TEXTBOOK NO. 7009

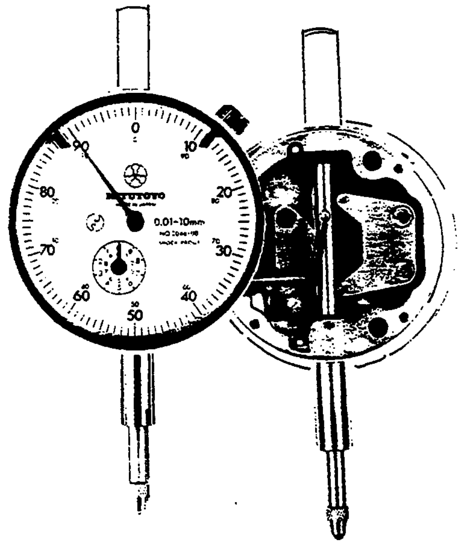
Dial Indicator and its Applications

TEXTBOOK

Mitutoyo

CONTENTS

PART I DIAL INDICATORS



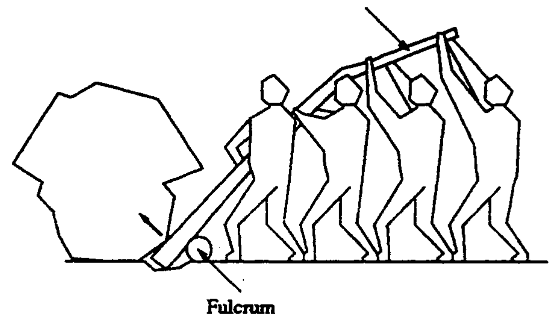


Fig. I Magnifying a force by a lever (The displacement is reduced)

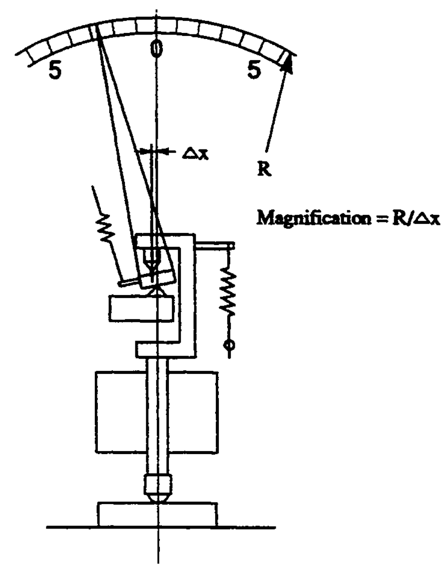


Fig. II Magnifying mechanism with a single lever (early dial indicator)

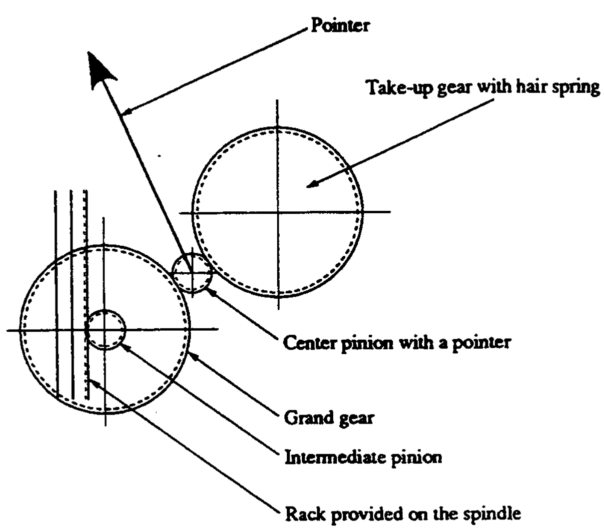
INTRODUCTION

Dial indicators or dial gages are widely used as lightweight and compact gages for measuring dimensions. On a dial indicator, a minute displacement of the spindle is magnified and converted into a change of the pointer's angular position on the dial face. The pointer will revolve from one turn to several dozen turns depending on the type of the indicator. The magnified displacement is easy to read on the dial face, which makes the dial indicator useful for measuring variations such as run-out of revolving part and flatness of a continuous surface.

The displacement magnification in the early dial indicators was done by means of a lever, which in principle can be traced in history up the banks of the Nile river to the great pyramids of Egypt. Dial indicators provided with such a lever have been used in industry as displacement measuring gages since the 1800's. But the Hirth's Minimeter, manufactured in 1907, was the first for which the working parts correspond to what we know today as dial indicators; it had a rather simple structure that included only a single lever to do single-stage magnification.

The construction in earlier models did not permit a wide measuring range (only ±20 graduations on the dial), and required uneven graduation intervals. Above all, the measuring range was very restricted when the indicator had a high magnification.
To cope with these difficulties, a dial indicator with two pointers for low and high magnifications was developed by the Krupp company, and a variety of other dial indicators, including those which had a multiple-lever mechanism to do two-stage magnification or a combination of levers and gears, we developed by Fortuna and Krupp, and named "Mi meter" or "Mikrotast" respectively. (One of the ori nal Krupp dial indicators is in the Numata Memo

Hall of Mitutoyo.)
'ince those days various changes and improvements .ave been made to dial indicators leading to today's dial indicators and the Digimatic indicators. (These developments will be covered in greater depth in chapter 8.)



ig. iii Magnifying mechanism of 0.01mm dial indicators (for today)

1. BASIC CONSTRUCTION OF DIAL INDICATORS

1.1 Basic Construction of Dial Indicators

Fig.1.1 (a) shows a cut away view of a 0.01mm reading dial indicator, and (b) is a diagram that explains the operational concept.
The linear movement of the spindle (s), which has a contact point (p) at its end, is transmitted to a stepped gear (a,b) via a rack provided on the spindle. Then it is magnified and transmitted to gear (c) which is coaxial to pointer (e) to show the angular displacement finally on the dial (f).
In the above described structure, there is some play in the engagement between the rack and pinion (intermediate pinion) and the engagement between the grand gear and the center pinion. In order to eliminate .ne play (backlash), the center pinion is engaged with another gear (d) (take-up gear) against which it is .neld by the tension of the hair spring (h).

The resolution using this structure is;

$$\text{Resolution} = \text{Pitch of rack} \times \frac{\text{Number of teeth of pinion (a)} \times \text{Number of teeth of pinion (c)}}{\text{Number of teeth of gear (b)} \times \text{Number of graduations for one revolution of pointer}}$$

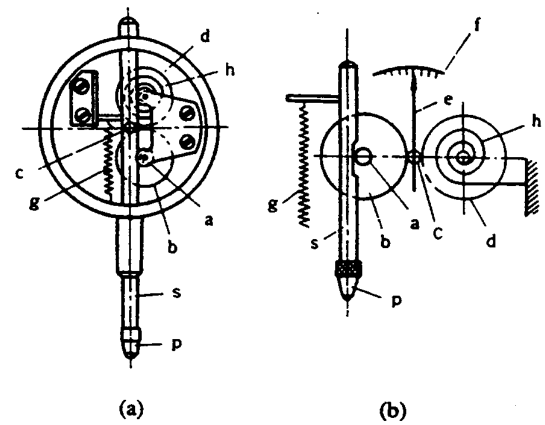


Fig. 1.1 Construction (a), (b)

1.2 Magnifying Mechanism in Dial Indicators

The magnifying mechanisms differ depending on the amount of spindle displacement per revolution of the pointer, i.e. the resolution. (See **Fig. 1.2.**)

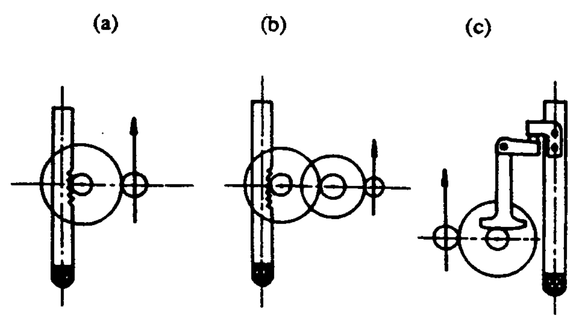


Fig. 1.2 Magnifying mechanism (a), (b), (c)

(a) This is the most popular type where a 1mm spindle displacement corresponds to one revolution of pointer. The most popular Mitutoyo dial indicator of this type (Code No. 2046-08 or 2046F) provides 0.01mm graduations and a measuring range of 10mm.
(b) This has a two-stage magnification by means of gears. Among the indicators that have a spindle displacement of 0.2mm to 0.5mm per pointer

revolution, this type has the wider measuring range. For example, the Mitutoyo 2119-50 and 1013 series fall in this category.

(c) A type to which a single-stage lever is added to the above described (a).
This is mostly used for high-precision purposes where the spindle's 0.1 to 0.2mm displacement corresponds to one revolution of the pointer. The Mitutoyo 2109 series is a representative type and Hicators use this mechanism as well.

1.3 Stems and Backs

A dial indicator is generally held either by a stem or lug on the back when monted on a stand or jig.
Holding by the back is popular in the United States, and holding by the stem is popular in Europe. In Japan, when the dial indicator is held by a universal tool such as a stand, it is held by the back, and when the dial indicator is designed and fabricated as a mass-produced inspection instrument, it is held by the stem.
Both types have their strong and weak points. For example, holding by the stem allows the axis of a dial indicator to easily be adjusted perpendicular to a measured surface. In addition, it is easy to change the position of holding the stem as required. However, the stem is a crucial part because the spindle must move through it with the least amount of friction. Therefore, it should be fabricated so that even when it is clamped by a screw it will not be deformed. This requires strict standards on the finishing of the stem, i.e. it should be made of hardened steel and have a diameter of $\varnothing 8^{0}_{-0.009}$ to conform to DIN specifications, as are used in the European countries.
Mitutoyo has been manufacturing dial indicators with a stem that has dimensions to conform to DIN specifications. This stem is made of stainless steel to prevent it from rusting and is hardened to HRC 40 to clamp it directly by the screw, which has the same hardness as the stem. **Fig.1.3** shows the relationship of the torque applied to the screw v.s. the distortion of the stem, until the stem finally is compressed enough to cause a sliding malfunction of the spindle. Even when the torque of the screw is less than 30kgf-cm, the stem is held tightly enough by the screw, and with the torque greater than 40kgf-cm, the stem is held so firmly that it is not shaky at all even in harsh measuring operations. It is clear from the figure below that the hardened stainless steel stems exceed the required strength requirements. For the zinc diecast stem, the fastening method shown in **Fig.1.4** (b) is generally used.
Whatever the fastening method is, for the normal operation of the spindle it is desirable to hold the sten at least 8mm from the end.

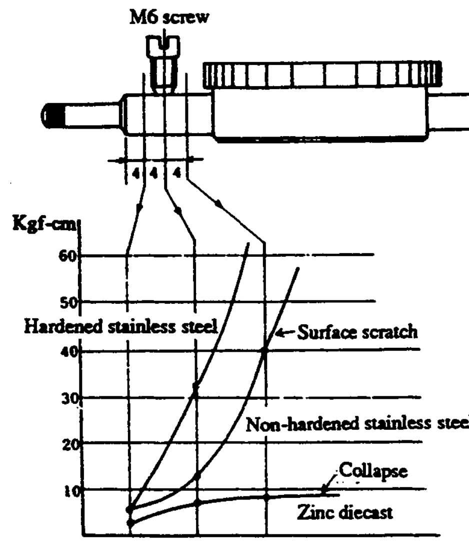


Fig. 1.3 Fastening strain v.s. stem strength

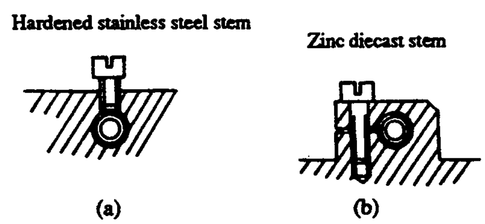


Fig. 1.4 Fastening the stem

When a dial indicator is held by the back, its mounting position is determined by the lug on its back.
The ANSI specifications of the United States provide that the distance between the lug and the spindle end at its most retracted position should have a specified value as shown in **Fig.1.5**.
Because dial indicators in the United States are often held by the back, various styles of backs as shown in **Fig.1.6** are supplied: the center lug back, the offset back which has an off-centered lug, the post back which has a handle, the screw back whose post is tapped screw threads to be fastened from the back, a adjustable bracket back for adjusting the mountin position, the rack back which has a dovetail bracke

with a rack on it for fine positional adjustment, and a magnetic back type to be directly attached to a machine.

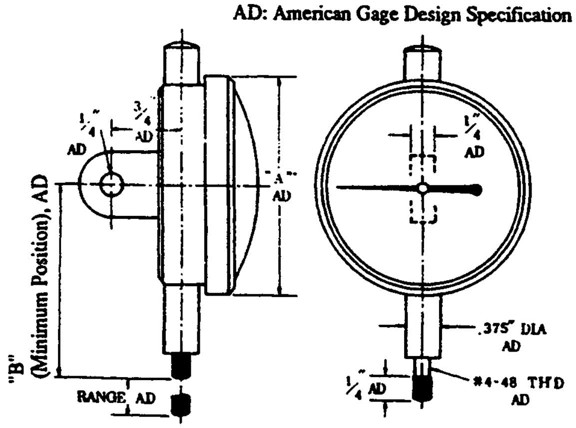


Fig. 1.5 ANSI specifications

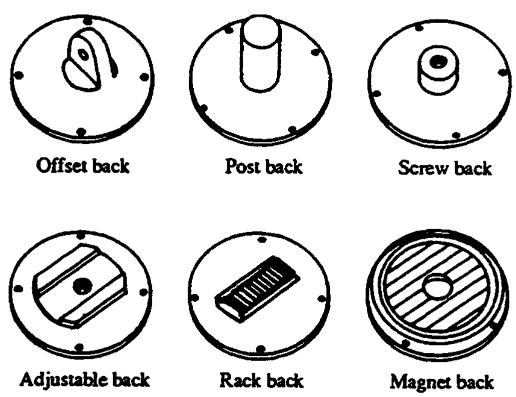


Fig. 1.6 Backs

1.4 Lifting Lever and Bezel Clamp

For easy zero adjustment, the bezel of a dial indicator is generally designed so that it can be rotated together with the dial face and yet be clamped by the bezel clamp when the clamp screw is fastened. This clamp ensures that the zero position will not be changed during measurement.

At the top of the dial indicator a lifting lever can be mounted for lifting up the spindle to allow a workpiece to be easily inserted as well as to move the spindle up and down several times to ensure a stable reading. The construction is shown in **Fig.1.7**. The lifting lever can be mounted on the other side in place of the bezel clamp, as necessary.

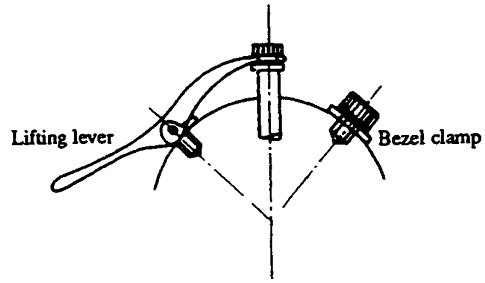


Fig. 1.7 Bezel clamp and lifting lever

1.5 Contact Points

Various optional contact points are available for different workpiece forms.

For example, a contact point with a large radius of curvature is used where a spindle is to be pushed up as in **Fig.1.8**, where the workpiece must be slid under the spindle.

For other measuring operations, there are various types and materials of interchangeable contact points as shown in **Table 1.1**. For the United States, there are many contact points which have ANSI inch threads.

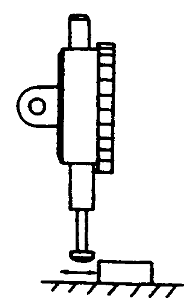
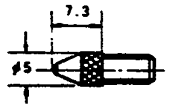


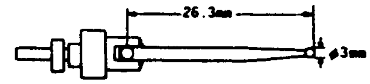
Fig. 1.8 Curvature of contact point

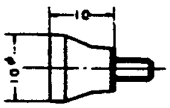
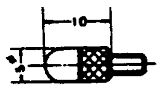
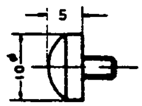
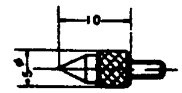
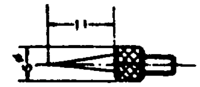
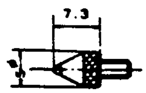
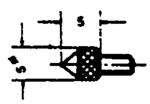
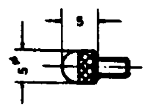
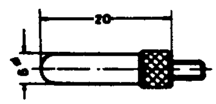
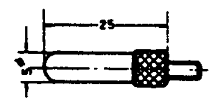
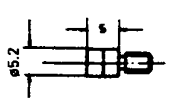
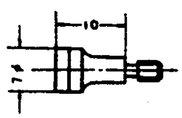
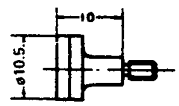
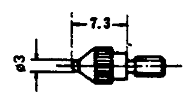
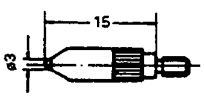
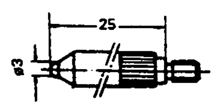
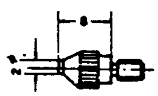
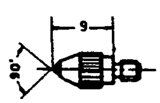
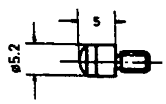
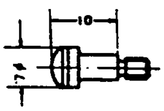
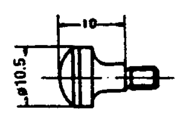
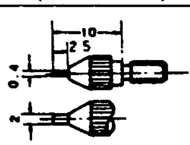
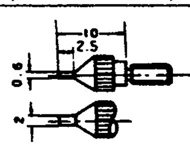
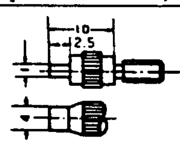
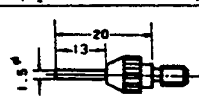
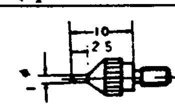
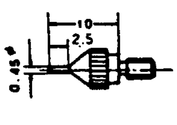
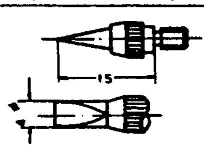
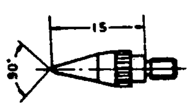
Table 1.1 Interchangeable contact points

900030
Ball point supplied as a standard



900391
Lever contact point



 **101117** (Flat)	 **101118** (Shell)	 **101119** (Spherical)	 **101120** (Conical, 60°)	 **101121** (Needle)
 **101122** (Ball point)	 **101385** (Conical, 90°)	 **101386** (Shell, 5mm)	 **101387** (Shell, 20mm)	 **101388** (Shell, 25mm)
 **120041** (Flat, Carbide)	 **120042** (Flat, Carbide)	 **120043** (Flat, Carbide)	 (Ball point)	**901312** Carbide Ball **120047** Ruby Ball **901994** Plastic Ball
 (Ball point)	**120049** Carbide Ball **120051** Ruby Ball	 (Ball point)	**120053** Carbide Ball **120055** Ruby Ball	
 **120056** (Flat, Carbide)	 **120057** (Conical, Carbide)	 **120058** (Spherical, Carbide)	 **120059** (Spherical, Carbide)	 **120060** (Spherical, Carbide)
 **120061** (Blade, Carbide)	 **120062** (Blade, Carbide)	 **120063** (Blade, Carbide)	 **120064** (Needle, Carbide)	 **120065** (Needle, Carbide)
 **120066** (Needle, Carbide)	 **120067** (Knife-edge, Carbide)	 **120068** (Conical, Carbide)		

* The attached numbers are the Part Nos. All have a screw of M2.5, 5mm.

2. STRONG POINTS OF MITUTOYO DIAL INDICATORS

2.1 Development of Dial Indicators

Most of the early dial indicators used a lever for magnifying the spindle displacement. As the manufacturing technology of gears progressed, the dial indicator came to adopt a gear train for magnifying the displacement. Today, reliable, high quality and inexpensive dial indicators, based on a gear train, are mass-produced. The modern development can be divided into the following steps.

① Developed first was a dial indicator with 0.01mm graduations for a 10mm measuring range (2046-08 type), which is still a major item today.
② In order to measure in higher accuracies, a type which could read to 0.001mm was developed.
③ To handle many different measuring applications, various types including one that has a wide measuring range, the AGD* series 1 which is a compact type, and the AGD 3 and 4 series, which are large-sized for easy reading from a distance, were developed.
④ In view of the typical operating conditions, a waterproof type, a shockproof type, and a high-durability type were developed.
⑤ As emerged from experiences on mass-production lines, a one-revolution type, which is easy to read and can eliminate reading errors, was developed.

Besides the above developments, dial indicators with +NG, GO, and -NG output for lighting external indicator lamps, and types with a digital display to eliminate reading errors, have been developed along with a data processing system (refer to Chapter 8) to statistically analyze the obtained data.
The following sections describes the major points of improvement on the dial indicators and the resultant products marketed from Mitutoyo.

*: Refer to page 11.

2.2 Shockproof Property of Materials

As the dial indicators have been introduced into harsh shop floor environment while still required to satisfy measuring accuracies, possible rough treatment has highlighted the shockproof capability of dial indicators. Normally, the operation of the dial indicator is as follows: the operator releases the lifting lever and the spindle is pushed by the internal coil spring and strikes against the workpiece surface. The spindle stops suddenly, and the inertia of the rotating pointer (concentric to a gear) changes to an impact on the gears, bearings, and spindle. This is a major cause of chipping or wear of the gear teeth, resulting in a deterioration of measuring accuracy or in malfunctions.
The amount of wear depends on the structure or stroke range of the spindle. If a conventional, brass grand gear were incorporated in the one inch dial indicator, it would be worn out on average after only 30,000 spindle strokes to the point where an operating malfunction is caused. To improve the durability of such dial indicators, Mitutoyo has developed a new type by incorporating a grand gear made of hardened stainless steel to withstand over 300,000 spindle strokes, which is 10 times as durable as the conventional brass-gear type.
Dial indicators are generally not lubricated because the oil tends to become sticky from degeneration or from mixing with abraded chips, which may then adhere to other interior parts.
It has generally been thought that a brass grand gear would softly contact the steel pinion gear to generate little sound and to have a good resistance to abrasion. This would be true if it were lubricated. However, in practice, such durability is not ensured because dial indicators are not lubricated for the aforesaid reasons. The lack of lubrication contributes to the abrasion of the brass grand gear by the steel pinion. The abraded chips adhere to the steel pinion, and increase the abrasion of the brass grand gear. This redoubled effect on the grand gear and pinion gears accelerates the wear of the grand gear teeth resulting in thin, bent or chipped gear teeth. Finally, the grand gear breaks and causes an operating malfunction.
Mitutoyo has extensively studied the above described cases and has made the following improvements to its dial indicators, beginning with the 2046-08 series.

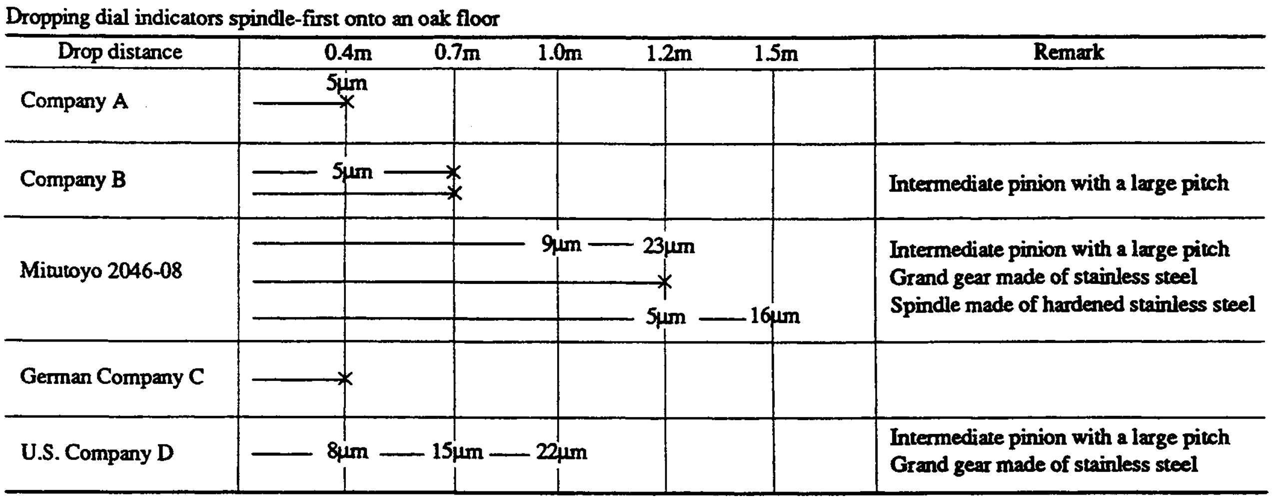
① With a stainless-steel grand gear, the above-described rapid wear does not occur. Of course, wear progresses gradually, but it takes a long time before a malfunction or before a deterioration in accuracy becomes significant.
② If the spindle is subjected to a strong impact, the intermediate pinion will be chipped, or the spindle will be deflected to disengage from the pinion. In order to prevent this kind of damage, the spindles of Mitutoyo dial indicators are hardened and have a diameter of 4.8mm. The interme-

diate pinion gear has a pitch as large as 0.625mm.

③ For further protection, a rubber shock absorber is provided at the upper inside part of the indicator unit.

These effects have resulted in the performance shown in **Fig.2.1** Drop test, and **Fig.2.2** Shock test.

Based on the above described studies, every component of the Mitutoyo dial indicator has beer improved to withstand the wear caused by shocks.



x: Malfunction. Figures are the change in measuring accuracy.

Fig. 2.1 Drop test of 0.01mm reading dial indicators

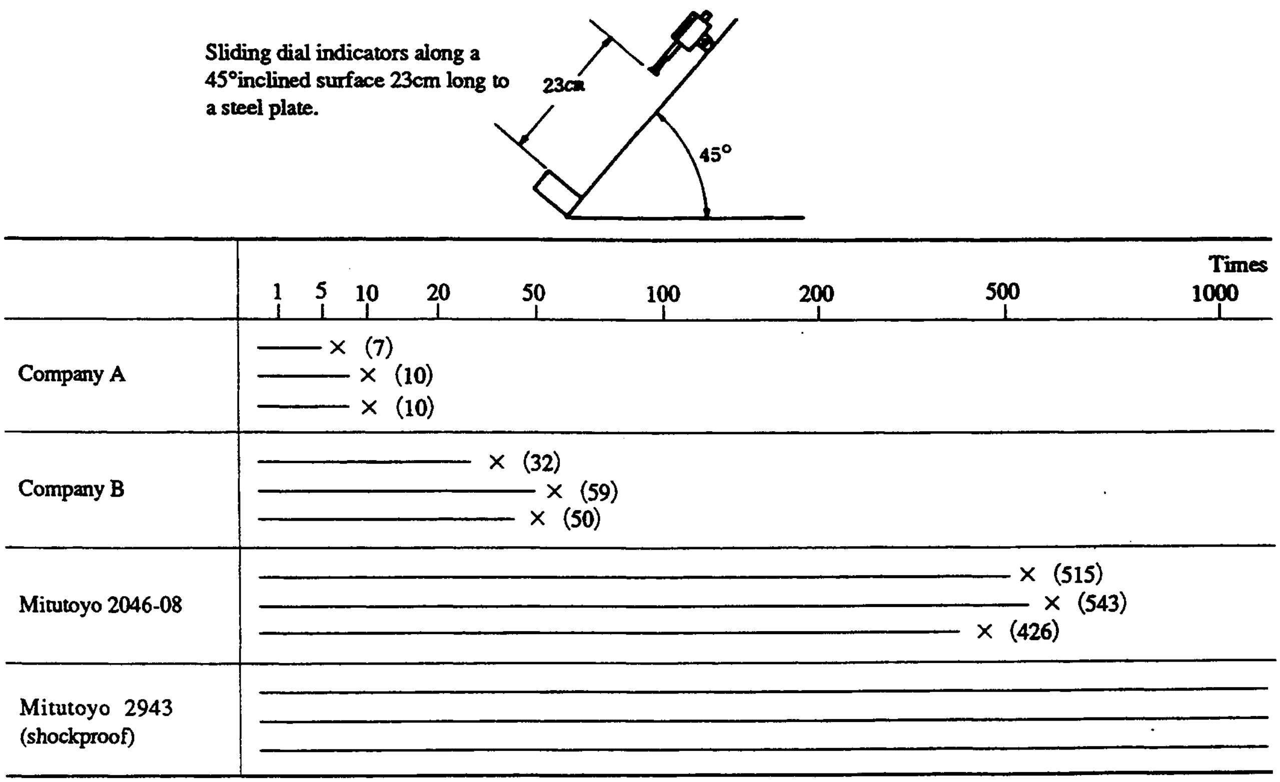


Fig. 2.2 Shock test of 0.01mm reading dial indicators

2.3 Shockproof Structure

The 2046-08 type has a good shockproof capability, as described previously, in normal operations where the spindle is lowered by the measuring force of the spring. However, when it is subjected to the shock given by a larger acceleration, the durability (number of times it can be dropped) is greatly reduced.
For example, if the measuring force were doubled by a stronger spring, or if the spindle stroke were doubled to 20mm, the durability or life would be decreased by a factor of 2^2 or 2^3, respectively.
In addition, if the shocks were similar to those caused by blows against a steel plate after sliding 23cm along an inclined plane, it would only be several hundred shocks until the dial indicator would malfunction. (Refer to **Fig.2.2.**)
To enhance the resistance to such repetitive shocks, the gear system must be sufficiently tough. With this in mind, the rack provided on the spindle is machined after hardening, and the material of the grand gear was changed from brass to hardened stainless steel, as described before. All the first-class dial indicators manufactured in the United States and Europe are also made of such materials, but, in practice, the Mitutoyo 2046-08 type has the highest shock resistance in its class.
In addition to the material properties of the components, the mechanism itself should have an shockproof capacity to cope with severe shocks, as shown in **Fig.2.3.** The internal structure is therefore constructed so that when the intermediate pinion is rotated by the spindle displacement a small cam on the pinion changes its position. As the grand gear is not directly coupled with the intermediate pinion, the grand gear, pointer, and take-up gear, which have a large inertia, will be rotated by the tension of the spiral spring until the small pin on the grand gear contacts the stopper piece on the intermediate pinion. If the spindle is displaced quickly, the cam rotates away from the pin and only the force of the spiral spring is applied to the pin to follow the cam. Thanks to this shockproof mechanism, the dial indicator can withstand several thousand repeated shocks, without any trouble.
These modifications were applied to the 2046-08 type to develop the 2943 type which has a measuring range of 5mm and graduations of 0.01mm. This can be said to be the the world's most practical and inexpensive shockproof dial indicator.

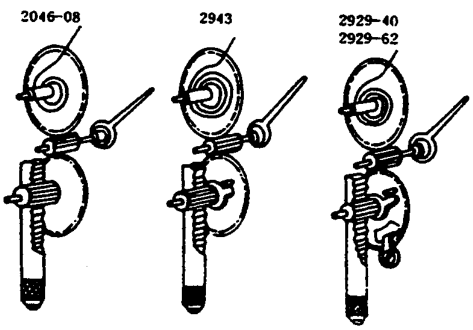


Fig. 2.3 Construction of shockproof mechanism

2.4 Dial indicator with 0.001mm Graduations

Basically, the 1μm reading dial indicator, including the Hicator, is constructed so that the sector gear is allowed to follow the spindle displcement slowly even when the spindle is pushed quickly. **Fig.2.4** shows the shockproof construction. Because of its large magnification ratio, the durability of the 1μm reading dial indicator depends greatly on the material properties of the movements and on the jeweled bearings.

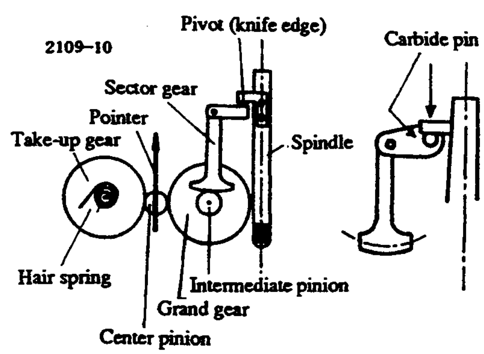


Fig. 2.4 Structure of 2109-10 (0.001mm reading)

In the Mitutoyo 2109-10 (0.001mm -1mm) dial indicator:

① Because the sector gear is the most subject to wear, it is made of hardened beryllium bronze so that it is durable enough to maintain the rated precision.
② A carbide pin is used as the contact for the lever.
③ In order to prevent operating malfunctions and

accuracy deterioration due to friction, six jeweled bearings are used.

④ The spindle is hardened to have sufficient stiffness, and is mirror-finished.

⑤ The stem is made of hardened stainless steel and has the outer diameter ground to ø8h6, which conforms to DIN specifications. The deviation of the zero point due to a change of temperature is restricted to 0.3μm/°C or less, half of that of the usual models which have a zinc diecast stem.

Ex.) Taking as an example the 0.001mm reading dial indicator which has a zinc diecast stem, a 5°C change in room temperature will change the zero point as much as 3 graduations. This is not negligible for accurate measurement.

2.5 One Revolution Dial Indicators

In the production line, reading error by one revolution of pointer on a standard dial indicator where the pointer turns more than one revolution would be devastating, particularly for the manufacturers who adopt the just-in-time supplying system. Aiming to be fool-proof, one revolution dial indicators have a dial with a red-colored dead zone, discriminated from the graduated section, to show that the pointer in this zone has no meaning.

(1) In addition to reading to 0.01mm, as does the 2943 series which has the shockproof structure shown in **Fig.2.3**, the 2929-40 and 2929-62 series have a pointer that turns less than one revolution. The 2929-62 series has a splash-proof structure. Because of these three advantages, a number of the 2929-62 series were used for a year in an automobile manufacturing company and proved their performance by their out-of-use rate being 10% or less of the conventional indicators.

(2) Although they also have the structure shown in **Fig.2.3**, 0.001mm reading dial indicators are constructed so that the range of pointer movement is limited to less than one revolution by restricting the movement of the sector gear. A representative 0.001mm reading dial indicator is the 2900-72 series, which has the same rugged features as the 2929-62 series. As 2900-72 series are easier to read than the conventional 2109 series and have a splash-proof structure, they can be said to bring microindicator accuracy to the shop floor.

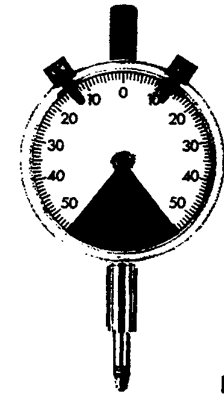


Fig. 2.5

2.6 Waterproof Dial Indicators

Dial indicators don't run into problems when they are used in a dry environment, such as an inspection room or an assembly section, but if they are used in places where they are subjected to oil, water or corrosive gas, they can be damaged.

In the case of machine oil, no problem occurs in the operation of a dial indicator even when it is often subjected to oil splashes, as long as the oil contaminant does not solidify and adhere to it. If the dial indicator is subjected to water coolant used for grinding, the dial indicator must be completely waterproof.

As the spindle moves up and down, it tends to draw in the watery metal chips as the spindle moves, and the air pressure inside the housing and rubber boot changes with respect to the atmospheric pressure. This will tend to draw in the outside watery metal chips. Therefore, measures should be taken both to seal the gap between the spindle and the stem and to minimize the effect of pressure changes caused by the spindle movement, by completely encasing the internal structure. Furthermore, in more severe conditions, the spindle should not be subjected to quick reciprocations or displacement for a long stroke range. The rubber boot is made thin enough for the spindle to move freely without resistance, but is hard to preserve thin rubber that has an excellent oil-resistance and durability at the same time. Therefore, the rubber boot should be changed twice a year, depending on the operating conditions.

In order to maintain the waterproof capability, the Mitutoyo waterproof type dial indicators have an easy-to-repair structure in which the movement can be removed from the front without opening the back cover. A representative one is the 2046-60 series which has 0.01mm-10mm specifications, and there are also 1μm and 2μm reading waterproof dial indicators.

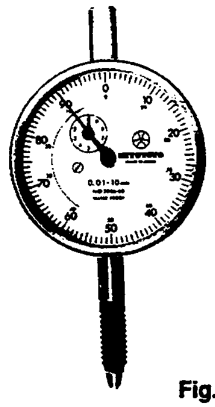


Fig. 2.6

2.7 Hicators

Among the different types of dial indicators, those which satisfy the JIS specifications for microindicators (graduations of 1μm or less, one-revolution type) are the high-precision Hicators (Microindicators JIS B 7519-1976). The Hicators are generally graduated to 1μm. In addition to the 524-501 type on which the graduated dial face is read directly, there are the 524-601 and 524-651 types (small size) which output +NG, OK, and –NG judgment signals which can turn the external indicator lamps on and off, and can be sed as well for various operation controls.

2.8 Back-plunger Type Dial Indicators

In the back-plunger type dial indicators, the dial face is perpendicular to the spindle axis, therefore it is useful for measuring a dimension in a tight space below eye level, which is hard to do using the normal dial indicators that must be read from directly opposite the dial face.
A general type is the 1160 (0.01mm - 5mm) series on which the pointer revolves several turns. The 1960 (0.01mm), 2960 (0.01mm), and 2990 (0.001mm) series are a one revolution type with enhanced durability. (Refer to **Fig.2.7.**)

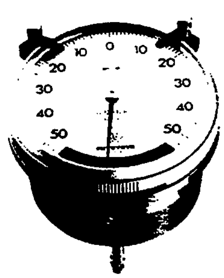


Fig. 2.7 Back-plunger type dial indicator (2990 series)

3. CLASSIFICATION OF DIAL INDICATORS

Mitutoyo dial indicators are widely used throughout the world. They are fabricated to meet the ANSI specifications of the United States, the DIN specifications for the European countries, and other specifications of various countries.
In addition to meeting these stringent specifications, dial indicators may encounter extremes of operating conditions: controlled measuring rooms or harsh shop floors, in water or in oil, in high temperatures or low, etc. Among these conditions, shocks and contamination by water are the major concerns that Mitutoyo dial indicators are designed and constructed to cope with.

Tables 3.2 thru **3.4** list the major models of Mitutoyo dial indicators. They vary widely in the size of the dial face, the measuring range, and the type of dial faces, etc.

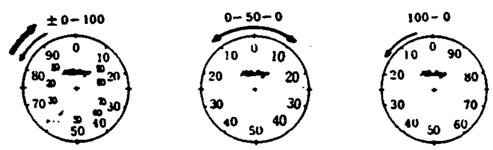


Fig. 3.1 Types of dial faces

Table 3.1 Bezel diameters by AGD series No.

Series No.	Bezel Diameter (mm)
1	41.0
2	55.6
3	77.0
4	90.5

Table 3.2 List of code Nos. of major dial indicators with 0.01mm graduations

Code Nos. of the major 0.01mm reading dial indicators					
Series No. (bezel diameter) / Measuring range (mm)	0 (ø31)	1 (ø41)	2 (ø56)	3 (ø77)	4 (ø91)
1		1929-62*	2929-62*		
1.6			2959-62*		
2.5	1911				
3.5		1040			
4		1003 (ø36)	2928-62*		
5		1044	2044-08		
10			2046-08W	3046E	4046*
20			2050-08	3050E	
30			2052	3052E	
50				3058E	
80				3060E	
100				3062E	

• Code Nos. with an * (asterisk) show the one revolution dial indicators.

Table 3.3 List of code Nos. of major dial indicators with 0.001mm graduations

Code Nos. of the major 0.001mm reading dial indicators					
Series No. (bezel diameter) / Measuring range (mm)	0 (ø31)	1 (ø41)	2 (ø56)	3 (ø77)	4 (ø91)
0.1		1900-72*	2900-72*		
0.16			2901-72*		
0.5	1913-10**				
1		1013-10	2109-10	3109-10	
2			2113-10		
5			2119-50		

• Code Nos. with an * (asterisk) show the one revolution dial indicators.
• Code Nos. with ** (two asterisks) show the 0.002mm reading dial indicators.

Table 3.4 List of code Nos. of major dial indicators for inch reading

Series No.	Grad	.0001"			.00025"	.0005"				.001"		.002"
	Range/rev / Revolution	.004"	.008"	.010"	.020"	.020"	.030"	.040"	.050"	.050"	.100"	.160"
0	2.5	1927-10 (.010")		1925-10 (.025")		1923 (.050")						
1	1		1910-72* (.006")						1909-62* (.040")			
	2.5			1803-10 (.025")			1570-10 (.075")	1670 (.100")	1506 (.125")	1780 (.125")	1410 (.250")	
2	1		2947-10* (.008")	2910-72* (.008")	2911-72* (.020")				2909-62* (.040")		2908-62* (.080")	2907-62* (.160")
	2.5		2937-10 (.020")	2802-10 (.025")	2470-50 (.050")		2570 (.075")	2670-08 (.100")	2506-09 (.125")	2780-08 (.125")	2410 (.250")	
	4										2412-08 (.400")	
	5			2804-10 (0.50")							2414-08 (.500")	
	10			2806-10 (.100")							2416 (1.000")	
	20										2424-10 (2.000")	
	25			2356-50 (.250")								
	50			2358-50 (.500")								
3	2.5			3802-10 (.025")			3570 (.075")			3780 (.125")	3410 (.250")	
	4										3412 (.400")	
	10										3416 (1.000")	
	20										3424-10 (2.000")	
	30										3426-10 (3.000")	
	40										3428-10 (4.000")	
4	2.5			4802-10 (.025")			4570 (.075")				4410 (.250")	
	30										4887 (3.000")	

• Figures in the parentheses are the measuring ranges, and codes with an * (asterisk) show the one revolution dial indicators.

4. USE OF DIAL INDICATORS

4.1 Comparison with Other Measuring Tools

Table 4.1 shows a comparison of the micrometer, caliper, and dial indicator features.

Table 4.1 Comparison with other measuring instruments

	Measuring range		Measuring accuracy	Operation speed	Object of measurement
	Standard	Special			
Micrometer	25mm	50mm	1-2μm	Slow	Actual length
Caliper	150mm	3000mm	20-50μm	Normal	Actual length
Dial indicator	10mm	100mm	2-15μm	Quick	Comparison

4.2 Applications of Dial Indicators

Although the dial indicator cannot measure at all without being attached to an auxiliary tool such as a jig or stand, it is an efficient, speedy, and highly accurate length measuring device when so attached. As higher macining accuracies are required for machine parts, the demand for "measurement in need on the spot" is increasing. To meet such demands, various types of inspection tools that incorporate a dial indicator are supplied for production lines. Also, in industrial fields other than length measurement, dial indicators are widely used for converting a variation in the measurement of some other quality into a change in length. For example, there is a Rockwell hardness tester and also a strain gage which incorporate a dial indicator.

5. DIAL TEST INDICATORS

While the usual dial indicators measure a workpiece through the linear displacement of a spindle, the lever-type dial test indicators measure through the circular movement of a lever which has a contact point at its end. As it is virtually frictionless and can therefore measure with a low measuring force, it possesses a very high measuring sensitivity.
However, as the contact point draws an arc, a cosine error is inherent in measurements. To minimize this error, the axis of a contact point should be set as parallel as possible to the measured surface (oriented perpendicular to the measuring direction).
From these reasons, the lever-type dial test indicators are often used for detecting surface undulations or parallelism, measuring run-out, and centering a workpiece.

5.1 Basic Structure

The lever-type dial test indicators come in two types, clutch type and no-clutch type. The no-clutch type, as-is, can measure both in the upward and downward directions of the contacting lever and the clutch type changes the measuring direction using a clutch.
In the clutch type, the direction in which measurement is performed is changed by reversing the direction of the measuring force with a clutch lever (Refe· to **Fig.5.1**).
On the other hand, the conventional no-clutch type operates as shown in **Fig.5.2**; When the contact point moves upward, section A of the arm contacts the pin on the sector, then pushes the sector (gear side) downward. When the contact point moves downward, section B of the arm contacts the opposite pin on the sector, then pushes the left end of the sector upward, resulting in the gear side going downward. This movement is transmitted through the intermediate pinion, crown gear, and center pinion and is finally converted to a revolving movement of the pointer.
However, because the conventional no-clutch type has one more fulcrum than the clutch type, the retrace error (the difference between the measured values obtained in the forward direction and the backward direction) readily becomes increased. In the cases where a high sensitivity is required, therefore, the clutch type is most often used. The no-clutch type has a rather poor shockproof capability, because the sector gear tends to over-spin, if the contact point is struck against a workpiece.
By adopting the structure of the clutch type test indi cator and giving it an anti-shock property, a new no-clutch type was developed. It is a vertical-type and

has both the convenience of the no-clutch type and the performance of the clutch type (Refer to **Fig.5.3**).

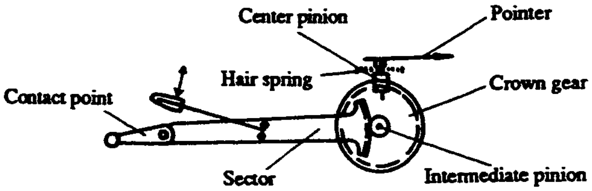


Fig. 5.1 Clutch type

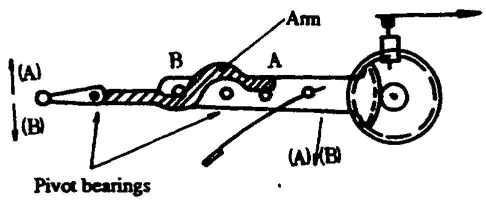


Fig. 5.2 No-clutch type

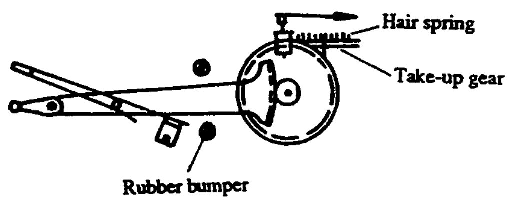


Fig. 5.3 New no-clutch type

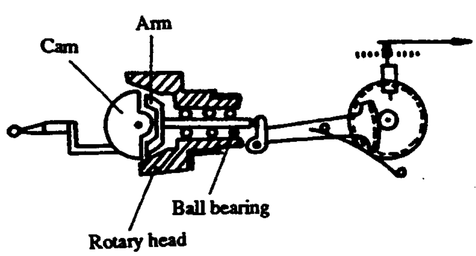


Fig. 5.4 Universal type

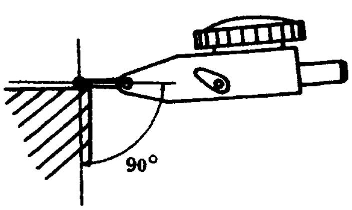


Fig. 5.5 Measuring in perpendicular direction

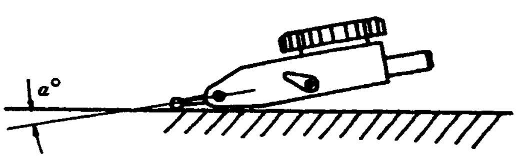


Fig. 5.6 Measuring in oblique direction

Mitutoyo no-clutch dial test indicators are provided with the following features.

① As the number of fulcrums in the route from the contact point to the pointer is one fewer than that of the dial indicators of other makers, it has a better sensitivity and causes less retrace error.
② The contact point is supported steadily by a ball bearing with a long axis, which is an innovation of Mitutoyo.
③ Provided with a take-up gear to eliminate the backlash of the crown gear. The hair spring is tough enough to prevent any deformation caused by shock or any malfunction due to contamination with oil.
④ The contact point can move continuously from the lowest point through a neutral point to the highest point and ensure correct measurements along the entire path.
⑤ Superior anti-shock capabilities. The sector can be stopped at the neutral point because the pin on the sector contacts a special spring. At the highest and lowest positions, the sector is stopped by a rubber bumper. The sector is made of heat-treated beryllium bronze. The crown gear is large, like that of the pocket type dial indicator.
⑥ Provided with three zinc diecast dovetail mounts. Each of them has a high hardness and is integrated with the housing. They allow a horizontal type dial test indicator to be mounted so it can be used as a vertical type in centering a workpiece hole. Also a stem can be attached directly to the dovetail in order to allow the stem to be inserted into the hole of a holder.
⑦ The forms of the dovetails are standard worldwide. Therefore, various holders are available for fixing the dial test indicators.

Because of the cosine error inherent to the lever-type dial test indicator in which the contact point traces an arc, the JIS provides that the contact point should be positioned so that its center line is perpendicular to the axis of measurement.
In practice, the position of the lever-type dial test indicator is inevitably slightly inclined to a long and flat measured surface, as shown in **Fig.5.6**. Therefore, there are some types developed to give the best accuracy when they are placed at a certain definite angle.

5.2 Types of Lever-type Dial Test Indicator

There are three major types of lever-type dial test indicators to suit various measuring operations: the horizontal type, the vertical type, and the parallel type. Most of them have 0.01mm or 0.002mm graduations. Each of the major types is further divided into various categories, such as the long-point type that has a long contact point for measuring inside a deep hole, the dust-proof/splash-proof type, and the clutch type or no-clutch type.

The horizontal type is most often used for measuring the run-out of a body of revolution and of a linear displacement on a workpiece.

A vertical type dial test indicator as shown in **Fig.5.7** is used for centering a workpiece hole on the X-Y coordinates of a jig borer or a vertical milling machine. This is because if the horizontal type is attached to the rotary axis of the jig borer for measurement, the operator can't see it when it is facing the opposite side. (See **Fig.5.8.**)

A new horizontal type, which has a dovetail on its slant face, is conveniently used as a vertical type, too. (Refer to **Fig.5.9.**)

In addition to the three major types described above, the new universal type (as shown in **Fig.5.4** in the previous page) has been developed. In the universal type, not only can the measuring head rotate by 360° but also the measuring direction (direction of measuring force) can be adjusted to any angle. This gives it the merits both of the horizontal type and of the parallel type along with an additional function to measure oblique directions. The 513-127 is a miniature-sized model, which has a low measuring force to ensure a high sensitivity even when it is held on a long flexible arm.

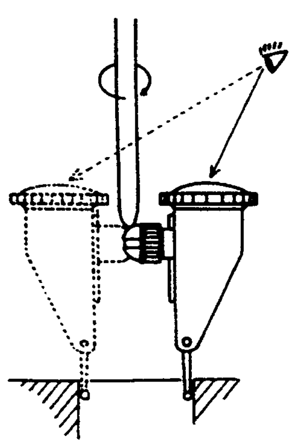


Fig. 5.7 Vertical type

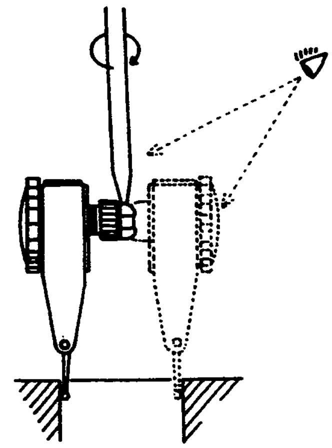


Fig. 5.8 Horizontal type

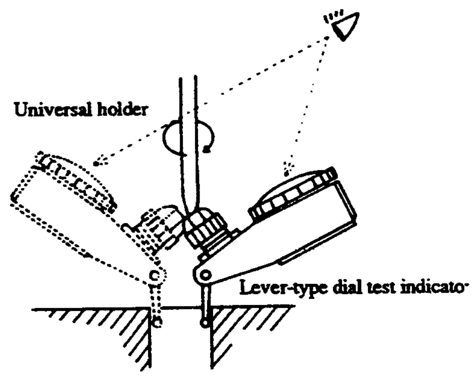


Fig. 5.9 513-127 model

5.3 Optional Accessories

As a lever-type dial test indicator is often used for run-out or comparison measurement, it is generally attached to a stand, the tool post of a lathe, or the collet chuck of a milling machine, etc.

The stem diameters are ø4, ø6, ø8 and ø9.9mm, and the holder sizes are 9mm x 9mm and 1.4 in x 1.4 in. Any combination of stem and holder can be selected, to match the application.

When measuring a workpiece with a lever-type test indicator which is attached to a machine tool and is fed automatically, the contact point may chip or the indicator body be broken if it comes across a sharply convex point or a deeply concave point on the workpiece. But if the new universal holder is used to support the dial indicator in such a case, the coupling of the universal holder will slip due to the excessive force, thus protecting the dial test indicator from damage.

6. SPECIAL APPLICATIONS OF DIAL INDICATOR

As a dial indicator cannot be used until it is attached to an appropriate jig, the frequently-used dial indicators listed below have been integrated with a standard jig.

- Dial Thickness Gage (The small type is called "pocket gage")
- Bore Gage (refer to PART II BORE GAGES.)
- Dial Snap Gage
- Dial Depth Gage
- Dial Caliper Gage

6.1 Dial Thickness Gage

This gage measures the thickness of a workpiece inserted between the contact point of the spindle and the anvil which is fixed to the frame. There are two types, one that has a dial indicator attached to the frame and another that incorporates a dial indicator in the frame. The former has either standard 0.01mm graduations or optional 0.001mm graduations. Their anvil and contact point will be either flat or spherical. There are some types called "Dial lens meter" or "Dial pipe gage" (Refer to **Fig.6.1**).
As an example of the latter type, a pocket gage (7360, 7309) which has a dial indicator integrated in the frame, and the 7331 model which is a compact type of the standard dial thickness gage model 7301, are supplied (Refer to **Fig.6.2**).

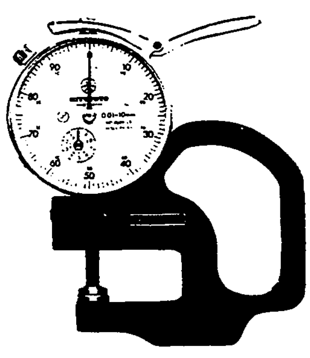


Fig. 6.1 Dial thickness gage

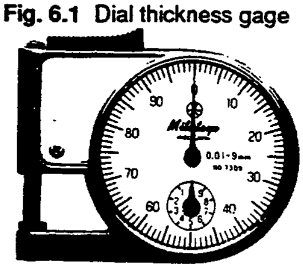


Fig. 6.2 Pocket gage

6.2 Dial Snap Gage

This gage is used for measuring the diameter of a cylinder while it is mounted on a machine tool for precision machining. The measurable diameter of the snap gages ranges up to 300mm in 12 steps. Provided with a workpiece stopper. The major use is the dimensional control of grinding.

Fig. 6.3

6.3 Dial Depth Gage

This is used to measure the depth (top face to bottom face) of a cylindrical hole, a narrow groove, or a step height. It can measure a depth of up to 200mm using various lengths of extension rods.

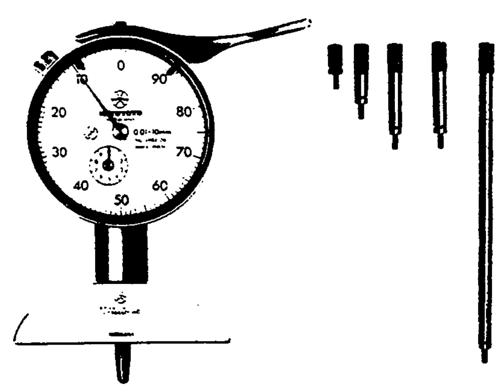


Fig. 6.4

7. NOTES ON USE OF DIAL INDICATORS

7.1 Stands

Generally, a certain level of accuracy is required for measurement even when the temperature or other conditions do not perfectly meet the industrial standards of measurement.
By applying the principle of comparison measurement it is possible to minimize measurement errors, by selecting the stand and zero-setting gage to correspond to the workpiece in form and size in order to offset the effect of the expansion or contraction of the materials.
In a measuring room or for use in measuring a large-sized workpiece, a stationary stand which has a thick column and ample weight is desirable for accurate measurement. On the other hand, to measure a small-sized workpiece on a shop floor, it is better to use a light weight stand.
There are various types of stands for supporting the dial indicators, depending on the measuring purpose and conditions.

- Dial gage stand
  Used in measuring precision small parts. Depending on the workpiece type, a flat anvil, serrated anvil, or a domed anvil can be used. The measuring range is 0 to 100mm.

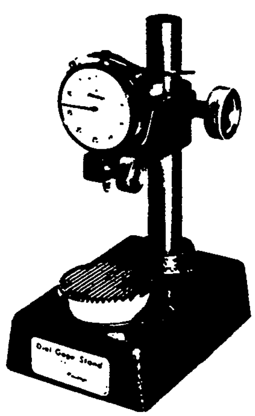


Fig. 7.1

- Granite comparator stand
  Used for general measurement. Has a granite (or ceramic) anvil to prevent the workpiece from sticking.
  Measuring range is 0 to 100mm.

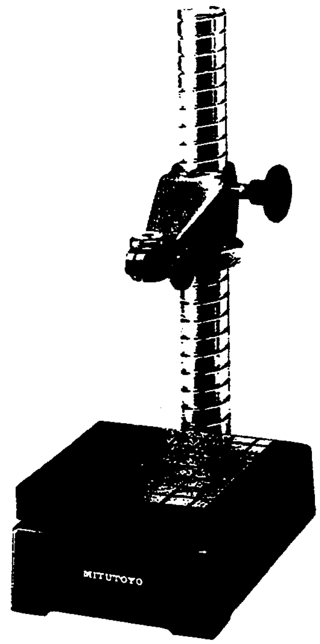


Fig. 7.2

- Magnetic stand
  Is attached either to a surface plate or to a machine on the shop floor.

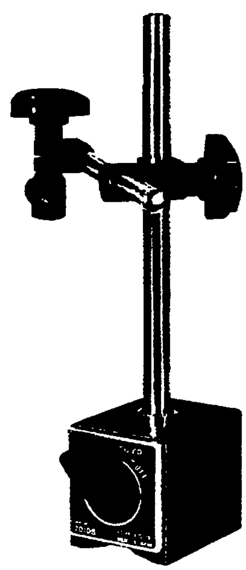


Fig. 7.3

- BS type comparator stand (215-403)
  For shop floor use. Measuring range is either 0 to 150mm or 0 to 250mm. For small to medium sized workpieces. Can use whatever anvil is appropriate for the measuring purpose.

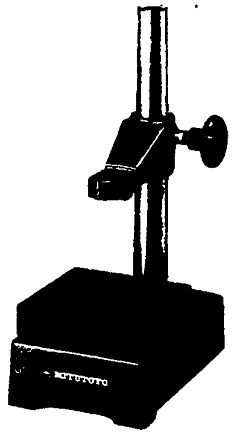


Fig. 7.4

- KS type comparator stand (215-813)
  For precision measurement. Generally mounts the serrated anvil to perform comparison measurement with gauge blocks.
  Measuring range is 0 to 150mm.

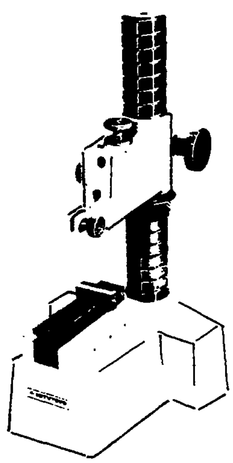


Fig. 7.5

- Transfer stand (519-109)
  For large-sized workpieces. It has an anvil, but the stand itself, instead of the workpiece, is moved when it is used in combination with a test indicator or an electronic comparator on a surface plate.
  Measuring range is 0 to 300mm (0 to 450mm on a surface plate).

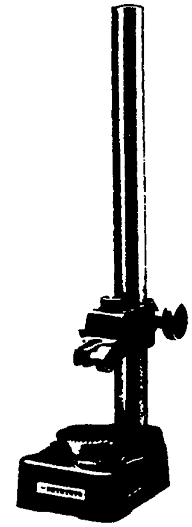


Fig. 7.6

- Transfer stand (heavy duty type) (519-251)
  For large-sized precision workpieces. Generally used on a surface plate in a precision measuring room. It has an anvil, but the stand itself, instead of the workpiece, is moved when it is used in combination with a test indicator or an electronic comparator on a surface plate.
  Effective measuring range is to 450mm.

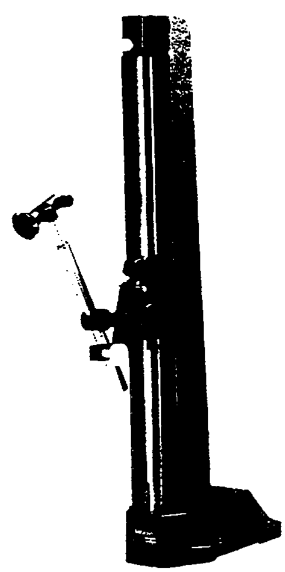


Fig. 7.7

Beside the above described specific-purpose stands, the lever-type dial test indicators can be attached to a Height Gage.

7.2 Measuring Force and Supporting Tool

In order to magnify a minute spindle displacement into an accurate angular change of the pointer, or to withstand a shock caused when the spindle strikes a workpiece surface, the dial indicator is required to have an appropriate measuring force.

The measuring force is mostly given by the internal coil spring, however, the force is affected by the anti-backlash hair spring and by the position of the spindle as well. Although the measuring force of a spindle cannot be constant for every spindle position within the measuring range (changing with the flexure of the spring), its variation should be as constant as possible. This does not matter much when the dial indicator is held firmly on a jig or when it is used for a comparison measurement for a narrow measuring range. Increasing the complexity of the internal mechanism to reduce the variation of the measuring force has the side effect of increasing friction, resulting in a discrepancy between the measuring force in the forward direction and that in the backward direction, which will reduce the measuring stability and increase the retrace error.

When a dial indicator is held at the end of a long arm of a stand, as shown in the diagram below, the deflection of the arm varies due to a change of measuring force or due to the hysterisis of the arm itself. This affects the perpendicularity of the spindle movement to the workpiece surface, and a reduction of sensitivity or an increase of retrace error results. In such cases correct measurement is not guaranteed.

For the stand, use a column as thick as possible and an arm as short as possible. This is because the deflection is proportional to the cube of the column length, and inversely proportional to the diameter to the fourth power. **Table 7.1** shows how the deflections vary with the measuring forces and stand lengths. The figures clearly show that the deflection of arm varies much with the diameter (D) of the main column and the diameter (d) of the arm.

Therefore, it is recommended to use a lever-type dial test indicator, which has a low measuring force, in measuring the run-out of an axle.

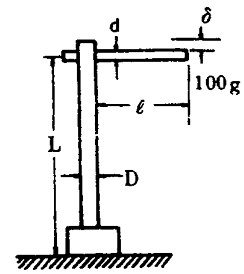


Fig. 7.8 Bending of measuring head supporting portion

In order to make the variation of measuring force as small as possible within the spindle stroke, Mitutoyo dial indicators adopt a special structure including a long coil spring.

In order to use a low measuring force and, at the same time, to restrict the variation of the measuring force, Mitutoyo has released two types that incorporate jeweled bearings to reduce friction, the 2046-10 (measuring force: 80gf or less) and the 1044-10 (measuring force: 40gf or less).

The 1044-10 type can measure the thickness of soft plastic materials by using a flat contact point.

Table 7.1 Arm deflection with the measuring force

Arm length (mm) L x *l*	Measuring force (gf)	Deflection δ (μm) D = ø12 d = ø10	Deflection δ (μm) D = ø22 d = ø15
100 x 50	100	1.6	0.2
100 x 100	100	8.0	1.2
200 x 50	100	2.8	0.4
200 x 100	100	12.5	1.8
200 x 150	100	21.4	3.3

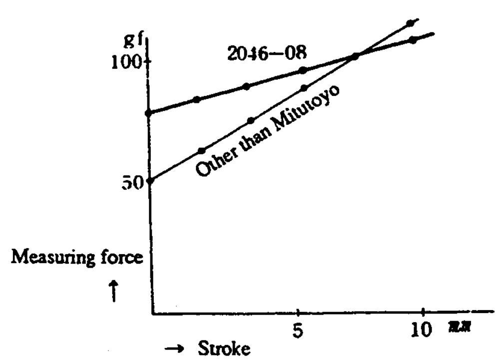


Fig. 7.9 Variation of measuring force

7.3 About the Jigs for Dial Indicators

Dial indicators always need to be held on a jig to perform measurement. Often the measurement jig costs much more than the dial indicator to design and manufacture. To save the expense of such jigs, Mitutoyo dial indicators are designed so that they can be attached easily to general purpose, low-cost jigs.

① The stem is hardened so that it can be directly screwed-down to a jig. Therefore, a dial indicator can be used as a depth gage, when it is attached to a depth measurement jig, as shown in **Fig.7.10**. Depending on the measuring depth, a 10mm, 20mm, or 30mm stroke type can be selected, and an 0.001mm reading type is available for high-accuracy measurement. Holes provided close to the jig end will be useful if a depth near the hole brim is to be measured by the dial gage. When measuring the depth of a hole in a small-sized part, a ring-type jig that has a side screw hole, as shown in **Fig.7.11**, is sufficient. In both cases, as long as its fastened tightly by the screw, the dial indicator is never loose.

② As the back is secured by four screw positions, the center lug can be oriented either up or to the side. When the center lug is oriented to the side, the dial indicator can be held either by a simple measuring stand, made from two cylindrical bars as shown in **Fig.7.13**, or by a block as shown in **Fig.7.14**, so that the dial indicator can rotate at its lug hole or have the freedom to displace a little for centering a screw, or pipe, etc.

③ The top-cap side spindle has M2.5 screw threads to attach a contact point. This is convenient in measuring inside diameters with the measuring direction reversed as shown in **Fig.7.14**.

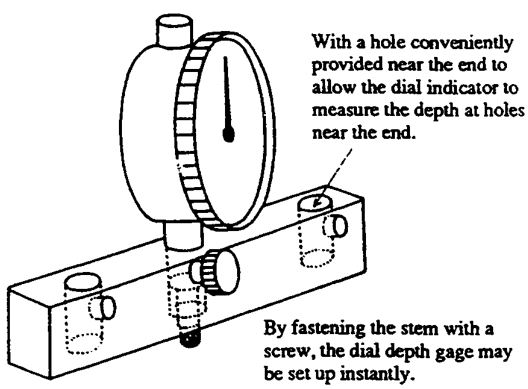


Fig. 7.10 Jig for depth measurement

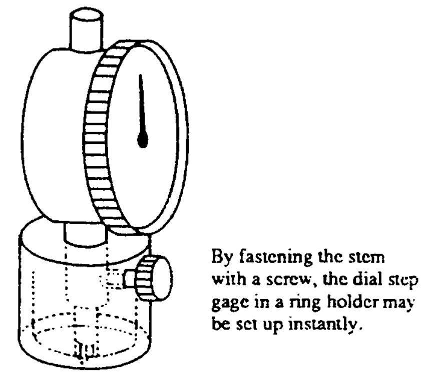


Fig. 7.11 Jig for step measurement

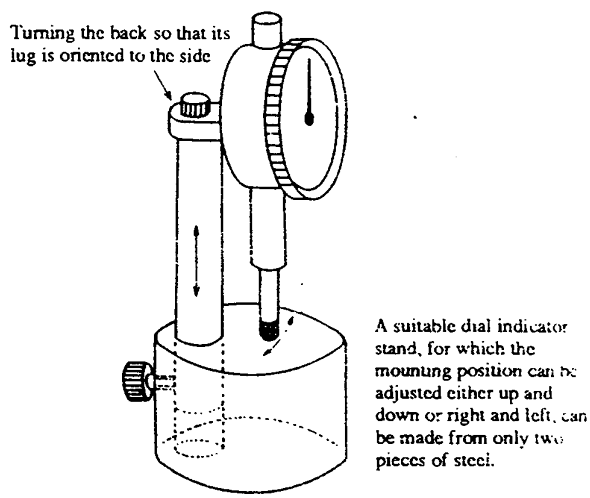


Fig. 7.12 Hand-made stand

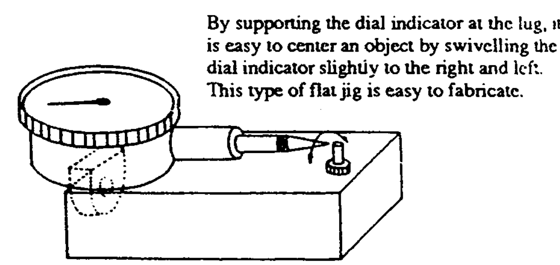


Fig. 7.13 Centering a pipe or screw

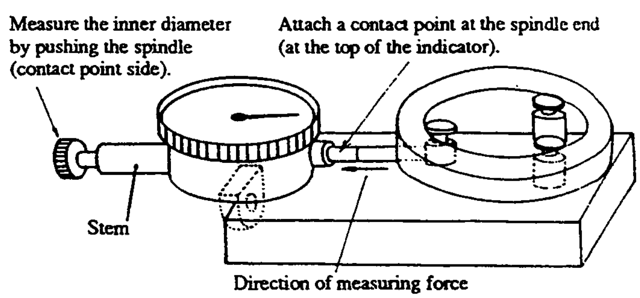


Fig. 7.14 Measuring an inner diameter

7.4 Inspection of Functions and Performance

(1) Inspecting the appearance and functions

Dial indicators and lever-type dial test indicators must be inspected on receipt in accordance with the in-house or national standards, and must be periodically inspected afterwards at the inspection intervals determined by the user's own periodic inspection codes. (For details, refer to the separate Mitutoyo textbook titled "Periodic Inspection".)

Even when the dial indicator is inspected according to the above described codes, it is still desirable to check the following points each time before the measurement.

① Ensure that the spindle moves smoothly and makes no abnormal sounds when it is extended and retracted several times through its full stroke range.

② Ensure that the pointer tip has a clearance of 1mm or less above the dial face. Ensure that the clearance is even during a full pointer revolution.

③ Check the stability of dial reading by measuring the same point several times. Check also if the pointer lags (it is loose on the supporting pin) or if the holder clamp or the screw thread of the contact point is loose.

④ Check if the crystal, tolerance limit marker, or clamp is missing. Check also if the pointer is broken or bent.

(2) Performance check

The dial indicators must be inspected on receipt and periodically afterwards on the following points: wide range accuracy for forward spindle displacement, narrow range accuracy for forward spindle displacement, narrow range adjacent error, retrace error, and measuring force. (For details, refer to the separate Mitutoyo textbook "Periodic Inspection".)

(3) Maintenance and storage

The dial indicators should be stored in a place where they will not be subjected to a significantly high temperature or to a high relative humidity. The person responsible for the storage should be aware of the special storage requirements and manage the storage place accordingly. The inventory must be stocked and periodic inspections must be carried out. The codes for the periodic inspection should be established as in-house standards.

7.5 Reduction of Measurement Errors

The measuring error of a dial indicator can be minimized, theoretically, by observing the ideal operating conditions and correct operation procedures. However, in practice, dial indicators are generally used in harsh shop floor conditions and in haste, making it difficult to reduce measuring errors.

In particular, product dimensions are always defined at the industrial standard temperature of 20°C. The requirements for correct operations and the requirements of practical use seem to be contradictory, but the problem can be overcome if the measuring instrument and the workpiece are both biased from the ideal conditions to the same degree (temperature, etc.). This principle is known as "comparison measurement".

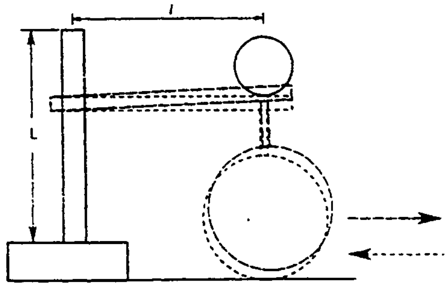
The notes described below are therefore especially to minimize the measurement error in the use of dial indicators and lever-type dial test indicators.

① However smoothly the spindle of a dial indicator may move, it cannot be perfectly free from friction; there will be inevitably a difference between the measuring forces in the forward and backward directions. In order to minimize this difference, as described in **7.2 Measuring Force and Supporting Tool**, the arm holding the dial indicator should be as short as possible to prevent a small displacement in measurement from being absorbed by the deflection of the arm. In order to avoid such displacement absorption effects, move the lifting lever as slowly as possible, or measure with a measuring force in the forward direction only. In addition, review whether the sensitivity of the dial indicator suits the measurement.

② Consider the error caused when the measuring direction is not aligned with the direction of spindle displacement (Refer to **Figs.5.5** and **5.6** for lever-type dial test indicators). This is partially explained as a "cosine error", and is described in section **5.1**.

③ In order to prevent parallax error, read the graduations so that your line of sight passes through the pointer and is perpendicular to the dial face.

④ Always insert the workpiece from the same direction, because the deflection of the stand varies with the direction of friction, as shown in the figure below.



On a sturdy stand: 0.4 to 2.6μm difference
On a thin stand: 2 to 12μm difference, where L=100mm, l =100mm and the workpiece is machined.

Fig. 7.15 Inserting direction and reading

8. DIGIMATIC INDICATORS

In contrast to the conventional dial indicators which display the measured values mechanically by means of the revolution of a pointer, those which can display the measured values electrically on a digital display are called "Digimatic Indicators" (ID).
The benefits of digitization of dial indicators include: that new functions can be added to them, reading errors can be prevented because of the digital display, and they are ready to output measured data because it is already converted into electrical signals. In addition, various data processing systems including the Mitutoyo DP series have been developed for statistical processing and printout, which is a powerful tool for quality control and labor saving.

The basic construction of a Digimatic indicator (ID) has a linear encoder built in that will electrically read the main scale displacement, as shown in **Fig.8.1**. This structure completely did away with the mechanical displacement magnifying system and has the capability of measuring a wide range to accuracies which the mechanical dial indicators have never attained.
There are two detecting systems, a photoelectric type and a capacitance type.

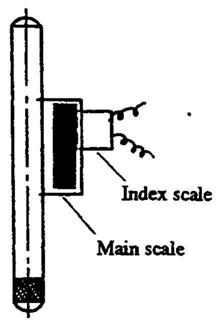


Fig. 8.1 Structure of a Digimatic indicator

8.1 Photoelectric-type Digimatic Indicators

This method is to shine a light through gratings marked on a glass scale and to convert the variation of light intensity into electrical signals. Mitutoyo ID series indicators adopt this photoelectric system.

8.2 Capacitance-type Digimatic Indicators

This method is to read directly the variation of capacitance between the two electrodes which are provided on the main scale and index scale. A significant virtue of this method is that the indicator can be driven by a button type battery (SR-44), and therefore requires no power cord, because it has a very low power consumption.
Mitutoyo IDA and IDC series have almost the same size circular face as the AGD series 2, and have a rotary bezel (up to 330° in IDC series). All these features allow the Digimatic indicator to use the same jigs that are designed for conventional dial indicators.

8.3 Functions Provided with the Digimatic Indicators

1) Zero-set function
The digital display can be zero-set at any position within the measuring range. This eliminates the need for a gage stand to fine-adjust its position to zero-set the Digimatic indicator, therefore the stand can have the ideal structure of a thick column (30mm) and a simple and rigid bracket, allowing the indicator to make stable measurements.
There are some types that have two interchangeable modes for absolute measurement and for comparison measurement.
2) Output function
It is possible to connect the Digimatic indicator to a Mitutoyo Digimatic Mini-Processor for statistical processing and data printout.
It is also possible to transmit signals to an external computer. Interfaces are available for converting the data into BCD or RS-232C format.
3) Direction changeover function
The direction of counting the spindle's retracting motion can be either positive (this is normal) or negative.
4) Preset function
The initial counting position can be set to a desired value. Therefore, if used in combination with a gauge block, it can read a measured value

which may exceed the measuring range of the dial indicator.

5) Tolerance judgment function (tolerance limit setting)
   By preliminarily setting upper and lower tolerance limits, it is possible to make GO/±NG judgements of the measured values (on IDA series).
6) Bar graph display function
   On the Digimatic indicator IDA series, it is possible to make an analog display with a bar graph in addition to a digital display. The resolution of the bar graph can be switched between 1μm and 10μm.

APPENDICES

1. Types of Magnifying Mechanisms

A comparison measuring instrument that magnifies a minute linear displacement mechanically and reads it as the pointer's angular change on a dial face is called a microindicator (if the pointer does not revolve more than one turn) or a dial indicator. They may be classified into the following types, as discriminated by the displacement magnifying mechanism adopted:

(1) Using a single lever (Refer to **Fig.1.**)
(2) Using a multiple lever mechanism (Refer to **Fig.2.**)
(3) Using a combination of lever and gear (Refer to **Fig.3.**)
(4) Using parallel reeds (Refer to **Fig.6.**)
(5) Using a twisted reed (Refer to **Fig.7.**)
(6) Using gears only (Refer to **Fig.8.**)

In addition, the following types of bearings and spindle guides, etc. are used in the above dial indicators.

- As the bearing for the revolving axis:
  Combination of a knife edge and support, special ball bearing, jewelled bearing, a plate spring (crossed spring or twisted spring).
- As the spindle guide:
  Sliding guide (plain guide), spring suspension guide.
- For zero-setting the dial:
  Adjusting the pointer by the internal mechanism, adjusting the dial face by turning it.

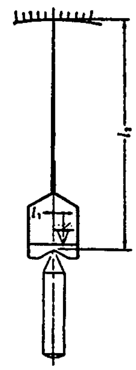


Fig. 1 Single lever type

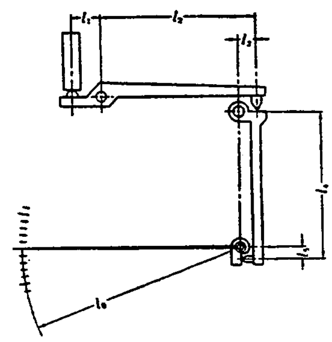


Fig. 2 Multiple lever type

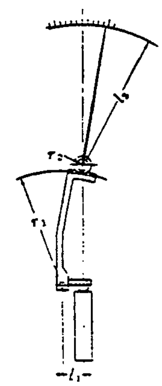


Fig. 3 Combination of lever and gear (principle of magnification)

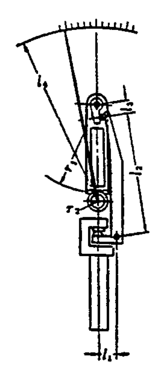


Fig. 4 Combination of lever and gear (two-stage magnification by multiple lever)

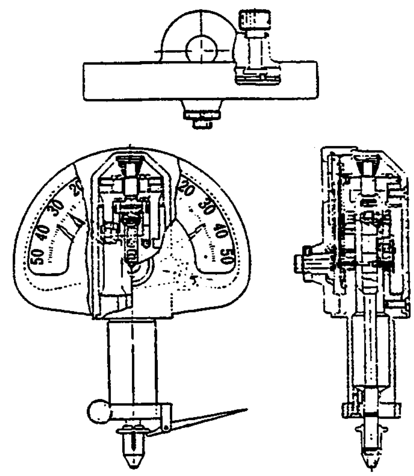


Fig. 5 Combination of lever and gear (microindicator)

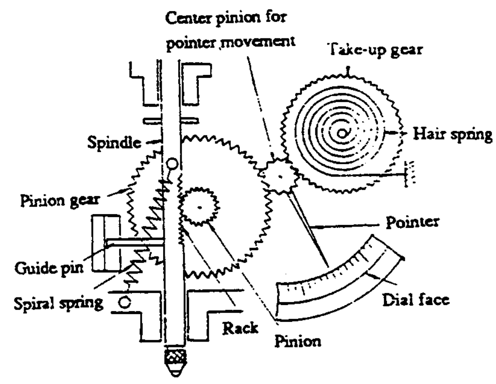


Fig. 8 Gear type (0.01mm)

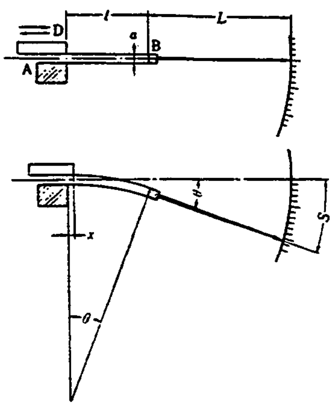


Fig. 6 Parallel-reed type

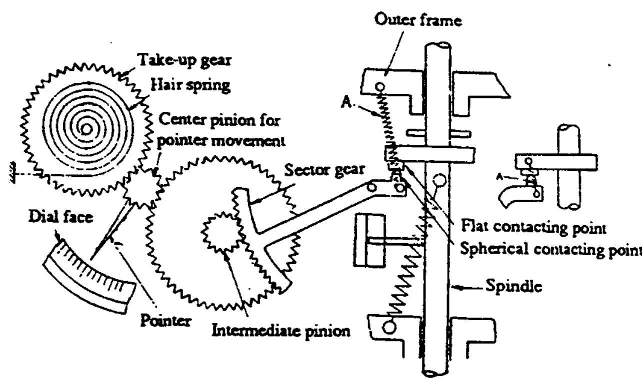


Fig. 9 Combination of lever and gear (0.001mm reading)

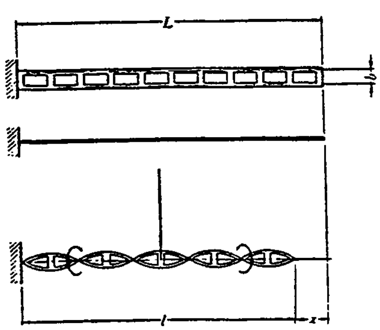


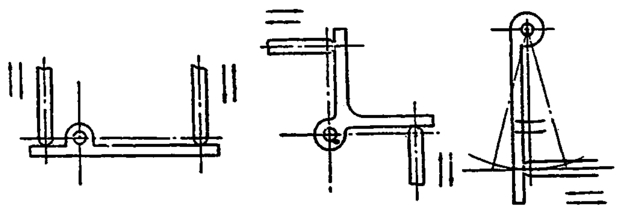
Fig. 7 Twisted-reed type

2. Mechanical Elements for Magnification

This chapter explains the mechanical elements used for dial indicators, highlighting their physical characteristics.

2.1 Lever

A lever is a well-known means to transmit a mechanical motion, and is used widely in various machines, tools, and other precision instruments. In addition to knowing that the lever transmits a force, it is necessary to know a principle of leverage as stated "Applied force x Distance from fulcrum = Constant".



(a) (b) (c)

(a) The scope of motion is magnified or reduced.
(b) Direction of motion is changed.
(c) Linear displacement is converted to angular displacement.

Fig. 10 Function of lever

Section (a) of **Fig.10** shows a mechanism either to magnify or reduce the scope of motion applied, section (b) shows a change of the direction of motion, and section (c) shows a change from linear displacement to angular displacement.

It is very important to note that when a linear displacement is converted to an angular (circular) displacement by means of a lever, or vice versa, there is always a trigonometrical transformation involving the direction of motion and the range of motion. For example, on a microindicator which uses a sector lever, the contact point must be placed as perpendicular as possible to the measured surface to eliminate the cosine error as previously explained. (Importance of linearity)
In other cases where you would rather increase the measurement repeatability and reduce the retrace errors than correctly convert a displacement between a length and an angle, the friction of the contacting points should be minimized. (Importance of smoothness)

2.1.1 Length of a lever

The point where the spindle pushes a lever has a structure called a "knife edge". As shown in **Fig.11** below, the longer the lever becomes (from the fulcrum to the point where the force is applied), a unit of linear displacement of the knife edge produces a decreasing angle of revolution of the lever, and vice versa. This relationship is expressed by the following formula.

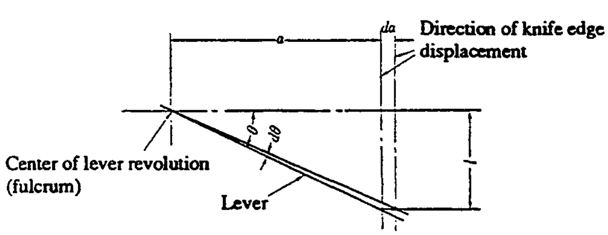


Fig. 11 Knife edge displacement and angle of lever revolution

Suppose that the horizontal distance from the fulcrum to the contacting point of knife edge be a, the linear displacement of knife edge *l*, and the angle of revolution θ, *l* can be given by the following;

$$l = a \cdot \tan\theta$$

If there is a positional error da with respect to a, the resultant angular error dθ can be calculated by the following formula;

$$d\theta = -l/(a^2 + l^2)\, da$$

From this formula, it is seen that the larger the a becomes, the revolution error dθ is reduced as compared to the error da. Therefore, in designing a dial indicator which has a lever magnifying mechanism, the length a should be as large as possible, while taking the magnifying ratio into consideration.

2.1.2 Form and position of knife edge tip

The tip of a knife edge generally has a spherical surface with a small radius of curvature. This tip will be subjected to elastic deformation due to the friction and force caused by a contact with the lever. Supposing that the tip has a radius of curvature **r** and the lever is correctly positioned (the linear displacement is perpendicular to the contacting surface of the lever), there are two cases to consider on the relationship between the contacting point of the knife edge and the center of lever revolution, as follows:

(1) When the contacting point exists on a plane which includes the center of lever revolution
If the lever revolves in both the positive and negative directions by the same angle θ, the forward displacement of the knife edge l_1 and the backward displacement l_2 provide the following relationship;

Forward: $l_1 = l - \Delta l$
Backward: $l_2 = l + \Delta l$
As $l = a \cdot \tan\theta$, therefore;
$\Delta l = -r\,(1 - \sec\theta)$
$l_1 - l_2 = 2r\,(1 - \sec\theta) < 0$

Thus, it is shown that the linear displacement is not transmitted proportionally to the circular displacement.
However, since the tip has a small radius of curvature so that the friction is negligible and the

lateral displacement is small, the transmission of motion is very smooth.

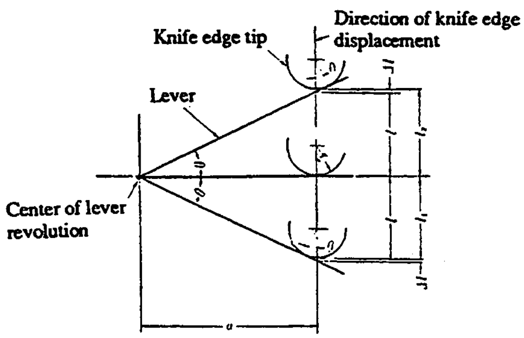


Fig. 12 When the contacting point exists on a plane which includes the center of lever revolution

(2) When the center of the knife edge tip is on a plane which includes the center of lever revolution

In this case, the contacting point is on a plane which is parallel and distant by the radius of tip curvature r to the other plane which includes the center of lever revolution. (Supposing that a circle with the same radius as the knife edge tip exists at the center of revolution of the lever, the contacting point is on the external tangent line of the two circles.)

Therefore, the difference in the relationship between the angle of lever revolution and the displacement of the knife edge from case 1) will be as follows;

Forward: $l_1 = l'_1 - r - \Delta l$
Backward: $l_2 = l'_2 + R + \Delta l$
As $l = r(\sec\theta - 1)$, therefore;
$l'_1 = a \cdot \tan\theta + r \cdot \sec\theta$
$l'_2 = a \cdot \tan\theta - r \cdot \sec\theta$

$l_1 = l_2 = a \cdot \tan\theta$

This leads to the conclusion that the amount of knife edge displacement in both the forward and backward directions is the same if the angular displacement for both directions are equal.

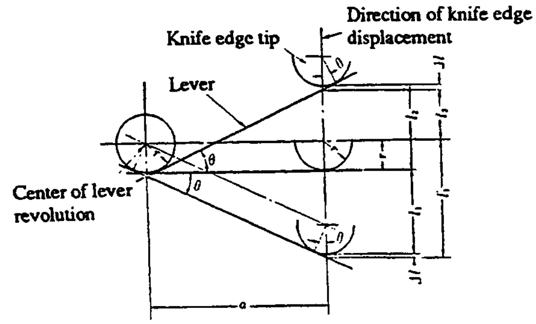


Fig. 13 When the center of the knife edge tip is on a plane which includes the center of lever revolution

2.2 Gears

Gears are used to transmit angular displacements which are magnified or reduced depending on the ratio of the number of teeth between each pair of gears. In precision instruments gears are used to attain a high ratio of magnification. Especially in dial indicators, it is very important to correctly magnify and accurately transmit the angular displacement. For this purpose, dial indicators most often use involute gears. However, as it is hard to precisely manufacture a small gear with a small number of involute teeth, to a certain extent errors are unavoidable in the gear transmission. If the primary magnification mechanism for precision measurement uses gears, errors inherent to the gears will greatly affect the subsequent transmission of displacement. Therefore, 0.001mm reading dial indicators use a lever, instead of gears, for the primary magnification.

2.2.1 Geometrical errors of gears

As it is hardly possible to process gear teeth in a true involute form, every gear has more or less geometrical errors with respect to profile, thickness, center distance, eccentricity of pitch circle, lead angle, etc. depending on the shape of the cutter or various conditions in processing including the method of mounting the gear material. For dial indicators, the eccentricity of a pinion gear is crucial to correct measurements.

2.2.2 Sector gear and its angular position

As shown in **Fig.14**, the center of gravity of a sector gear is not on the axis of rotation. This makes the rotating torque of the sector gear vary with its angular

position, which is a cause for various errors.
In Fig.15 a counterweight is used for moving the center of gravity into the center of rotation so that a uniform rotating torque is given at any angular position. In other words, the contacting pressure on the tooth flank is always constant. However, small-sized and light-weight sector gears may be used as-is, without taking particular balancing measures.

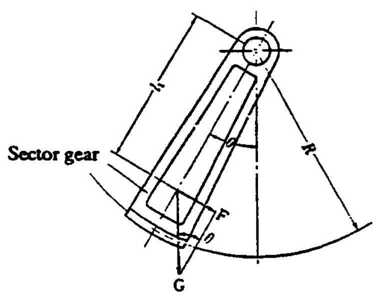


Fig. 14 Sector gear and its angular position

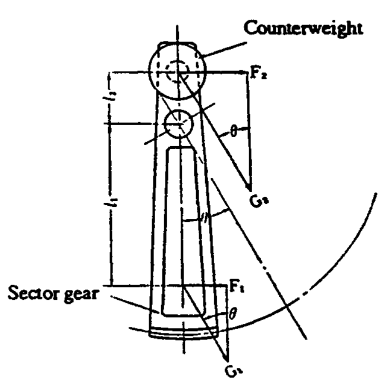


Fig. 15 Sector gear with a counterweight

2.3 Bearing

Different from those used for general machines, bearings incorporated in precision instruments are not subject to a large load and their axes have only a low speed and a narrow range of angular movement. Friction on the bearings will directly affect the measuring accuracy. Therefore, the smaller the rotating torque becomes, the more the importance of bearings increases. This is why the bearings in precision instruments such as a dial indicator, balance, watch, and so on should have low friction and yet sufficient durability.

Bearings of precision instruments are required to have the following features:

① Low friction. As on the measuring instruments driven by a small torque the friction will directly affect the measuring accuracy, this should be the most important characteristic. A significant increase of friction due to seizure of or galling on the bearings should be avoided as much as possible.
② Wear resistance and durability. Hard materials are generally used for bearings, except some types of journal bearing. However, if the axis and a bearing have the same hardness, wear may be accelerated. It would be better if they had an appropriate difference in hardness.
③ Corrosion resistance. A bearing should be made from a uniform composition of high-quality materials. It must also be properly processed against corrosion.
④ Toughness against a specified load. Since in precision instruments the contacting area between the axis and bearing is small in order to reduce friction, such as in a pivot bearing, the specific load per area of contact can be considerable even if the actual load is small. In addition, as the bearings are the major parts that encounter external vibrations and impacts, they should have the capacity to withstand a dynamic load more than 10 times larger than the anticipated static load.
⑤ Lubrication. If required, the lubrication must be of a quality so that the it is not lost or does not deteriorate too quickly.
Beside the above listed conditions, the bearings used for precision instruments should be provided with the following properties:
Compact and light-weight, ease of getting the material, simple structure for easy manufacture, ease of maintenance and repair, low cost, sealed from water or dust, no vibration, no sound, and no heat.

There are various types of bearings that include a journal bearing (or called a "plain bearing", including a jewelled bearing), a pivot bearing, ball bearing (including a miniature ball bearing), a knife edge (knife edge and support), an elastic bearing, fluid bearing, and magnetic bearing, etc.

PART II BORE GAGES

INTRODUCTION

The bore gage is an application of the dial indicator.
A bore gage is very easy to handle, and is useful for measuring bore diameters of a same nominal size. Some bore gages can measure the bore diameters in deep positions with the aid of an extension rod.
Bore gages are divided into two types depending on the method of changing the direction of the displacement of the contact points: 1) Cam type and 2) Cone type. Descriptions of the structure and use of each type of bore gage follow.

Note) JISB7515-1982 (Definitions)

(1) Bore gage: A gage in which the displacement of a plunger is mechanically transmitted in a direction perpendicular to its displacement, to an attached indicator, such as a dial gage, on which the displacement of the plunger can be read.

(2) Effective measuring range: The operating range of the plunger within which the performance of the bore gage is warranted. In general, it is the range from the origin, which is the position where the plunger is pressed in 0.1mm, to the position where the plunger is pressed in 1.2mm more.

1. TYPES AND CONSTRUCTION

1.1 Cam Conversion Type

In bore gages the displacement of the plunger is transmitted at a right angle, therefore there are various shapes of cams available as shown in **Fig.1.1**.
Mitutoyo bore gages for measuring the inside diameters from ø18mm to ø400mm are manufactured using shape (a) to conform to JIS B7515, and those for measuring inside diameters from ø6mm to ø18mm are manufactured using shape (c) to conform to JMAS (Japan Precision Measuring Instrument Association Standard) 5009. **Figs.1.2** and **1.3** show the representative constructions of bore gages using shapes (a) and (c).

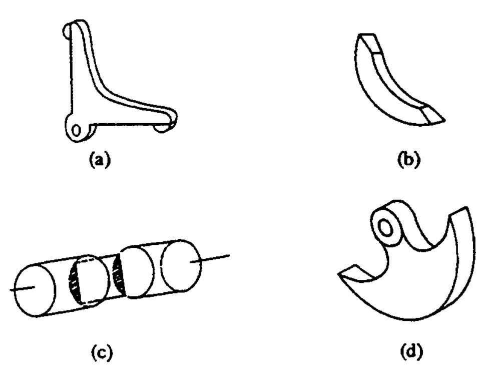


Fig. 1.1 Types of cams

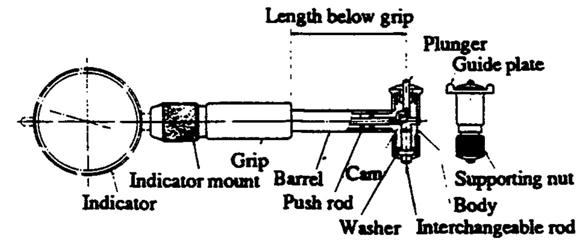


Fig. 1.2 Large hole bore gage

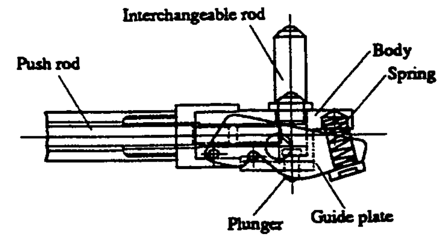


Fig. 1.3 Miniature hole bore gage

1.1.1 Large hole bore gage (ø18mm to ø400mm)

Fig.1.2 shows the external view and names of each component of a bore gage for measuring large holes. The JIS specifies as shown in **Fig.1.4** that the displacement range of the plunger should be more than 1.4mm, therefore after a margin of 0.1mm is subtracted for each end, the effective measuring range becomes 1.2mm. The measuring accuracy is guaranteed within this effective measuring range.
In order to set a measuring range of the bore gage according to its target bore diameter, a combination of an interchangeable rod and a number of washers is used; the former is used for a rough adjustment to the target bore diameter and the latter is used for finer adjustment. An appropriate interchangeable rod should be selected so that the target dimension to be measured comes closest to the center of the effective measuring range. On the other hand, the interchangeable washers have a thickness at 0.5mm increments. When an interchangeable rod is set in position, the plunger of the bore gage is extended 0.7mm over the target dimension (Refer to **Table 1.1**).
In attaching a dial indicator to a bore gage, fasten the stem of the dial indicator taking into consideration that the plunger of the bore gage has a displacement range of 1.4mm.

Table 1.1 Product specifications varying with the measuring range from 18 to 400mm

Unit: mm

Measuring range	Interchangeable rod		Interchangeable washer		Measuring depth	Remark
18 - 35	18, 20, 22···34	9pcs.	0.5, 1	2pcs.	100 (500)	
35 - 60	35, 40, 45···60	6pcs.	0.5, 1, 2, 3	4pcs.	150 (1000)	
50 - 100	50, 55, 60···100	11pcs.	0.5, 1, 2, 3	4pcs.	150 (1000)	
50 - 150	50, 55, 60···100	11pcs.	0.5, 1, 2, 3	4pcs.	150 (1000)	*
100 - 160	100, 105, 110···160	13pcs.	0.5, 1, 2, 3	4pcs.	150 (1000)	
160 - 250	160, 175, 190···235	6pcs.	0.5, 1, 2···6	7pcs.	250 (1000)	
250 - 400	250, 265, 280···310	5pcs.	0.5, 1, 2···6	7pcs.	250 (1000)	*

Note 1: The bore gage of 50-150mm range is provided with a 50mm sub-anvil, and that of 250-400mm range is provided with a 75mm sub-anvil.

Note 2: Figures in parentheses in the measuring depth column show the maximum dimensions when the optional extension rod is used.

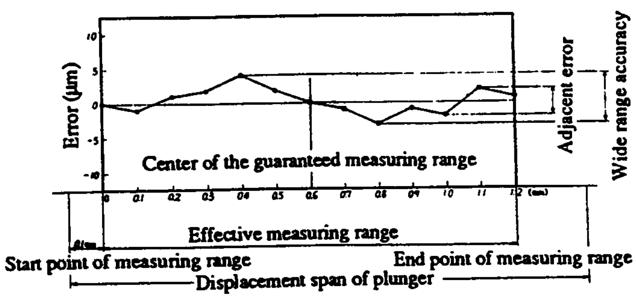


Fig. 1.4 The start and end points of effective measuring range

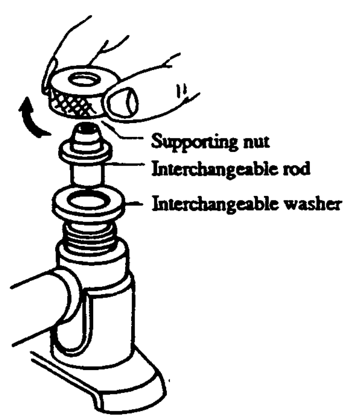


Fig. 1.5 Replacing an interchangeable rod

1.1.2 Small hole bore gage (ø6mm - ø18.5mm)

Fig.1.3 shows the external view and names of each component of the bore gage for small holes. The bore gages for small holes are classified into the following two types depending on their measuring range.

(a) For a range from ø6mm to ø10mm
(b) For a range from ø10mm to ø18.5mm

The effective measuring ranges of these two types are shown in **Figs.1.6** and **1.7** respectively. Type (a) has an effective measuring range of 0.5mm, and type (b) has an effective measuring range of 0.6mm. Within the above described ranges, the measuring accuracy of each bore gage is guaranteed. When the measuring range needs to be altered, type (b) uses an interchangeable rod only and type (b) uses a combination of interchangeable rod and washer. (Refer to **Figs. 1.8** and **1.9**, and **Table 1.2**.)

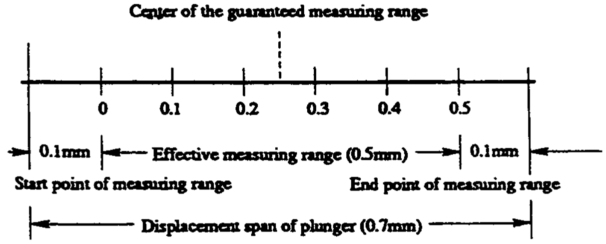


Fig. 1.6 Effective measuring range of type (a)

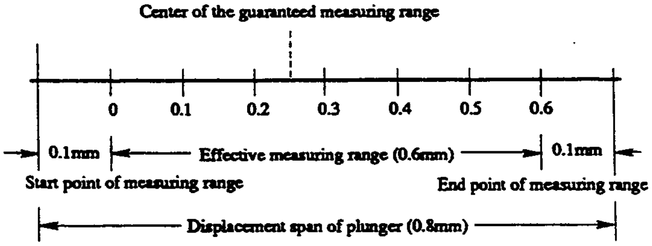


Fig. 1.7 Effective measuring range of type (b)

Table 1.2 Product specifications varying with the measuring range from 6 to 18.5mm

Unit: mm

Measuring range	Interchangeable rod	Interchangeable washer	Measuring depth	Supplied accessory
6 – 10	6, 6.5, 7···10 9pcs.	None	47	Wrench
10 – 18.5	10, 11, 12···18 9pcs.	0.5 1pc.	100	Tweezers

1.1.3 Bore gage with a micrometer head

The effective measuring range of a bore gage is generally so narrow that the measuring range must be altered by replacing the interchangeable rod or washer, and the bore gage must be zero-set each time a rod or washer is replaced.
In order to eliminate the need for replacing the interchangeable rod as described above, a bore gage with a micrometer head uses the micrometer head instead of an interchangeable rod so that the measuring range can be altered within the stroke range of the micrometer head. The structure is shown in **Fig.1.10**. Unlike bore gages which need interchangeable rods and washers, the bore gage with a micrometer head can set a measuring length exceeding the displacement range of the micrometer head by merely replacing a sub-anvil. In addition, when a reference dimension is set with a ring gage or a master gage, the measuring length of the bore gage itself can be set by operating the micrometer head. The product specifications are shown in **Table 1.3**.

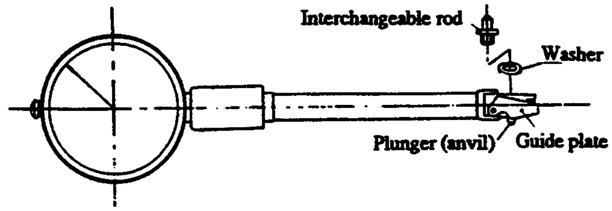


Fig. 1.9 Changing the measuring range of type (b)

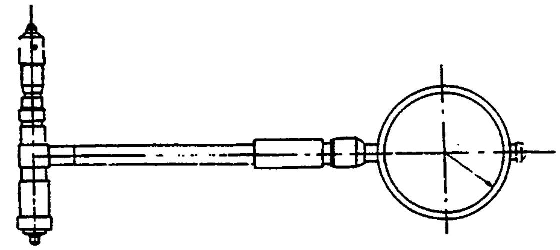


Fig. 1.10 Bore gage with a micrometer head

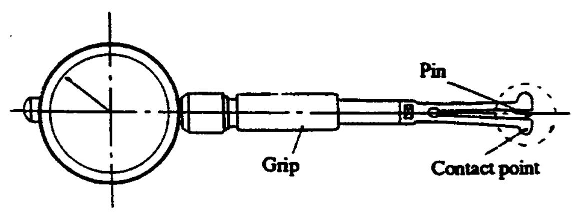


Fig. 1.11 Bore gage with a conversion cone

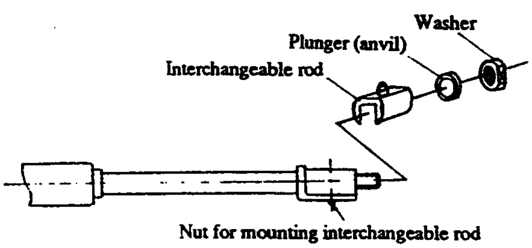


Fig. 1.8 Changing the measuring range of type (a)

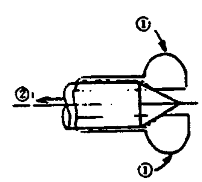


Fig. 1.12 Enlarged view of contact points

Table 1.3 Specifications of bore gages with a micrometer head

Measuring range (mm)	Stroke range of micrometer head	Sub-anvil	Measuring depth (mm)
35 – 60	5mm	5, 10, 15, 20	150
60 – 100	10mm	10, 20	150
100 – 160	13mm	10, 20	150
150 – 250	25mm	25, 50	250
250 – 400	50mm	50, 50	250
400 – 600	50mm	50, 100	250
600 – 800	50mm	50, 100	250

1.2 Cone Conversion Type (ø0.95 to ø18mm)

In this type of bore gages a cone is used to convert the contact point displacement in the perpendicular direction. The external view and names of each component are shown in **Fig.1.11**.
An enlarged view of the contact points is shown in **Fig.1.12** where the direction of contact point displacement is changed at a right angle by means of a cone provided at the end of the pin plunger. The plunger movement is limited to a narrow range because of the accuracy (linearity) limitations of the circular movement of the contact points. It is thus designed for measuring small inside diameters.
The cone type bore gage has an effective measuring range in which the measuring accuracy is guaranteed, and the effective measuring range varies with each measuring range.
To change the measuring range, only the contact point is replaced for the 01, 02, 03, 05 types. For the 04 type the pin plunger should also be replaced depending on whether the measuring range is from ø1.50 to ø2.45mm or from ø2.25 to ø4.00mm. (See **Table 1.4**.)

Table 1.4 Product specifications of bore gages (Boretest) with a measuring range of 0.95 to 7.30mm and standard type (O-type) with a measuring range of 7 to 18mm

Measuring range (mm)	Interchangeable contact point and measuring range		Number of pins	Ring gage (mm)	Other supplied accessories
	Type	mm			
		0.95 – 1.05		1.0	
		1.07 – 1.25		1.1	Wrench (1 pc.)
0.95 – 1.55	05	1.17 – 1.35	1	1.2	Dial protection cover set
		1.27 – 1.45		1.3	
		1.37 – 1.55		1.4	
		1.50 – 1.90		1.75	
		1.80 – 2.20	1	2.00	
		2.02 – 2.45		2.25	
		2.25 – 2.75		2.50	
1.50 – 4.00	04	2.50 – 3.00		2.75	Wrench (1 pc.)
		2.75 – 3.25		3.00	Dial protection cover set
		3.00 – 3.50	1	3.25	
		3.25 – 3.75		3.50	
		3.50 – 4.00		3.75	
		3.70 – 4.30		4.0	
		4.20 – 4.80		4.5	
		4.70 – 5.30		5.0	Wrench (1 pc.)
3.70 – 7.30	03	5.20 – 5.80	1	5.5	Dial protection cover set
		5.70 – 6.30		6.0	
		6.20 – 6.80		6.5	
		6.70 – 7.30		7.0	
7 – 10	02	0.5mm increments	1		Same as above
10 – 18	01	1.0mm increments	1		Same as above

1.3 Effect of Guide Plate

Every bore gage, except cone type small hole bore gages, is equipped with a guide plate at the side where the contact point is. As shown in **Fig.1.13**, this guide plate is pushed in the direction F by a spring, and also the anvil is held against the inner surface of he workpiece. Because F acts on the center of the guide plate, the lines of the reactions to the guide plate always pass through the center of the hole.

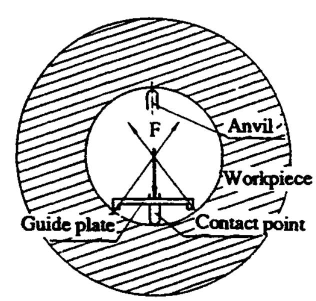


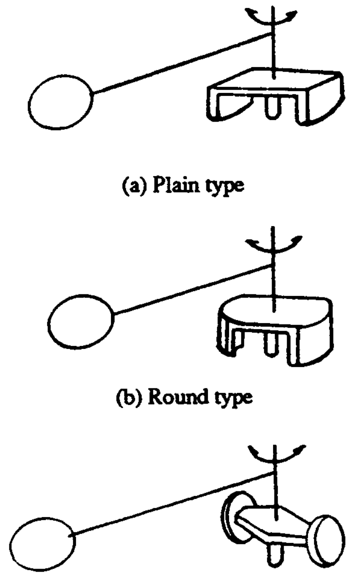
Fig. 1.13 Effect of guide plate

Therefore, the contact point at the center of the guide plate and the anvil at the opposite position to the contact point on the center line span the workpiece inner surface by the maximum distance, i.e. the diameter. The force F on the guide plate and the reactions both on the guide plate and anvil always center the contact point and anvil across the diameter of the inner circle.
Guide plates have three types that include; (a) plain type, (b) round type, and (c) roller guide. (Refer to **Fig.1.14.**)

(a) Plain guide
This is a standard guide plate that conforms to JIS. In measurements, the axis of the bore should be parallel to that of the bore gage body.

(b) Round guide
A Mitutoyo patent. When inserting the bore gage into a bore, the axis of the cylinder does not have to be parallel to that of the bore gage body.

(c) Roller guide
A Mitutoyo patent. Besides having the same capability as (b), it allows the bore gage to be inserted smoothly into a bore and ensures stable indications.



(a) Plain type

(b) Round type

(c) Roller guide

Fig. 1.14 Types of guide plate

1.4 Summary of Various Types

The bore gages described so far are summarized according to their structure in **Table 1.5.**

Table 1.5 Summary of bore gage types

- Bore Gages
  - Cam conversion type
    - Large hole bore gage (conforming to JIS) (18 to 400mm)
      - Plain guide
      - Round guide (18 to 60mm)
      - Roller guide (50 to 400mm)
    - Small hole bore gage (10 to 18mm)
      - Plain guide
      - Without guide (6 to 10mm)
    - Bore gage with a micrometer head (35 to 800mm)
      - Round guide (35 to 60mm)
      - Roller guide (60 to 800mm)
  - Cone conversion type
    - 01 type bore gage (10 to 18mm)
    - 02 type bore gage (7 to 10mm)
    - 03 type bore gage (3.7 to 7.3mm)
    - 04 type bore gage (1.5 to 4.0mm)
    - 05 type bore gage (0.95 to 1.55mm)

2. NOTES ON USE OF BORE GAGES

As the bore gages are comparison measurement gages for inside diameters, zero-point checking or reference dimension setting is necessary before measurement.
In any operating conditions other than standard industrial conditions, or due to temperature changes during operation, the zero-point may deviate. Therefore, the zero-point or reference dimension should be confirmed again at the end of the measuring operations for reviewing the obtained measurements, and at the middle of measuring operations if a large number of workpieces are measured.
When a bore has a small diameter, i.e. a small radius of curvature, a guide plate is not necessary and the bore gage can be positioned to give the maximum distance across a cross section of hole, equal to the diameter of the hole, due to the reactions from the contacting force. However in the large hole bore gages, positioning must be assisted by a guide plate. In addition, even when it is positioned at the center line of a hole, it must still search for the point that gives the minimum distance in the plane containing the hole axis. This is required both when measuring a bore and when setting a reference dimension.
To do this, move the bore gage in the direction of the arrow as shown in **Fig.2.1**. In practice, first insert the bore gage at an angle into the bore, then adjust it so that it gradually becomes parallel to the axis of bore. In this case, the pointer will turn clockwise to the minimum point, then turn counterclockwise after passing the minimum point. The value where the pointer movement reverses shows position (a) in **Fig.2.2.**
This procedure can also be applied to the the bore gages for miniature holes.

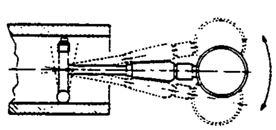


Fig. 2.1 How to measure the minimum dimension in the axial direction of the bore

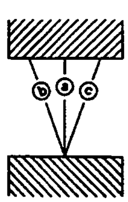


Fig. 2.2 Searching for the minimum dimension

2.1 Setting a Reference Dimension (Zero-setting the dial indicator)

A reference dimension can be set using;
1) A master ring or ring gage.
2) An outside micrometer.
3) Gauge blocks.
4) Height Master.

Each case is shown in **Figs.2.3**, 2.4, and 2.5 respectively.

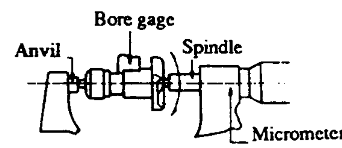


Fig. 2.3 Reference dimension setting with an outside micrometer

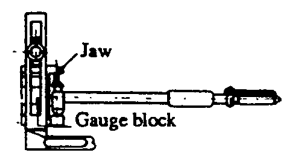


Fig. 2.4 Reference dimension setting with gauge blocks

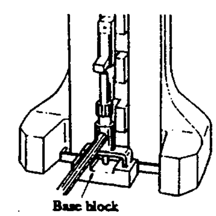


Fig. 2.5 Reference dimension setting with a Height Master

2.2 Explanation of Special Features

Some bore gages have a special guide plate specification as shown in **Fig.2.6** below. In its operation, refer to the following procedure.

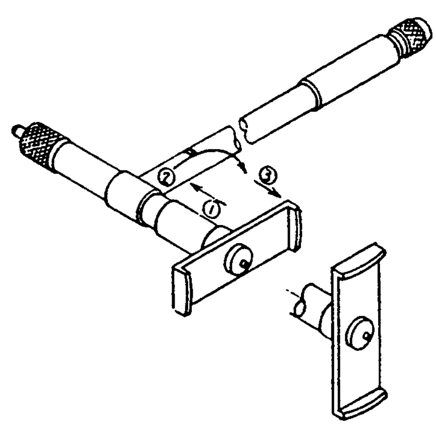


Fig. 2.6 Turning the guide plate

1) Push the guide plate lightly as far as it can go in the direction of arrow ① in **Fig.2.6**, then turn it clockwise 90° in the direction of arrow ②.
2) Leave the angular position of the guide plate as is, and draw it back in the direction of arrow ③.

When storing the guide plate in a case, do the above-described procedure in the reverse order.

The grip has a structure to which an optional extension rod can be added. Use the following procedure when mounting or removing the extension rod.

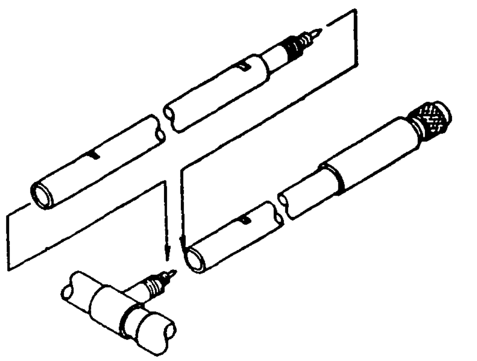


Fig. 2.7 Mounting/dismounting an extension rod

1) Separate the joint between the grip and measuring head using the wrench supplied with the extension rod.
2) Screw-in the extension rod into the joint of the grip, then screw-in the measuring head into the extension rod.

3. CURRENT DEVELOPMENT

New types of bore gages have been continuously developed to accommodate the variety of today's applications.

1) Shallow hole bore gage
   This is available for measuring an inside diameter near the bottom of the shallow holes. Diameters can be measured at a minimum of 2.5mm from the bottom.
   There are four types including 511-401 (15 to 35mm) through 511-404 (50 to 150mm).
2) Short leg bore gage
   When there is not enough space above the objective measuring hole as shown in **Fig.3.1**, it may not be possible to measure because the leg is too long. To cope with such a case, the leg is shortened to be convenient in measuring a shallow hole, resulting in a light weight and compact design.
3) Dial bore gage
   This is an American-type rugged bore gage which has built-in a dial indicator. As the interchangeable rod is fastened by a double-nut, the zero-position can be adjusted as desired for comparison measurement. In addition, as it has a flat bottom, zero-adjustment with a ring gage can be done with the bore gage standing upright on a surface plate. The flat bottom saves storing space, too.

As 0.01mm reading bore gages, there are three types that include the 545-104 (35mm to 50mm) through 545-106 (75 to 150mm), and as 0.001mm reading bore gages, there are three types that include 545-114 through 545-116.

Beside the above described, special types for measuring an extra large diameter or extra deep hole are manufactured. For measuring diameters of holes deeper than 2m, an electric comparator (cartridge head probe of a Mu-Checker) is often incorporated in the hollow rod of a bore gage to collect measurements and output them through a cable. In recent models, a Digimatic indicator is often attached to a bore gage so that the obtained data can be statistically analyzed by the external data processor, etc.

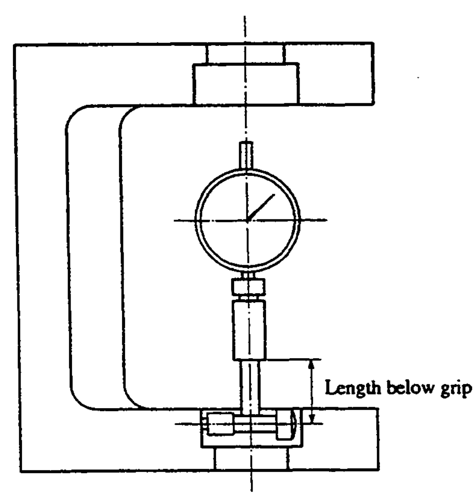


Fig. 3.1 Short leg bore gage

APPENDICES

1. JIS B7515-1982: Cylinder Gauges

6. Performance

The performance of the cylinder gauge shall comply with **Table 2.**

Table 2. Performance of Cylinder gauge

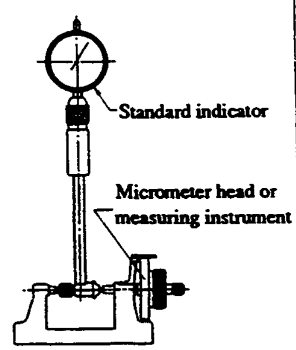
Measuring range (mm)	Permissible value for wide range accuracy (μm)		Permissible value for adjacent error (μm)		Permissible value for repeated accuracy (μm)		Permissible value for error due to rotation of plunger (¹) (μm)		Permissible value for error due to guide plate (μm)		Measuring force N {gf}
	Grade A	Grade B	Grade A	Grade B	Grade A	Grade B	Grade A	Grade B	Grade A	Grade B	
18 to 35	5	10	2	4	2	3	2	4	1	2	4 max. {408}
35 to 60											
50 to 100											5 max. {510}
100 to 160											
160 to 250									2	3	6 max. {612}
250 to 400											

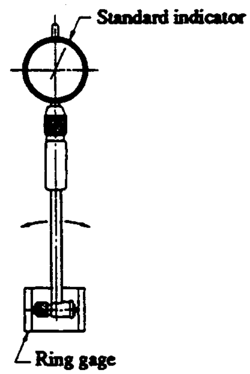
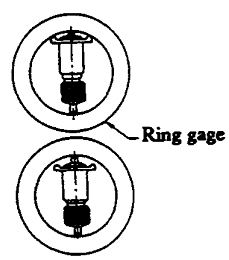
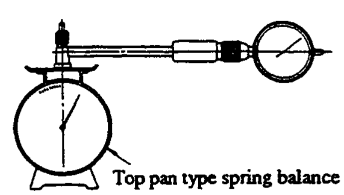
Note (¹) To be applied to the rotatable plunger.
Remark: The values in this Table are referred to 20°C temperature.

10. Measuring Method for Performance

The measuring method for the performance of the cylinder gauge shall be as specified in **Table 4.** When performing measurement, the standard indicator shall be mounted. As the standard indicator, a dial indicator with a measuring range of 2mm complying with JIS B 7509, or one at least equivalent thereto, shall be used.

Table 4. Measuring Method for Performance

No.	Item	Method of measurement	Illustration, shown for example	Measuring instrument
1	Wide range accuracy	Support the barrel of the bore gage vertically. Referring to the reading of the standard indicator, push the plunger in 0.1mm increments, starting with the start point and up to the end point of the effective measuring range. Calculate the error by subtracting the reading of the micrometer head or measuring instrument from the reading of the standard indicator; draw an error diagram (see Attached Figure), and obtain the accuracy or error from it. Before beginning the measurement, fix the body of the standard indicator and calculate its instrumental error.		Micrometer head or measuring instrument (scale interval of 1μm or less, instrumental error within ±1μm), standard indicator
2	Adjacent accuracy			

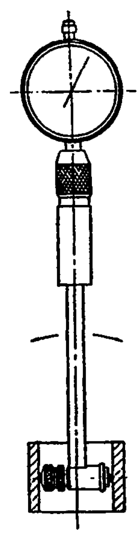
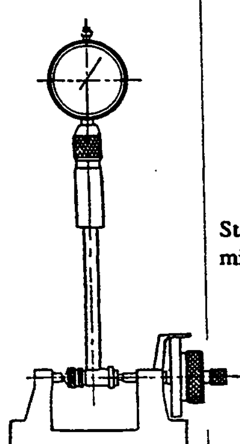
No.	Item	Method of measurement	Illustration, shown for example	Measuring instrument
3	Repeated accuracy	Insert the body into the ring gage, move the barrel back-and-forth three times in the plane of the axes of the plunger and barrel, read the minimum indication each time during each forward (or backward) motion, and remove the body from the ring gage. Repeat this procedure three times, and determine the difference between the maximum and minimum values among the nine readings taken. When making this measurement, press the bore gage tips at the same places on the inside wall of ring gage.		Standard indicator, ring gage
4	Error of rotatable plunger (²)	In the same way as No.3 above, swing the barrel to make three backward-and-forward motions, read the minimum value during each motion, and remove the bore gage from the ring gage. Repeat this procedure turning the plunger axis 90° each time, and determine the difference between the mean values for the respective angular positions.		
5	Error due to guide plate	Make three measurements on the ring gage under the condition such that the guide plate is touching the ring gage, and under the condition such that they are not touching, and determine the difference between the mean values for the two cases.		Standard indicator, ring gage
6	Measuring force	Support the barrel horizontally and push in the plunger while measuring the force required to do so. Measure the force at the origin and at the limit of the effective measuring range. To determine the measuring force of the plunger itself subtract the measuring force of the standard indicator from each of the two obtained values.		Standard indicator, top pan type spring balance (20g or less scale interval) or dynamometer (0.2 N {20 gf} or less sensitivity)

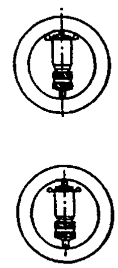
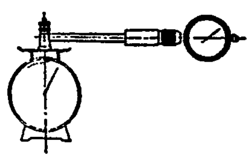
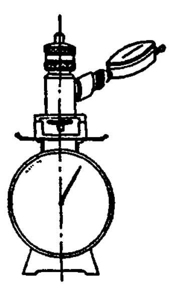
Note (²) To be applied to rotatable plunger.

2. JMSA5009-1966: Performance Check of Small Hole Bore Gage

Table 7. JMSA5009-1966 (extract)

Unit: μ = 0.001mm

No.	Item		Method of inspection	Illustration	Measuring instrument	Permissible value	
						Grade A	Grade B
1	Stability of indication		Insert the body into the ring gage. Move the barrel back-and-forth three times in the plane of the axes of the plunger and barrel, and read the minimum indication during each forward (or backward) motion. Remove the body from the ring. Repeat this procedure five times, and determine the difference between the maximum and minimum values of the fifteen readings taken. When making this measurement, move the tip but keep the end of the interchangeable rod at the same place on the inside wall of the ring gage.		Standard indicator, ring gage	2 or less	3 or less
2	Wide range accuracy	Accuracy of right-angle cam	Insert the end of the plunger between the measuring faces of the micrometer head, and set the datum position for inspection by feeding the micrometer head 0.05mm for the (03) type (0.1mm datum position for the (02) and (01) types). Starting from the datum point, check the bore gage readings by feeding the micrometer head at 0.05mm intervals (0.1mm intervals for (02) and (01) types) to cover the entire guaranteed measuring range of the bore gage. Subtract the reading of the bore gage from that of the micrometer head, create an error diagram (see **Fig.2**), then let the difference between the maximum and minimum values be the wide range accuracy, and let the maximum difference between the adjacent points be the adjacent accuracy.		Standard indicator, micrometer head	8 or less	15 or less
						Mitutoyo	
						5 or less	10 or less
		Adjacent accuracy				2 or less	4 or less

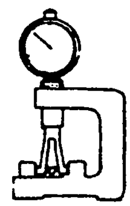
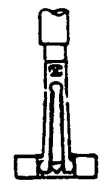
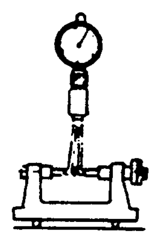
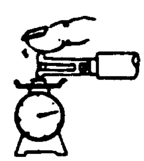
No.	Item	Method of inspection	Illustration	Measuring instrument	Permissible value	
					Grade A	Grade B
3	Effect of guide plate	Take several measurements both when the guide plate is in effect and when it is not, and obtain the difference between the means of each measurement.		Standard indicator, ring gage	2 or less Mitutoyo: 1 or less	3 or less Mitutoyo: 2 or less
4	Measuring force	Take measurements on the top pan type spring balance by supporting the barrel horizontally and push the plunger continuously starting from the datum point of the effective measuring range and up to the final limit.		Standard indicator, Top pan type spring balance	The remainder after subtracting the measuring force of the standard indicator from the difference between the start and final values should be 300g or less.	
5	Supporting force of guide plate	Place a U-shaped jig on the top pan of a spring balance, and let the contacting surface of the guide plate contact with the upper brim of the U-shaped jig. Take measurements by continuously pushing the guide plate against the jig from the time its spring is fully extended to the time it is compressed to the end. In this operation, be careful not to allow the contact point of the bore gage to touch the surface of the jig.		Top pan type spring balance, U-shaped jig	The obtained difference should be 400g or less. However, this should be greater than the measuring force obtained in the inspection No.4.	

Remarks
1. The values in No.3 are referred to 20°C temperature.
2. When inspecting the accuracy of right-angle cam, calibrate the standard indicator and bench micrometer beforehand.
3. Mitutoyo supplies Grade A products unless otherwise specially ordered.

3. JMAS5010-1966: Performance Check of Cone-type Small Hole Bore Gage

Table 8. JMAS5010-1966 (extract)

Unit: μ = 0.001mm

No.	Item	Method of inspection	Illustration	Measuring instrument	Permissible value	
					Grade A	Grade B
1	Stability of indication	Type 1 Mount the bore gage on a stand so that the contact points are placed inside the ring gage to show its diameter. Then find a position to give stable indications by operating the release about ten times. Operate the release ten more times to take readings on the bore gage. Calculate the difference between the maximum and minimum of the readings obtained.		Standard indicator, ring gage, stand	2 or less	3 or less
		Type 2 Insert the bore gage into the ring gage, swing the barrel to make ten backward-and-forward motions in the plane of the axis of the barrel and the two contact points. Read the minimum indication during each forward (or backward) motion, and remove the body from the ring. Determine the difference between the maximum and minimum values among the 10 readings taken.		Standard indicator Ring gage		
2	Measuring error	Fit the contact points of the bore gage between the two measuring faces (spherical steel) of an indicating micrometer, and determine the datum point so that the distance between the measuring faces is the maximum measuring range of the bore gage. Starting from that datum point, measure on the indicating micrometer at 0.1mm intervals for the entire measuring range of the bore gage. Obtain each difference between the readings on the indicating micrometer and standard indicator, then let the maximum difference between the adjacent values be the measuring error.		Indicating micrometer (with a total accuracy of 1μ or less)	3 or less Mitutoyo Within the guaranteed range, 01 6 0.2 – 0.5 4	4 or less 10 6
3	Measuring force	Support the barrel horizontally, continuously push the contact point by your finger and read the balance when the pointer points to the middle of the measuring range.		Standard indicator Top pan type spring balance	800g or less	

Remarks
1. The values in No.2 are referred to 20°C temperature.
2. When inspecting the indication error, calibrate the standard indicator and bench micrometer beforehand.

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