to all models:

(1) The measured values are digitally displayed so quick, error-free readings can be made.
(2) They can measure and scribe to an accuracy of 0.01mm.
(3) The zero-setting function permits the datum point to be set where desired. This eliminates the need to calculate the difference in height, which is particularly convenient in step measurements.
(4) Cordless power allows carefree operation.
(5) The data hold function makes measuring operations convenient. For example, some measurements must be taken in positions where it is not possible to read the display. The display can be held so that it is read from an amiable position.
(6) With the presetting function, any desired value can be set on the datum plane.
(7) The slider feed wheel provides both coarse and fine feeding, allowing easy positioning for scribing and efficient measurement.

4.3.1.5 Detecting mechanism

The rotary encoder converts the linear displacement of the slider to a rotational motion of a slit disc. The number of revolutions of the disc is then digitized to determine the displacement. In **Fig. 4.9**, the pinion, which is engaged with the rack on the main column, turns as the slider moves up or down. The rotation of the pinion is transmitted via a gear to the center pinion and turns the slit disc which is coaxial with the center pinion. Any backlash between the rack and the center pinion is removed by the torque of the spiral spring that is provided between the anti-backlash pinion and gear. The disc has 125 slits that are arranged radially close to the circumference. As the disc rotates, the photoelectric device receives light, which periodically changes in intensity, through the slits and generates output signals of 125 cycles per rotation of the disc. Each signal cycle is further divided electrically into four pulses. Because the disc is designed to rotate once for every 5mm the slider is displaced, a resolution of 0.01mm is obtained.

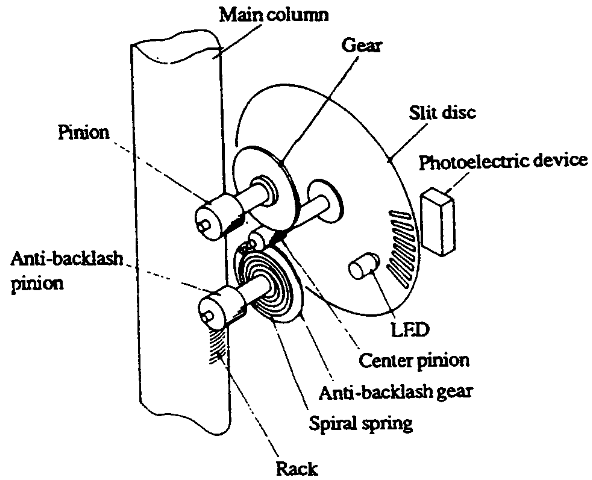


Fig. 4.9 Displacement detection mechanism

4.3.1.6 Two-directional touch signal probe

(1) Application

The two-directional touch signal probe (**Fig. 4.8**) is specially designed for use with the HDM series height gages. In addition to ordinary height measurement, it offers many other useful applications. For example, it automatically compensates for the probe ball diameter to allow direct measurements of inside and outside widths without the need for calculating for the diameter compensation after the measurement is taken. Another feature of this probe is that it has a constant measuring force in both directions. These features greatly improve the measuring efficiency of the height gage.

(2) Detecting mechanism

Ordinary touch signal probes send a signal the moment the stylus touches the workpiece. As shown in **Fig. 4.10**, when measuring inside or outside widths with such probes, the actual width, *L*, is either greater or smaller than the measured value, *l*, by diameter, *d*, of the probe ball, and the difference has to be compensated for by calculation. An automatic compensation function eliminates any errors that might be made in manual compensation calculations. The two-directional touch signal probe makes this compensation in a simple mechanical way. The probe body contains two disc contacts and one ball contact. The electrical circuit is closed and a signal sent the moment the spherical contact touches one of the disc contacts. The ball contact is normally positioned in the center between the two disk contacts at a distance of *d/2* (probe radius) from each of the disk contacts (**Figs. 4.11** and **4.12**). The ball contact and the probe ball are attached to the ends of a lever arm at the same distance from the fulcrum, so the ratio of their displacements is one to one. When the probe ball is displaced by *d/2* after touching the workpiece, the ball contact touches a disk contact to issue a detection signal. This has the same effect as a fixed probe issuing a signal when the center of the probe ball comes to the measurement point. Probing in the opposite direction will work in the same manner as described above, to determine the measurement point. Thus, the probe ball diameter is automatically compensated for, regardless of whether the workpiece surface is probed in the upward or downward direction. In addition, the disk contacts have a certain amount of play to absorb probe overtravel, which prevents the workpiece from going out of position when the stylus is excessively displaced by coming into contact with the workpiece.

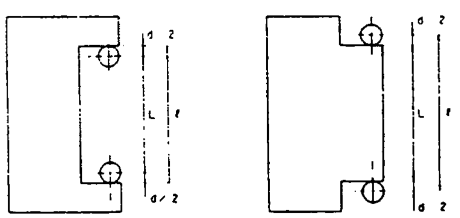


Fig. 4.10 Measurement with ordinary touch signal probe

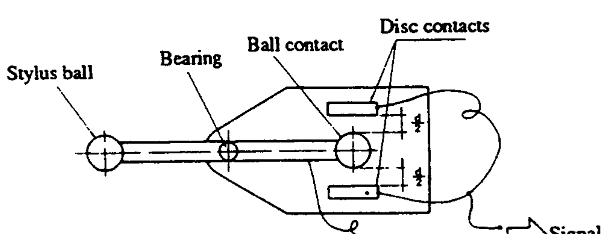


Fig. 4.11 Two-directional touch signal probe

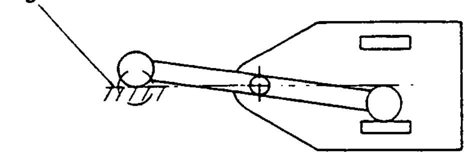


Fig. 4.12 Operating mechanism of two-directional touch signal probe

4.3.2 Capacitance detector type

The HDS series Digimatic Height Gages are popular and economic type of gage suitable for shop-floor use. They can be used for both measuring and scribing work. Operation is very similar to that of a vernier height gage. For simplicity, the number of switches is minimized. For instance, zeroing the display is accomplished by simply pressing a switch, instead of having to move the main scale as with conventional mechanical height gages. Another advantage is that most of the accessory attachments for mechanical type height gages can be used for the HDS series height gages.

4.3.2.1 Series names and outline

There are two types in the HDS series; the S-type (standard type) and the M-type, which has data output capability.

(1) S-type (**Fig. 4.13**)

The electronic unit of the S-type is the same one that is used in the Digimatic Calipers. It has a robust construction with a thick scale column in order to provide accurate and repeatable measurements. The measuring range is 200mm (8in.).

(2) M-type (**Fig. 4.14**)

The M-type is equipped with an output capability as standard and uses the electronic unit that was specially developed for it. It is easy to operate because the LCD screen is horizontal and the graduated column face can be used as a guide for measuring/scribing operations. The measuring ranges of the M-type are 300mm, 600mm and 1000mm (12in, 18in, 24in and 40in).

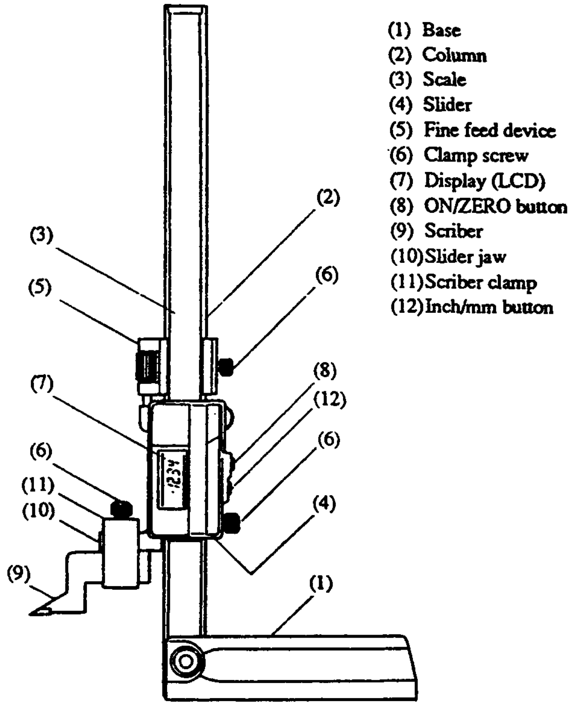


Fig. 4.13 S-type (standard type)

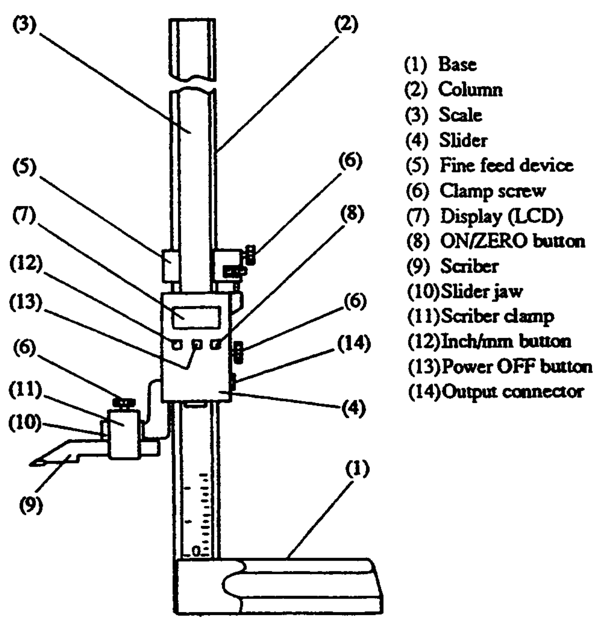


Fig. 4.14 M-type with data output capability

4.3.2.2 Features of the HDS series

(1) The column has a robust construction with a large square cross section for shop-floor use.
(2) The HDS series uses the same type of capacitance type detector that is used in Digimatic Calipers, which is very compact and highly durable because of the non-contact detection system.
(3) The high response speed allows the slider to be fed quickly, providing increased measuring efficiency.
(4) The graduations on the column make it possible to quickly read the approximate dimension.
(5) It has a low power consumption circuit that is powered by a button-type battery for a long period of time. In addition, the built-in auto-power-off function minimizes power wastage during idle time.
Refer to **Figs. 4.15** and **4.16** for battery replacement.

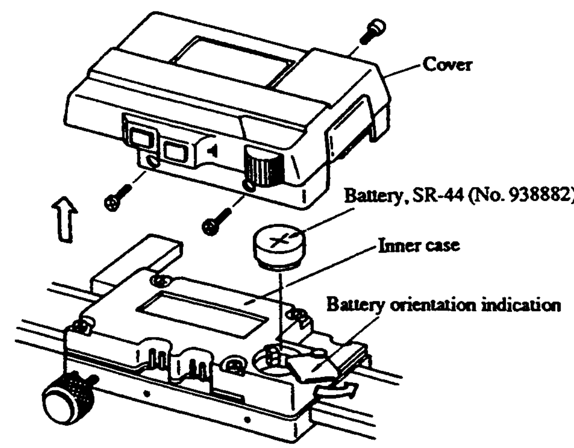


Fig. 4.15 Replacement of slider and battery (HDS, 200mm model)

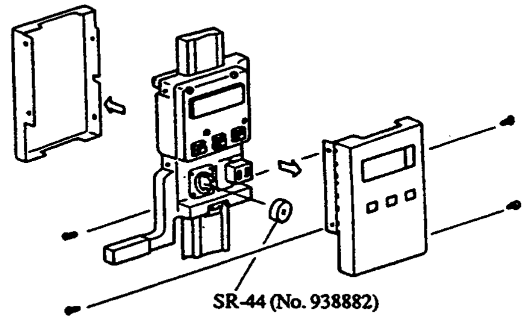


Fig. 4.16 Replacement of slider and battery (HDS, 300mm model)

(6) By connecting a Digimatic Mini-processor to the data output connector (provided on 300mm and larger range models), measurements can be printed, statistical analyses can be performed, and histograms can be generated.

4.3.2.3 Functions

The main functions of the HDS series include: zero-setting, auto-power-off, error alarm, low battery voltage alarm, and data output. (The data output function is only provided on models with a range of 300mm and greater.)

4.3.2.4 Nomenclature

Refer to **Figs. 4.13** and **4.14** for the nomenclature of the HDS series height gages.

5. CARE REQUIRED IN USING HEIGHT GAGES

The height gage is a precision measuring tool used for accurate scribing work and height measurement. To ensure accuracy, special care must be taken when using it.

5.1 Zero-point Checking

As with other types of measuring tools, zero-point checking is essential in measuring with height gages, especially if the zero point can be moved, whether it is a vernier, dial, or digital readout type.
To check the zero point, first lower the slider until the measuring face of the scriber gently touches the surface plate, then secure the slider in that position with the clamp screw. Do not press the scriber onto the surface plate with excessive force when making contact. If the scriber is pressed against the surface plate too hard, the base of the height gage may be raised, which will not allow accurate zero-setting. Check that the proper pressure is applied by sliding the scriber off, and then onto the surface plate. Repeat this a couple of times. If a bump is felt, the measuring face must be lower than the bottom of the base. If this happens, lift the scriber and then lower it again to the surface plate. In order to avoid this problem, clamp the fine feed device and use the fine feed roller to bring the measuring face into contact with the surface plate, as in height measurement.
For vernier height gages, with the scriber touching the surface plate, use the magnifying glass to check that the zero lines on the main scale and the vernier match. If they do not match, adjust the main scale with the fine feed roller that is at the top of the main scale beam. For dial height gages, turn the bezel until the pointer is aligned with the zero graduation on the dial.
Different zero-point checking or zero-setting procedures are used for the Digimatic Height Gages. Different procedures are used depending on whether a two-directional touch signal probe is used or not. When the touch signal probe is not used, simply press the zero-setting button (this is equivalent to zero-setting by adjusting the bezel on dial height gages). When the touch signal probe is used, zero-setting is completed by pressing the zero-setting button and then bringing the probe into contact with the datum surface.

5.2 Avoid Knocks

As with any measuring instrument, knocks impair measuring accuracy. In particular, when using a lever-type dial test indicator on a height gage, the zero point may be changed by knocks or overtravel of the lever. Exercise caution with scriber tip since it is very sharp.

5.3 Eye Position When Reading

Consider the height of the eyes and the direction of sight when reading the vernier scale in order to avoid parallax errors (see section **7.2** in **Vernier, Dial and Digital Calipers**). When using a magnifying glass, look at the graduations through the center portion of the lens, otherwise a parallax error may result even when the eyes are directly over the graduations because light through a portion close to a lens edge is refracted significantly.

5.4 Use a Clean Surface Plate

The height gage is often slid on the surface plate to perform measurements. Wipe the surface plate clean, because dust, oil, or sweat contaminants may cause the gage to stick on the plate, affecting measuring efficiency and accuracy. Wear gloves when making measurements as sweat greatly affects sliding smoothness.

5.5 Do Not Over-extend the Scriber Arm

The scriber arm should not be extended longer than necessary. As with caliper measurement, the line of measurement must be as close to the main scale as possible in order to minimize Abbe's error.
It is also important to keep an appropriate and constant measuring force as height gages are not provided with a such a device.

– MEMO –

DIAL HEIGHT GAGE
WITH DIGITAL COUNTER

PREFACE

This chapter describes Mitutoyo's original double-column dial height gage with digital counter. For general descriptions of calipers and height gages please refer to the appropriate chapters.

1. FEATURES

(1) The Mitutoyo dial height gage with a digital counter is a low-price digital readout height gage which allows zero-setting at any scriber position.
To keep it inexpensive, a mechanical counter is employed. Since there is a limited number of digits on the counter, a dial indicates fractions. To facilitate reading displacements in both directions, the counter provides two directional readouts.

(2) The high precision racks increase measuring and scribing accuracy and efficiency.
This height gage uses two round-bar columns which have a rack on them. The clearance between the sliding/engaged sections are minimized.

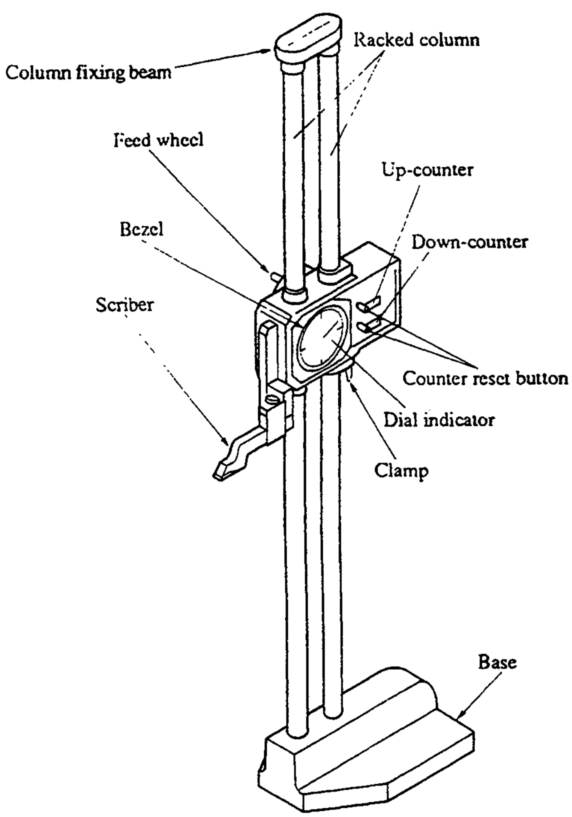


Fig. 1 Dial height gage with counter

Note: The HD and HDM series Digimatic Heigh' Gages (described previously) were develop as full-digital versions of this type by incorp rating a rotary encoder in place of the mechan cal counter.

2. PRODUCT OUTLINE

Fig. 1 shows the external view of the dial height gage with counter. As the feed wheel at the back of the slider is turned, the slider moves up or down via the pinion which is attached to the feed wheel on its axis and engaged with the rack on one of the columns. At the same time, another gear on the axis of the feed wheel drives the counter via a gear train in 1mm or 1in. increments. The pinion of the dial is engaged with the rack on the other column and rotates the pointer through an amplification mechanism as the slider moves up or down. Thus, slider displacements smaller than 1mm or 1in. are indicated on the dial.

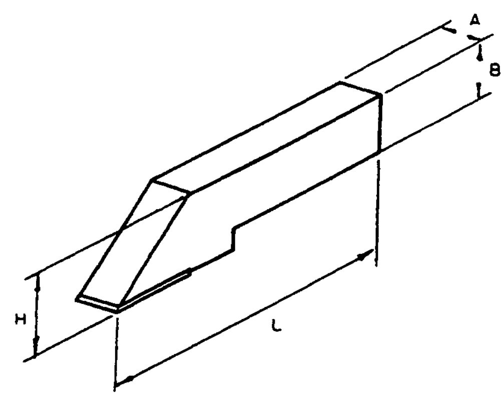


Fig. 2 Scriber

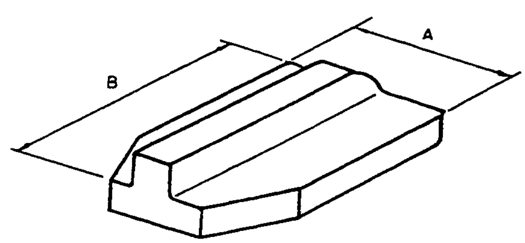


Fig. 3 Base

3. MAIN SPECIFICATIONS

Table 1 Main specifications of dial height gage with counter

Model No.	H730N	H760	H7100	HH730	H712N	H724	H740	HH712
Order No.	192-106	192-104	192-105	192-201	192-116	192-114	192-115	192-211
Measuring range	300mm	600mm	1000mm	300mm	12in.	24in.	40in.	12in.
Resolution	0.01mm				0.001in.			
Instrument error	±0.03mm	±0.05mm	±0.07mm	±0.02mm	±0.03mm	±0.05mm	±0.07mm	±0.02mm
Narrow range accuracy	0.02mm				0.02mm			
Return stroke error	0.01mm				0.01mm			
Clamping error	0.01mm				0.01mm			
Parallelism between base and scriber face	0.01mm				0.01mm			
Flatness of base	0.004mm				0.004mm			
Scriber dimensions A, B, H, L (Fig. 2)	9 x 9 x 15 x 80mm				(6.35 x 12.7 x 30 x 60mm) 1/4 x 1/2 x 1.18 x 2.36in.			
Base dimensions A x B (Fig. 3) mm	85 x 125	120 x 180	150 x 250	92 x 140	85 x 125	120 x 180	150 x 250	92 x 140
Column diameter	15mm	20mm	20mm	20mm	15mm	20mm	20mm	20mm
Distance between columns	33mm	38mm	38mm	38mm	33mm	38mm	38mm	38mm
Rack pitch	Dial 0.5mm				0.02in.			
	Counter 1mm				1mm			
Displacement per feed wheel revolution	20mm				20mm			
Overall height	454mm	790mm	1195mm	504mm	454mm	790mm	1195mm	504mm
Weight	3.4kg	8.4kg	16.6kg	6.0kg	3.4kg	8.4kg	16.6kg	6.0kg

4. CONSTRUCTION

The dial height gage consists of a main unit, a counter, and a dial.

4.1 Main Unit

The main unit consists of a base, a main column (front column with the rack for the dial), a sub-column (rear column with the rack for scale feed and the counter), a slider frame, and a column fixing beam. The column fixing beam, provided at the top of the columns, directly affects the overall accuracy and must not be removed.

4.2 Counter

The counter is attached to the slider frame and has a feed wheel shaft in it. The feed wheel is fixed to the shaft with a box nut. When screwing or unscrewing the box nut, hold the feed wheel (holding the slider may damage the column rack and gears). The gear on the feed wheel shaft has twenty teeth and is engaged with the column rack which has a 1mm pitch. Thus, one rotation of the feed wheel vertically displaces the slider by 20mm. The rotation of this shaft drives the counter through a gear train.

4.3 Dial

The same dial mechanism is used in both the dial height gage and the dial indicator (No. 2046). As shown in **Fig. 4**, the amplification mechanism of the dial consists of pinion P1, amplifying gear G1, and center pinion P3. Pinion P1 is engaged with column rack R1. Amplifying gear G1 is fixed to the pinion shaft and rotates together with pinion P1. The pointer of the dial is attached to center pinion P3, which is seated on the base plate in the dial and engaged with the amplifying gear.
In order to remove backlash of the gears, another gear train which is identical to that for the amplification

mechanism is provided. It consists of anti-backlash pinion P2 and gear G2, and center pinion P3. Pinion P2 is engaged with the main column rack. Gear G2, which is fixed to the shaft of pinion P2 and engaged with center pinion P3, can turn in either direction but is torqued in one direction by a spring.
The entire mechanism is fixed to the slider frame. The dial face is attached to it and covered with a dust-protection crystal. The crystal is fitted in the groove of the bezel, secured by two springs in the groove, and can turn with the dial.
Table 2 shows the number of the gear teeth. The displacement of the slider that corresponds to one rotation of the pointer is given as follows:

$$\text{Metric model: } 0.5\text{mm} \times \frac{12 \times 20}{120} = 1.0\text{mm}$$

$$\text{Inch model: } 0.02\text{in} \times \frac{26 \times 20}{104} = 0.1\text{in}$$

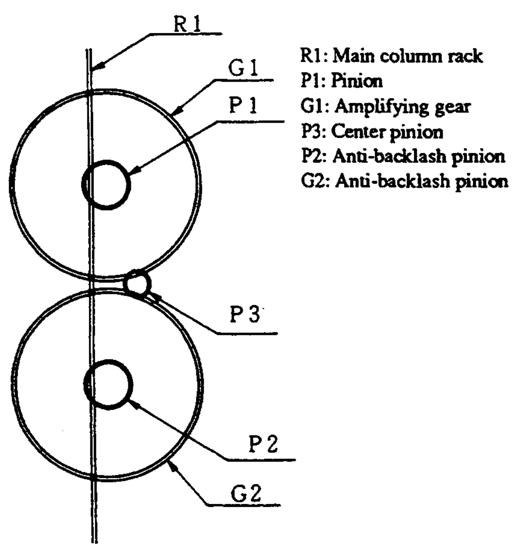


Fig. 4 Amplification and anti-backlash mechanisms

Table 2 Number of gear teeth of dial

	Module (P)	P1	G1	P3
Metric	0.1592(0.5mm)	20	120	12
Inch	0.1617 (0.02in)	20	104	26

5. READING

5.1 Zero Setting

Both the dial and the counter must be set to zero at the same scriber position.

5.2 Reading Measurements

As mentioned above, the counter indicates readings down to 1mm or 0.1" and the fractions are read on the dial.
Because two directional readouts are available, reading the measurements could be somewhat confusing when the slider is moved up or down near the zero point. Some practice using sample workpieces may be necessary to become familiar with making such readings. Special care must also be taken to avoid misreading the lowest digit of the counter by one count when the pointer is close to the "0" graduation. The lowest digit moves continuously when the dial pointer turns. This means that the lowest digit is almost in the same position immediately before and after the pointer passes the zero graduation, although the readings of the lowest digit differ by one count. For example, the measurements in **Figs. 5** and **6** should be read as 123.98mm and 124.02mm, respectively, although the values on the counter appear almost the same.

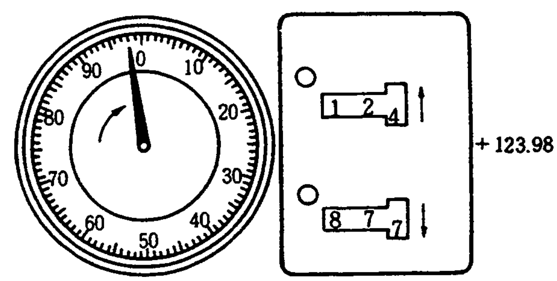


Fig. 5 Reading = 123.98

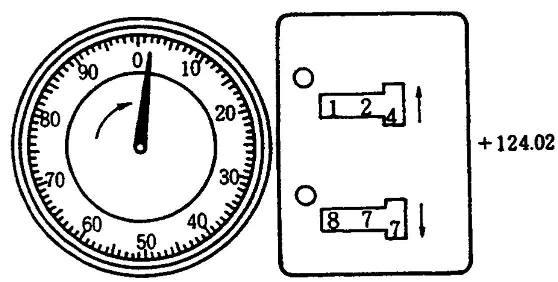


Fig. 6 Reading = 124.02

6. CARE REQUIRED IN USING THE HEIGHT GAGE WITH COUNTER

(1) Do not apply excessive force to the feed wheel when moving the slider down to bring the scriber into contact with the surface plate or datum surface. Otherwise, the base will tilt up and inaccurate measurements will result. Some expertise is required for this operation. To minimize operator errors, the slider should be moved with the feed wheel close to the surface plate or the workpiece surface, and then the slider should be held until the scriber touches the surface. Use of a touch sensor, which has a lamp that lights up the moment the scriber touches an object, will ensure accurate measurements.

(2) The maximum counter revolution is about 1000 rpm, which is equivalent to a feed wheel revolution of 500 rpm. Moving the slider by hand may exceed this speed limit due to acceleration. Therefore, avoid this operation, unless the scriber is to be moved a small distance.

(3) The anti-backlash mechanism cannot completely eliminate backlash. In order to ensure high accuracy, perform measurement by moving the slider in the same direction that it was moved for the zero-setting operation.

(4) Do not extend the scriber arm more than necessary, in order to minimize Abbe's error. Measurement errors are amplified when a non-standard long arm scriber is used.

(5) Do not leave the height gage uncovered on the shop floor. Cover the height gage to protect it from damage and dust when not in use.

(6) Do not hold the slider when carrying the height gage. Always support it by the base with one hand when carrying it.

– MEMO –

VERNIER AND DIAL DEPTH GAGES

1. OUTLINE

The depth gage is designed to measure the depths of holes, slots, and recesses, as well as height differences between steps or planes. It consists of a vernier with a base, and a main scale. Its graduation systems and construction are basically the same as those employed in vernier calipers. It is widely used as a dedicated tool for depth and height measurements, because of its high measurement reliability and ease of operation.

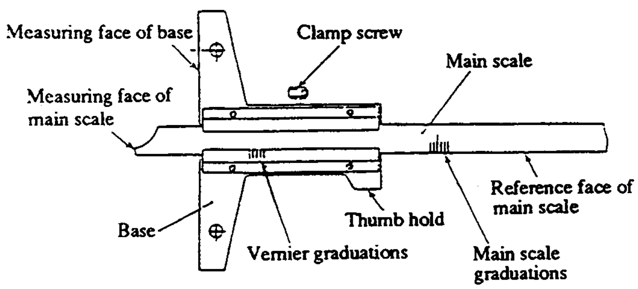


Fig. 1 (a) Depth gage without fine feed (VDS type)

2. NOMENCLATURE

Figs. 1 to 4 show the nomenclature of different types of depth gages.

3. TYPE AND CONSTRUCTION

As shown in Figs. 1 to 5, many different types of depth gages are available; with or without fine feed, hook type, dial type, and Digimatic Depth Gages.

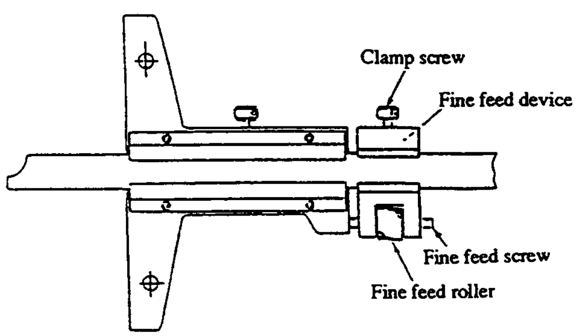


Fig. 2 (b) Depth gage with fine feed (VD type)

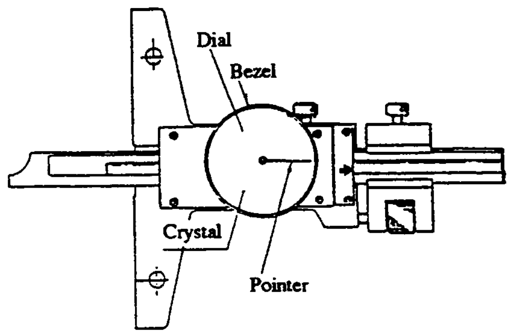


Fig. 3 (c) Dial depth gage (DVD type)

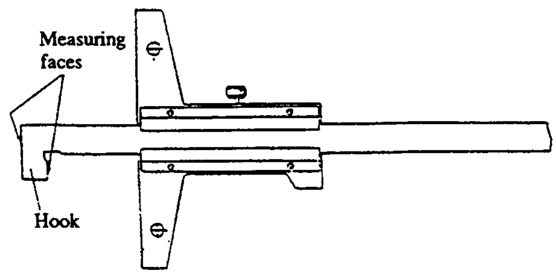


Fig. 4 (d) Hook type depth gage (VDS-H type)

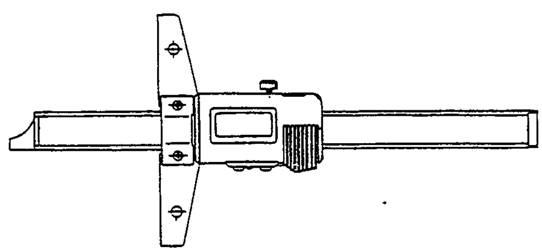


Fig. 5 (e) Digimatic Depth Gage (VDS-DM type)

(a) and (d): The VDS and VDS-H types do not have a fine feed mechanism, and provide 0.05mm accuracy.

(b): The VD type has a fine feed mechanism and provides 0.02mm accuracy.

(c): The DVD type dial depth gage provides 0.05mm accuracy.

(e): The VDS-DM type Digimatic Depth Gages provide 0.01mm accuracy.

Table 1 Depth gage types and graduations

Type	Measuring range	Main scale grad. Vernier/Dial grad.	Discrimination/ Resolution
(a) VDS	150–1000mm	1mm 20 divisions in 39mm	0.05mm
(b) VD	150–1000mm	1mm 50 divisions in 49mm	0.02mm
(c) DVD	150–300mm	1mm 5mm/100 divisions around circumference	0.05mm
(d) VDS-H	150–300mm	1mm 20 divisions in 39mm	0.05mm
(e) VDS-DM	150–300mm		0.01mm

Note:
150–300mm: 150, 200 and 300mm measuring ranges
150–1000mm: 150, 200, 300, 600 and 1000mm measuring ranges

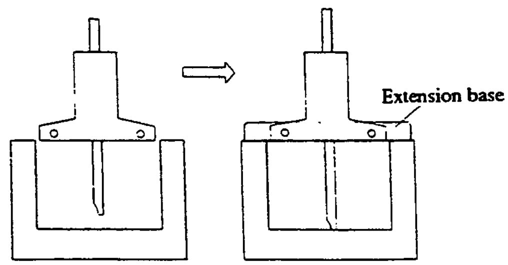


Fig. 8 Using an extension base

4. EXAMPLES OF USE

As shown in **Figs. 6** and **7**, depth gages can measure depths of holes and grooves, and height differences between steps. If the hole diameter or the groove width of the workpiece is too large for the measuring face of the base to span the edges, attach an extension base to the base, as shown in **Fig. 8**. Extension bases have two mounting holes that align with the holes in the base. To attach an extension base to the base, place the depth gage and the extension base on a surface plate with their measuring faces down so that the two faces are flush with each other, then slowly clamp them together. When in use, check from time to time that the measuring faces are flush with each other.

The hook type depth gage is used to measure the depth of a projected portion in a hole or a groove, as shown in **Fig. 9**,

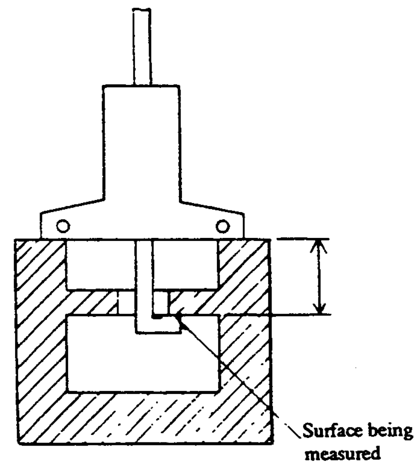


Fig. 9 Using a hook type depth gage

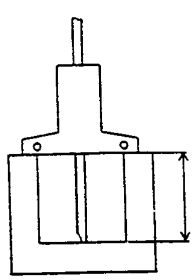


Fig. 6 Example of use 1

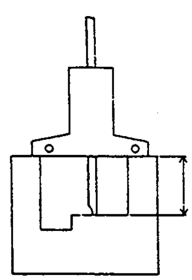


Fig. 7 Example of use 2

5. COMPARISON OF MEASURING ACCURACY

Depth gages are designed to provide more accurate depth measurements than calipers. An accuracy comparison made between a depth gage and a caliper with a depth bar shown that measurements made with a depth gage displays less variation than those obtained using a caliper. Therefore, use depth gages for depth measurement whenever possible.

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