TEXTBOOK NO. 7012⑤

Gage Blocks

TEXTBOOK

Mitutoyo

CONTENTS

1. DEFINITION OF THE METER

The first general meeting of the International Conference of Weights and Measures in 1889 approved the adoption of a new linear unit called the meter, defined as "one 10 millionths (1/10,000,000) of the earth quadrant measured from the pole to the equator." At the same time, a prototype produced according to this definition was approved as the International Prototype Meter (See **Fig.1**).

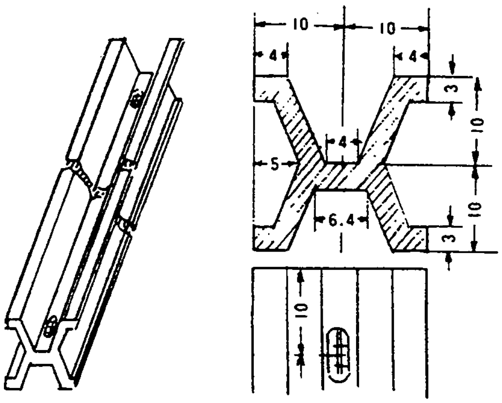


Fig. 1 The Prototype meter

This prototype had only two reference lines to indicate the two ends. The reference lines, however precise they might have been, could not avoid an uncertainty that gives an error of about 0.2 µm, due to the limitation of line sharpness. Deterioration of the accuracy over long periods of time was another question to be considered.

Studies continued to seek a natural constant to replace the prototype meter. At the 11th general meeting of the International Conference of Weights and Measures (1960), the meter was redefined as 1650763.73 times the wavelength of light (Kr^{86} orange spectral line) in a vacuum corresponding to the electron state transition of krypton-86 (Kr^{86}) atoms between the $2P_{10}$ and the $5d_5$ energy levels. This definition determined the meter length to an accuracy of about 10^{-9} m (or 1nm). With progress in the field of wavelength-stabilized laser technology, more suitable light sources, better than Kr^{86}, became available. This opened the way for further technological developments, culminating in a standard with even greater precision. In 1983, the 17th general meeting of the International Conference of Weights and Measures adopted a revised definition of the meter as the length of the path travelled by light in a vacuum during a time interval of 1/299792458 of a second. The Conference also recommended the following three methods for determining the meter length.

(1) Let l represent the distance that light travels in vacuum in a time interval t. The meter length can then be obtained from the following formula.
$l = c\,t$ (where c = light velocity)

(2) Let λ represent the wavelength of light with a frequency f, and obtain the value of λ using the following formula.
$\lambda = c / f$

(3) For methods that use stabilized lasers or spectral lamps as a standard, the Conference recommends the use of an iodine-stabilized helium-neon gas laser, a krypton-86 lamp, etc. The relationship between the frequency f and the wavelength λ is given by the following formula.
$c = \lambda f$

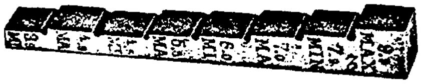
Method (1) above is effective for long distance measurements, for example, finding the distance between the earth and the moon. Methods (2) and (3), which determine length using λ, have been widely used for measuring gauge block sizes with an interferometer. Thus the new definition covers a wide range of requirements, from industrial to astronomical purposes.

2. THE LENGTH STANDARD

Length standards given by physical substances can be divided into two categories; the *line standard* (or line measure) and the *end standard* (or end measure). The former indicates length by the distance between two graduations. A standard scale for reference purposes is an example of a high-accuracy line standard, and an everyday tape measure is another example of the same type but with a much lower degree of accuracy. The end standard gives length by the distance between the two end faces of a standard piece, examples of which are gauge blocks and cylindrical plug gauges. These end standards are used as master gauges in comparative measurements.

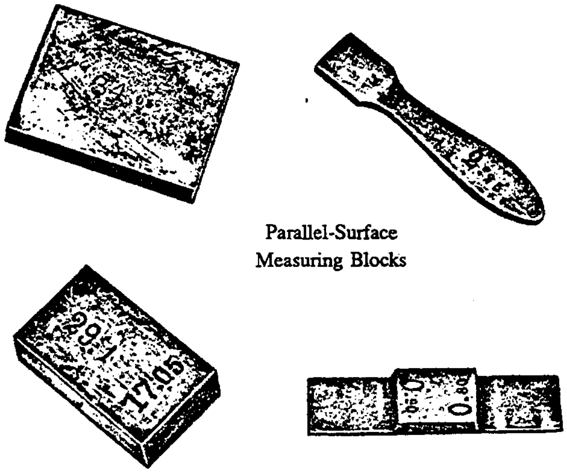
3. THE HISTORY OF GAUGE BLOCKS

In the early 18th century, a Swedish scientist named Christopher Polhem invented a rod-shape end standard, which opened a new age for the metal working industry (**Fig.2**). Later, in 1890, a Swedish arms manufacturer named Hjgalmer Ellstorm, designed a gauge block with two parallel end faces for inspecting rifles (**Fig.3**). In 1910, C.E. Johanson found that any deisred length could be obtained by combining a set of small gauges with different sizes and based on this idea, he made a set of gauge blocks consisting of 111 pieces that could realize any length within a range of 2 mm - 202 mm in steps of 1 µm. These pieces have a rectangular cross section and are called rectangular (Johanson type) gauge blocks. In 1918, Major William E. Hoke of the U.S. National Bureau of Standards designed a gauge block with a square cross section and a hole in the center. This type is widely used in the United States because of their ease of handling. These are called square (Hoke type) gauge blocks (**Fig.4**). In Japan, square gauge blocks were first marketed by Mitutoyo in 1982.



Gage bar

Fig.2



Parallel-Surface Measuring Blocks

Fig.3

4. REQUIREMENTS FOR GAUGE BLOCKS

Gauge blocks must satisfy the following requirements.

a. Dimensional accuracy
b. The ability to be wrung together
c. Dimensional stability over time
d. Abrasion resistance and hardness
e. A thermal expansion coefficient close to common metals
f. Rust resistant

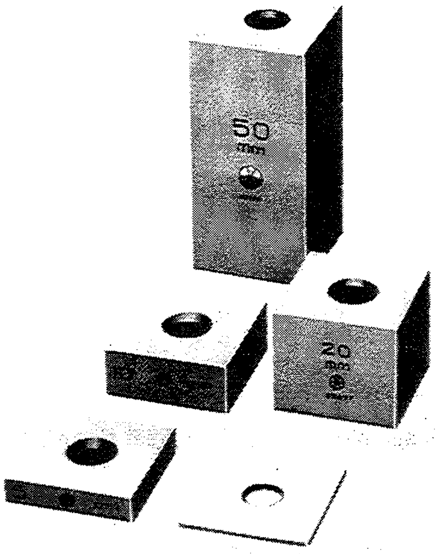


Fig.4 Square gauge blocks

5. METHODS OF MEASURING GAUGE BLOCKS

There are two methods of measuring gauge blocks, one is *absolute measurement* and the other is *comparison measurement.*

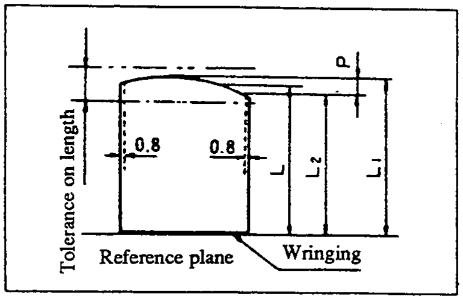
The absolute measurement method directly measures the size of a gauge block using the wavelength of light, which is the length standard. In the comparison measurement method, the size of a gauge block is measured by comparing it to a reference gauge block of known length. For comparison measurements, either an analog measuring instrument with graduations of 0.2 µm/div., or a digital measuring instrument with a resolution of 0.01 µm is used. The JIS requires absolute measurement to be carried out on Grade-00 gauge blocks, reference gauge blocks used for measuring Grade-0 gauge blocks, and other gauge blocks when deemed necessary. **Table 1** and **Fig. 5** show the JIS specifications for gauge blocks.

Table 1 Tolerances on size and permissible values of parallelism

Nominal size (mm)		Grade 00		Grade 0		Grade 1		Grade 2	
Over	Up to and incl.	Length	Parallelism	Length	Parallelism	Length	Parallelism	Length	Parallelism
0.5*	10	0.06	0.05	0.12	0.10	0.20	0.16	0.45	0.30
10	25	0.07	0.05	0.14	0.10	0.30	0.16	0.60	0.30
25	50	0.10	0.06	0.20	0.10	0.40	0.18	0.80	0.30
50	75	0.12	0.06	0.25	0.12	0.50	0.18	1.00	0.35
75	100	0.14	0.07	0.30	0.12	0.60	0.20	1.20	0.35
100	150	0.20	0.08	0.40	0.14	0.80	0.20	1.60	0.40
150	200	0.25	0.09	0.50	0.16	1.00	0.25	2.00	0.40
200	250	0.30	0.10	0.60	0.16	1.20	0.25	2.40	0.45
250	300	0.35	0.10	0.70	0.18	1.40	0.25	2.80	0.50
300	400	0.45	0.12	0.90	0.20	1.80	0.30	3.60	0.50
400	500	0.50	0.14	1.10	0.25	2.20	0.35	4.40	0.60
500	600	0.60	0.16	1.30	0.25	2.60	0.40	5.00	0.70
600	700	0.70	0.18	1.50	0.30	3.00	0.45	6.00	0.70
700	800	0.80	0.20	1.70	0.30	3.40	0.50	6.50	0.80
800	900	0.90	0.20	1.90	0.35	3.80	0.50	7.50	0.90
900	1000	1.00	0.25	2.00	0.40	4.20	0.60	8.00	1.00

*Note : Guage blocks with a nominal size of 0.5 mm shall be regarded to be included in this division.

Fig. 5 Definition of gauge block length (L) by the JIS



The size of a gauge block:
The distance (L) measured from a point on the measuring face of a gauge block to a reference plane of the same material and surface texture upon which the other measuring face of the gauge block has been wrung.
The parallelism of a gauge block:
The difference (P) between the maximum length (L_1) and the minimum length (L_2) of a gauge block.

6. TRACEABILITY OF GAUGE BLOCKS

A system in which the reference standard for a gage or measuring instrument (as a final product) can be calibrated by standards of higher orders, sequentially traceable to the highest national standard is called *traceability*. **Fig. 6** shows the traceability system for gauge blocks (end standard). Gauge block manufacturers and inspecting organizations possess interferometers and have their own system of accuracy control as any organization can carry out inspections of gauge blocks, if they have a lamp that can emit light of a known wavelength (recommended by the Conference of International Weights and Measures) with the necessary equipment to satisfy the required conditions for the emission. However, measurement using light interference needs sophisticated techniques such as error compensation for wavelength deviation and so forth. To cope with the problem of checking accuracy, gauge block manufacturers in Japan use an indirect traceability system called the round-robbin measurement system. With this system, a 100 mm gauge block, measured by an interferometer at the National Research Laboratory of Metrology, is sent in to gauge block manufacturers and inspecting institutes to verify their measurement technique, using their own interferometers. The criteria for this system is that the difference in measurement shall not exceed 0.03 µm from the measurement value of the Laboratory.

7. MEASUREMENT UNCERTAINTY

Any measurement will inevitably contain a degree of uncertainty in respect to its accuracy. In other words, there will always be a certain range of error distribution when measuring the same object repeatedly. This can be attributed to many factors, including the characteristics of measuring instrument, the environmental conditions, the reference standards and human error. In comparison measurement of gauge blocks, the uncertainty is generally within the range ±0.05 µm to ±0.07 µm. For incoming inspections (upon delivery), the U.S. Federal Standard stipulates that the values shown in **Table 2** should be included in the gauge block specifications in addition to the nominal values.

Table 2 Measurement uncertainty according to U.S. Federal Standard

Size	0.5		1		2		3	
	Size	Parallelism Flatness	Size	Parallelism Flatness	Size	Parallelism Flatness	Size	Parallelism Flatness
~100	0.03	0.03	0.05	0.03	0.05	0.03	0.05	0.05
~200			0.07	0.03	0.15	0.03	0.15	0.05
~300			0.10	0.03	0.20	0.03	0.20	0.05
~500			0.12	0.03	0.25	0.03	0.25	0.05

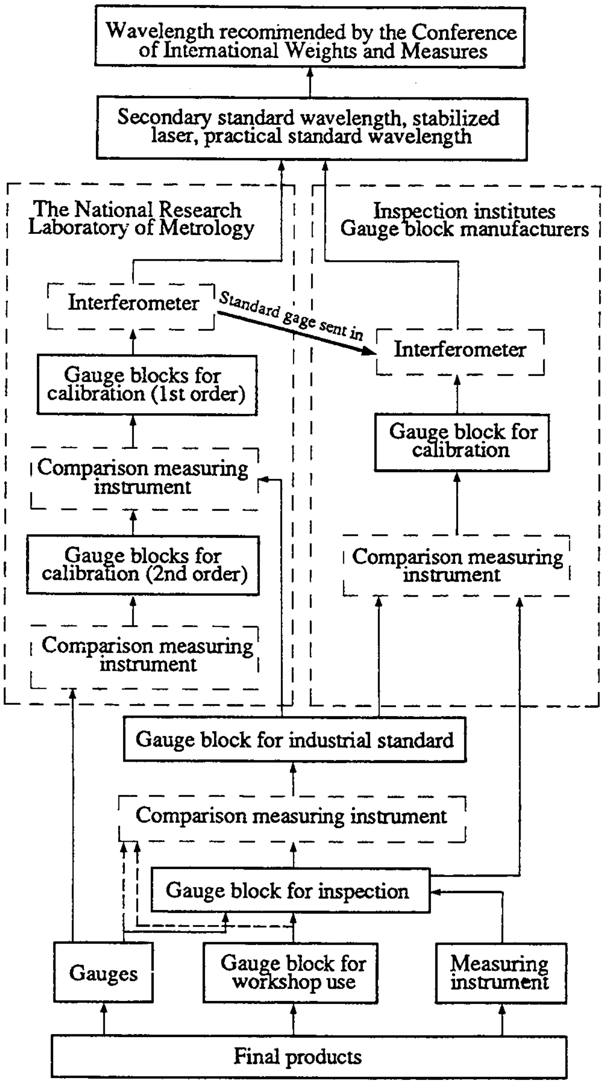


Fig. 6 Gauge block traceability system

8. SURFACE FINISH OF MEASURING FACE

After heat treating, the measuring face of a gauge block is finished to flat plane by grinding and lapping. For improved wringing characteristics and abrasion resistance, a high-degree of flatness and surface smoothness is required. The JIS stipulates that the surface roughness should not exceed 0.06 µm Rmax for Grade-00 and Grade-0 gauge blocks, and 0.08 µm Rmax for Grade-1 and Grade-2 gauge blocks. JIS also specifies the tolerance for the flatness of measuring face, shown in **Table 3.**

Table 3 Permissible values for flatness of measuring face (Unit: µm)

Nominal length (mm)		Grade 00	Grade 0	Grade 1	Grade 2
Over	Up to and incl.				
—	150	0.05	0.10	0.15	0.25
150	500	0.10	0.15	0.18	0.25
500	1000	0.15	0.18	0.20	0.25

Note: Gauge blocks whose nominal length is 2.5 mm or under shall be measured with their measuring face being wrung to an auxiliary body with sufficient rigidity and excellent flatness. The flatness of the measuring face when it is not being wrung shall not exceed 4 µm.

9. STABILIZING TREATMENT FOR GAUGE BLOCKS

One of the most important requirements for a gauge block is that after being finished to a high degree of accuracy, it must maintain its original dimensions for a long period of time.

The composition of the steel after heat-treatment is as follows.

(1) martensite
(2) residual austenite
(3) non-soluble carbide

The martensite formed immediately after heat-treatment has an unstable, transitional structure and is called *hardened martensite* (α-martensite). With time, it changes into *temper martensite* (β-martensite) which is stable. While this change is occurring the steel will contract. The tempering is a process used to control this change; the heat-treated steel is left in a temperature of about 150°C for a few hours.

Austenite that failed to change into martensite during heat-treatment is called *residual austenite*, which is unstable and expands as it gradually changes into martensite. This process can be controlled by a sub-zero treatment, a process whereby heat-treated steel is left in a temperature of about –80°C for a few hours. Even using sub-zero treatment, not all the residual austenite will be changed into martensite, however stability is improved by the tempering process. In practice, sub-zero treatment and tempering is repeated alternately to minimize the deterioration of accuracy over time.

10. HARDNESS

Gauge blocks require an even higher resistance to abrasion than other reference standards, thus a high degree of hardness is essential. Hardness and resistance to abrasion increases as the carbon content increases. The addition of Ti, Cr and W further improves abrasion resistance. These elements are formed into carbon compounds (carbides), and the hardness can exceed HV1000 (**Tables 4** and **5**).

Table 4 Gauge block material

Classification	Chemical component								Remarks
	C	Si	Mn	P	S	Cr	W	Ni	
SK1	1.30 - 1.50	< 0.35	< 0.50	< 0.030	< 0.030	< 0.20	—	< 0.25	
SK2	1.10 - 1.30	< 0.35	< 0.50	< 0.030	< 0.030	< 0.20	—	< 0.25	
SK3	0.90 - 1.00	< 0.35	< 0.50	< 0.030	< 0.030	< 0.20	—	< 0.25	
SUJ2	0.95 - 1.10	0.15 - 0.35	< 0.50	< 0.030	< 0.030	1.30 - 1.60	—	—	
SKS3	0.90 - 1.00	< 0.35	0.90 - 1.20	< 0.030	< 0.030	0.50 - 1.00	0.50 - 1.00	< 0.25	Similar to Beresta
SKS31	0.95 - 1.05	< 0.35	0.90 - 1.20	< 0.030	< 0.030	0.80 - 1.20	1.00 - 1.50	< 0.25	Equivalent to Beresta
DC - 8	2.00 - 2.20	< 0.40	< 0.50	< 0.025	< 0.020	12.00 - 13.00	0.60 - 1.00	< 0.10	Manufacturer: Daido Steel
AISI410 Stainless	< 0.15	< 1.00	< 1.00	< 0.040	< 0.030	11.5 - 13.5	—	—	equivalent to JIS SUS 52B
SAE52100	0.95 - 1.10	0.20 - 0.35	0.25 - 0.45	< 0.025	< 0.025	1.30 - 1.60	—	—	equivalent to JIS SUJ 2

Table 5 Steel characteristics by material

Type of steel	Difficulty of hardening	Deformation by the heat process	Resistance to abrasion	Resistance to corrosion	Machinability	Cost
High-carbon steel	difficult	large	small	inferior	superior	low
High-carbon low-chrome steel	medium	medium	medium	medium	medium	medium
High-carbon high-chrome steel	easy	small	large	superior	inferior	high

11. THERMAL EXPANSION COEFFICIENT

Gauge blocks are used as a reference in comparison measurement and, as they are mainly used by metal working industry, the thermal expansion coefficient of gauge blocks should be as close to that of steel as possible. According to the JIS, the thermal expansion coefficient of gauge blocks should be within a range of (11.5 ± 1) x 10^{-6}/°C. The thermal expansion coefficient of the residual austenite is about twice that of the martensite and the temperature expansion coefficient of steel is determined by the ratio of these two components, with the dispersion normally being within about ±0.3 x 10^{-6}/°C. Gauge blocks currently being manufactured in Japan are made of high-carbon, high-chrome steel with a thermal expansion coefficient of about 10.9 x 10^{-6}/°C.

12. WRINGABILITY

One of the most important characteristics of the gauge block is that any required dimension can be obtained by wringing them together. The principle of wringing is defined by ISO as intermolecular force. The wringing force varies depending on the liquid used. Grease and Vaseline are most frequently used for this purpose. **Table 6** shows the test results of wringing errors for six different people.

Table 6 Test results of wringing errors (unit: µm)

	A	B	C	D	E	F
① Built-up length (*[1])	+ 0.18	+ 0.17	+ 0.16	+ 0.18	+ 0.19	+ 0.21
② The total of the measured, individual block lengths (*[2])	+ 0.17					
③ Difference (③ – ②)	+ 0.01	0	– 0.01	+ 0.01	+ 0.02	+ 0.04
④ Difference per wring (③ / 5)	+ 0.0025	0	– 0.0025	+ 0.0025	+ 0.005	+ 0.01

Note)

*[1] The built-up length (length of a stack of gauge blocks) is measured with an interferometer and then the total nominal value is subtracted from the measured results.

*[2] The size of each individual block is measured with an interferometer and then the total nominal value is subtracted from the total of the measured results.

Test method

The test was conducted by six people with different levels of skill, as shown below and a total of five gauge blocks were wrung together.

A and B: Highly skilled
C and D: Averagely skilled
E and F : Unskilled (guidance given on the wringing method)

Wringing error is normally below 0.01 μm but there are cases where burrs on the measuring face produce detrimental effects. To obtain the required dimension, there are many combinations of gauge blocks possible. For a measurement that needs particularly high accuracy, the recommended method is to take the average measurement value using two or three different combinations.

13. SELECTION OF GAUGE BLOCK

- Piece numbers in a gauge block set

Recently, a wide variety of gauge block sets have become available to meet specific purposes. A guideline when selecting a combination set is that any required size should be built up with no more than three or four pieces. 2mm based gauge blocks (e.g. 2.001 mm) are now available on the market in addition to 1 mm based gauge block (e.g. 1.001 mm). These are obviously designed to overcome the handling difficulty when wringing thin gauge blocks.

- Gauge block accuracy grade

The accuracy of gauge blocks is specified by the JIS into different grades. **Table 7** shows approximate guidelines for selecting suitable grade gauge blocks to meet each different application. According to the JIS rules, Grade-00 and Grade-0 gauge blocks should bear an inspection certificate, indicating the size measured at the center of the measuring face. There is a way to use lower rated blocks to obtain the same accuracy as higher rated blocks by making the necessary correction (calibration) against higher ones using the center of the measuring face. However, as the parallelism of lower rated gauge block is generally inferior, errors may be magnified as the number of pieces wrung increases. Therefore, it would be better not to wring more than three or four pieces. Mitutoyo provides inspection certificates for all gauge block sets including Grade-2.

Table 7 Selection of gauge block grade by application

Application		Grade
For the workshop	Cutting tool setup	2
	Fabrication of gauges Calibration of measuring instruments	1 or 2
For inspection	Inspection of machine parts, tools, etc.	1 or 2
	Calibration of gauges Calibration of measuring instruments, etc.	0 or 1
For standards	Calibration of gauge blocks for machining Calibration of inspection gauge blocks Calibration of measuring instrument, etc.	00 or 0
For reference standards	Calibration of standard gauge block Scientific and technological research	00

14. PRECAUTIONS WHEN HANDLING GAUGE BLOCKS

Necessary tools, etc.

- Paper

Used for wiping off rust-preventing oil, marks, dust, etc. Previously, cotton cloth was used, but now lint-free material such as lens cleaning paper is more popular because of its convenience.

- Solvent

Used to remove rust-preventing oil, etc. Highly volatile solvents, such as Freon, are recommended. Benzine-A is also effective but should be handled with care because of its toxicity.

- Blower brush

Used to blow dust off the measuring face. A blower brush for photographic lenses is best suited for this purpose. The brush at the tip should be periodically washed clean in a neutral detergent.

- Tweezers

Used when wiping a small size gauge block. It is difficult to clean a small gauge block while holding it with fingers.

- Cotton gloves

Used when handling a large size gauge block. Wearing gloves is an effective means of preventing rust and minimizing thermal expansion.

- Rust-preventing oil

There are many types of rust-preventing oil in different forms, liquid, paste, etc. It is safer to use a brand of oil recommended by the maker, as some types of rust-preventing oil may cause discoloration. Rust-preventing oil is sometimes used as wringing oil, however, there are some types of rust-preventing oil that contain solid lubricant, which is unsuitable for wringing. Paste-type (grease-type) oil is used for rust prevention for intermediate and long storage periods. Volatile corrosion/rust inhibiting paper (VCI paper) easily loses its active ingredients by evaporation in the open air, and so it is dangerous to place too much trust in its ability to protect.

- Optical flat

Used to check for minute protrusions and the flatness of the measuring face. One about 60 mm in diameter is desirable.

- Arkansas grindstone

Used to remove burrs from the measuring face. The best type is natural, hard Arkansas stone. The stone surface should be lap-finished with WA#3000 lapping powder. Before use, excess lapping material should be removed from the surface, with only the surface micro-cavities filled with the remaining material.

15. CALIBRATING GAUGE BLOCKS

- Burrs

Gauge blocks are made of material with a hardness number of HRC64 or greater. However, they can easily be scratched or indented by rough handling (especially when two gauge blocks are knocked against each other). A damaged gauge block, if used without removing burrs and flaws, can damage other gauge blocks when they are used together.

An optical flat is used to check for burrs on the measuring faces. Make sure that the surfaces of the optical flat and the gauge block are wiped clean before inspection. Gently bring the optical flat into contact with the measuring face of the gauge block and interference fringes will appear. (It should be noted, however, that interference fringes may fail to appear if there is a large burr present.) Next, press the optical flat softly against the measuring face. If the interference fringes disappear, it indicates that there is no burr present. If the interference fringes remain partially, move the position of the optical flat slightly to and fro. Then, if the fringes are seen in the same location on the measuring face, it indicates a burr on the gauge block surface; if the fringes remain in the same location on the optical flat, it indicates a burr on the optical flat.

- Flatness

For measuring the flatness of the spindle/anvil of a micrometer, an optical flat is brought into contact with the measuring face to be checked and the number of fringes counted. However, in the case of gauge blocks whose measuring face has a high degree of flatness, interference fringes often fail to appear using this method. In order to check the flatness of a gauge block, the curvature of the fringes is measured instead by slightly tilting the optical flat so that interference fringes are seen.

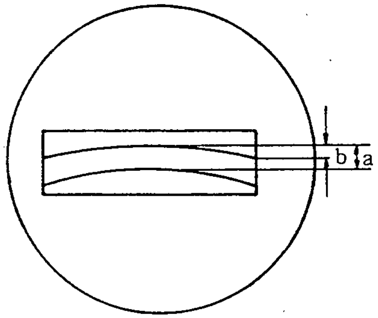


Fig .7 Measuring flatness using an optical flat

The flatness F is given by the following formula.

F = (b/a) x (l/2)
where, λ= wavelength of light ($\approx 0.6\mu m$)

Suppose the observation is made when the incident angle of light to the gauge block surface is θ(**Fig. 8**), the flatness is expressed by $F = f/\cos\theta$, with f being the apparent flatness.

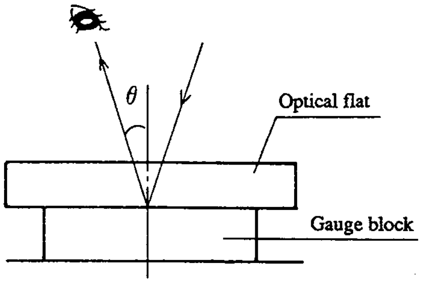


Fig. 8 The relationship between the incident angle of light and flatness

[Note]

To judge whether a surface is concave or convex is difficult by merely observing the interference fringes. In order to make the judgment easier, the following method can be used. First, place an optical flat on the measuring face to cause interference fringes to appear as described above. Then, observe the curvature of the fringes and the direction of the fringe movement while applying slight pressure on the optical flat. If the convex side of the fringe curves and the the direction of movement coincide, it means that the measured position is a convex; if the concave side and direction of movement coincide, the measured position is a convex (**Fig.9**).

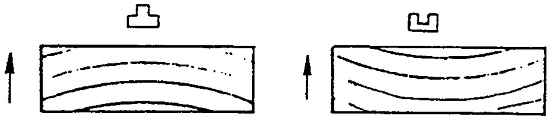


Fig.9 Judgment of a convex/concave surface

16. REMOVING BURRS

Burrs or protrusions on a measuring face should be removed by grinding with an Arkansas stone. Wipe clean both the measuring face and the stone's surfaces using solvent to ensure that foreign material such as dust have been completely removed. Then, place the gauge block on the Arkansas stone and slide it gently back and forth while pressing it lightly against the stone. After 10 or 20 movements, check the measuring face with an optical flat to see whether the burr has been removed. Repeat the procedure until the burr is completely removed. There is a limit to burr size that an Arkansas stone can remove using this method, and it may be better to replace the block with a new one if the burr is too large. Since thin gauge blocks are easily bent, use a supporting rubber pad to press the gauge block against the stone.

17. WRINGING BLOCKS

There are many different ways to build up gauge blocks to obtain the required size. The following points should be kept in mind when wringing blocks together.

1. Use a minimum number of pieces to obtain the required size.
2. Select thick gauge blocks wherever possible.
3. Select gauge blocks starting with one having the required least significant digit and then working up sequentially to higher places (Refer to **Table 8**).
4. Avoid using gauge blocks of 5 mm and multiples there of (i.e. 10, 15, 20, 25 mm, ···) wherever possible.

Table 8 How to select gauge blocks to build up the required size (35.745 mm)

Combining order	(A)	(B)	(C)
<1>	1.005	1.005	1.005
<2>	1.24	1.24	1.24
<3>	13.5	16.5	15.5
<4>	20	17.0	18.0
	35.745	35.745	35.745

It is better to use combinations (B) or (C) instead of (A), in order to avoid the 20 mm size.

The wringing procedure (refer to **Fig. 10**)

1. Clean the measuring face
2. Check for burrs
3. Apply a very small amount of oil to the measuring face and spread it evenly over the entire surface.
4. When wringing two thick gauge blocks, bring the two measuring faces into contact at right angles to each other. When wringing a thin gauge block to a thick block, place one end of the thin block onto one end the thick block so that they are parallel with each other.
5. Gently slide one gauge block over the other on the wringing face while applying a small amount of pressure, and the two blocks will stick together as if they were held by a vacuum. Make sure that the pressure is applied evenly over the entire wringing surface. Since a thin gauge block is liable to bend,

a different method must be used to wring two thin gauge blocks together. First temporarily wring one of the blocks to a thick gauge block, and then wring the other thin block to the first one. Finally, gently remove the thick gauge block used as a support.

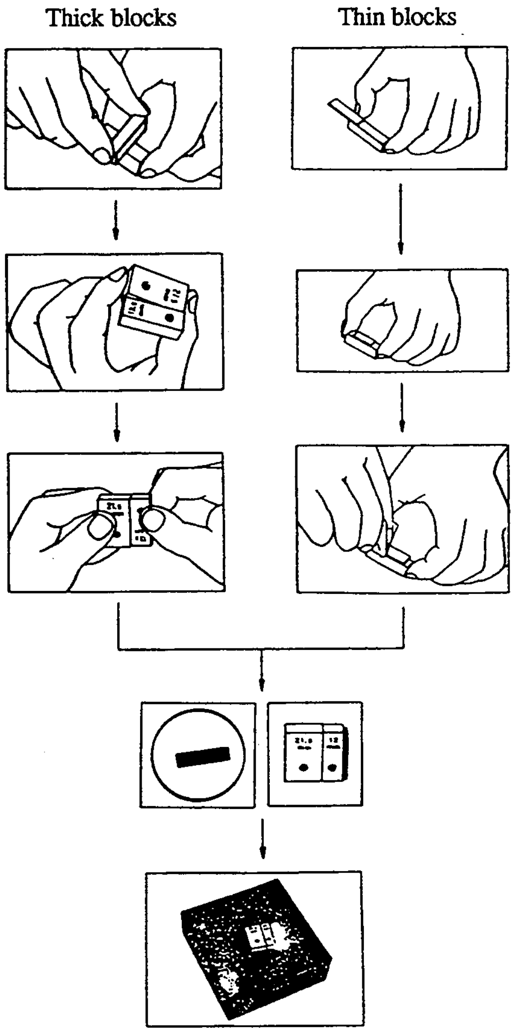


Fig. 10 The wringing procedure

18. JOINING LONG GAUGE BLOCKS

It is extremely difficult to wring long gauge blocks together. If they slip off, it can cause damage such as a dent or scratch on the measuring face or if a holder is used to clamp the whole length of gauge blocks, excessive compression deformation can occur. The JIS recommends to provide a hole for joining near the end of the block (**Fig.11**), and there are special holders available for joining this type of gauge block. All Mitutoyo gauge blocks over 100 mm in length are provided with a hole for joining.

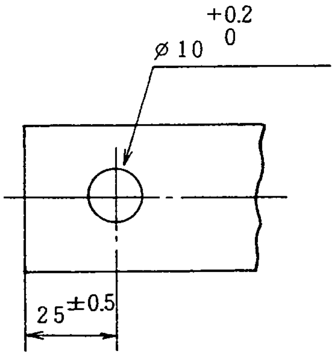


Fig.11 Hole for jointing

19. ERROR FACTORS AFFECTING GAUGE BLOCKS

(1) Influence of temperature changes

In a precision measurement of length, the influence of temperature must be taken into consideration. Generally, the relationship between the temperature and the length of an object is given by the following formula.

$$l_t = l_{20} \times \{1+\alpha(t-20)\}$$

where,

l_t = Length of the gauge at t°C

l_{20} = Length of the gauge at 20°C

α = Linear expansion coefficient

t = Temperature of the gauge at the time of measurement

Fig. 12 shows the length variation of a 100 mm gauge block while being handled during a measurement. As can be seen from the graph, the degree of dimensional change is different for each handling method. To make accurate measurements, it is recommended to obtain experimental data in advance. Use a material with good thermal conductivity and a large thermal capacity to adjust gauge blocks to the required temperature. In a comparison measurement, when the coefficient of linear expansion of the workpiece is different from that of the gauge block, the measurement must be carried out at 20°C. If the coefficients of linear expansion are the same for both the gauge block and the workpiece, measurements do not have to be performed at 20°C, provided that the two pieces are kept at the same temperature.

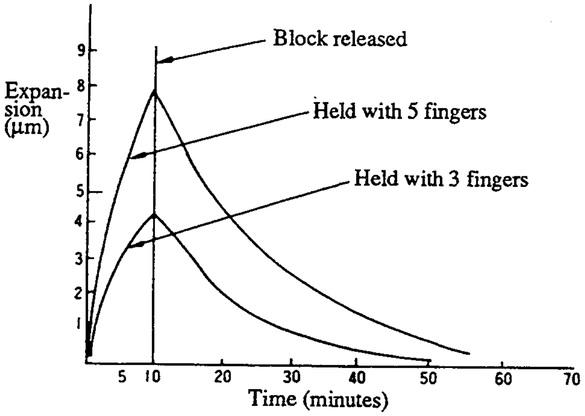


Fig.12 Dimensional changes under different handling conditions

(2) Gauge block deformation due to its own weight

- When supported horizontally

When a gauge block is supported horizontally, it will bend more or less under its own weight. It must be noted that the degree of bending varies depending on the positioning of the support points. The best support positions are at the Airy points, where the two measuring faces of the gauge block are approximately parallel.

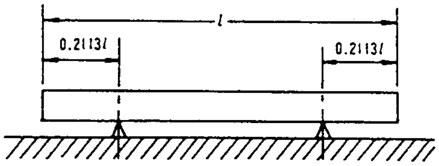


Fig.13 Airy point support

The apparent contraction of a gauge block Δl when it is supported at the Airy points is given by the following formula.

$$\Delta l = 1.15 \times 10^{-6} \times \frac{L^7 W^2}{E^2 I^2}$$

where,

L = Length of the gauge block

W = Weight per unit length of the gauge block

E = Modulus of longitudinal elasticity

I = Geometrical moment of inertia

Table 9 shows the apparent contraction of a 1000 mm gauge block when it is supported horizontally at the Airy points and at both ends.

Table 9 Dimensional changes of a 1000 mm gauge block (with 35 x 9 mm section) under its own weight (unit: µm)

Apparent contraction		Center of the block	Error (δl) at both ends due to sagging
Airy point supports	with 35 mm sides set vertically	0.000016	0
	with 9 mm sides set vertically	0.004	0
End supports	with 35 mm sides set vertically	0.0065	10.4
	with 9 mm sides set vertically	0.15	44.6

- When held upright

When a gauge block is held upright, the contraction under its own weight Δl is given by the following formula.

$$\Delta l = \frac{L^2 \times M}{2 \times E}$$

where,

M= Weight per unit volume of the gauge block

E = Modulus of longitudinal elasticity

L = Size of the gauge block

Using the above formula the value Δl for a 1000 mm gauge block will be approximately 0.2 µm.

(3) Elastic deformation due to external forces

When using gauge blocks with accessories, a holder is frequently used as well. The holder is designed to hold the gauge blocks with clamping screws. Excessive clamping force on these screws leads to measurement errors. The amount of contraction Δl is expressed by the following formula.

$$\Delta l = \frac{L \times P}{E \times S}$$

where,

P: clamping force

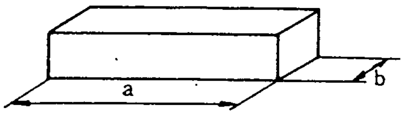
S: sectional area of the gauge block

For example, a 250 mm gauge block would contract by 1.2 µm under a clamping force of 30 kg·f. There have been cases where a 100 mm gauge block contracted as much as 3 µm under a clamping force. Besides other factors that should be considered, gauge blocks with a joining hole are recommended when using long gauge blocks.

20. TYPES OF GAUGE BLOCK BY SHAPE AND CHARACTERISTICS

- Shape

Figs. 14 and **15** show the shapes of rectangular and square gauge blocks.



Nominal size	Sectional area (a x b)
up to 10.1 mm	$30^{\,0}_{-0.3} \times 9^{-0.05}_{-0.2}$
over 10.1 mm	$35^{\,0}_{-0.3} \times 9^{-0.05}_{-0.2}$

Fig. 14 Shape and dimensions of rectangular gauge blocks

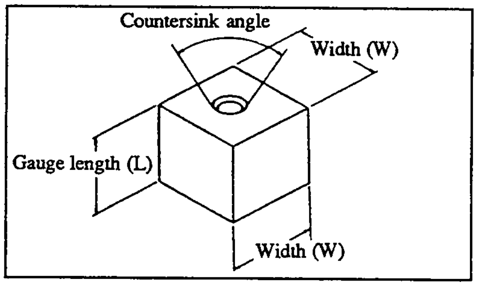


Fig. 15 Shape and dimensions of square gauge blocks

Dimensions of the measuring face (WxW) :
(24.1 ± 0.2) x (24.1 ± 0.2) mm
Diameter of the center hole : ϕ6.7 ± 0.1mm
Countersink angle : 70° - 84°
(Countersinks are provided in 5 mm or larger size gauge blocks)

- Measuring position

The measuring point of rectangular gauge blocks is the center of the measuring face, where the gauge block length is defined as the central dimension. Square gauge blocks have a hole in the center, and their measuring point is shown by the dots in the diagram (**Fig.16**).

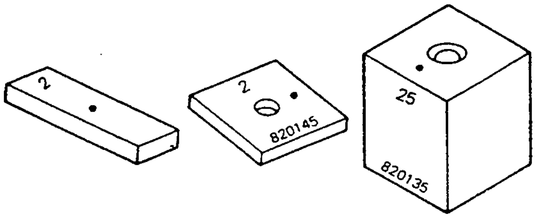


Fig. 16 Measuring points

- Characteristics

The advantages and shortcomings of square gauge blocks as compared with rectangular gauge blocks are as follows.

Advantages:

* The measuring face area is almost twice that of the rectangular type. Therefore,

1. Wringing is easy, therefore even an unskilled worker can use them.
2. Gauge blocks are frequently used in upright position on a surface plate, so the stability of the square gauge blocks increases work efficiency.
3. In precision measurement, where rollers and sine bars are often placed on the measuring face of a gauge block, square gauge blocks simplify the set up procedure.
4. When using a gauge block as a reference for measuring inside/outside diameters with a measuring machine, the measuring faces must be set parallel to the hole or cylinder axis. The large 24 mm square dimensions facilitate parallel adjustments and makes an accurate setting possible.
5. The service life is longer because of the larger measuring face area.

* Through hole in the measuring face

1. Gauge blocks are easily joined together without the need for troublesome wringing.
2. Joining gauge blocks with a tie rod prevents accidental detachment during measurement.
3. Gauge blocks with inferior wringability due to scratches or other flaws can still be joined using a tie rod, resulting in a longer service life.
4. By fixing gauge blocks together with a tie rod, any gauge size for a specific purpose use can be built up.

Protective wear blocks made of carbide are also available.

Shortcomings:

1. It takes longer to thermally stabilize the blocks due to their greater mass.
2. Because of their large size, it is difficult to use them in a small space.

21. ACCESSORIES AND THEIR USES

There are various gauge block accessories available for a wide range of applications. The following description applies to both rectangular and square gauge blocks since the functions and applications of both types are practically the same, overlooking the difference in shape. For further information, please refer to the respective catalogs and manuals.

- Holder (Tie rod)

Holders are used for joining gauge blocks to other accessories such as jaws and base blocks. Tie rods are used for joining square gauge blocks, whereby the rod passes through the holes in the blocks and clamps them together at both ends using screws.

- Half-round jaws

These are used for inside and outside measurements. The wringing face is used for measuring the outside dimensions of a workpiece (or the inside dimensions of a measuring tool), and the measuring face is used for measuring the inside dimensions of a workpiece (or the outside dimensions of a measuring tool).

- Plain jaws

Plain jaws are available in two types; type A and type B. Type A has two wringing faces (bottom and top faces) and is used for both inside and outside measurements. Type B has only one wringing surface and is used for outside measurements.

- Scriber point

This is used as a scribing needle.

- Base block

This is used as the base for supporting gauge blocks when they are used in the upright position. One application is the combined use of a base block and gauge blocks with a jaw or a scriber point for use as a height gauge.

- Center point

This serves as the reference point of a compass and is used together with a scriber point to scribe circles, divide lines and so forth.

- Trammel point

This has a pointed tip, and a pair of trammel points is used to calibrate graduations on a scale, etc.

- Straightedge

A straightedge has a blade edge with a high degree of straightness and is used to measure the flatness of a workpiece surface by observing the gap between the two.

22. PERIODIC INSPECTION OF GAUGE BLOCKS

The size of a gauge block is subject to a minute changes due to abrasion during use. Dimensional changes may take place over time even if stored unused. For the time interval between periodic size inspections, refer to the guidelines shown in **Table 10**, giving considerations to such factors as the grade of the gauge block and the frequency of use. Also check the gauge blocks for burrs once a month or after each use, and correct any problems whenever required.

Table 10 The interval between periodic inspections

Application	Interval	Grade (reference)
For highest standards	1 - 2 years	00
For standards	2 years	00 or 0
For inspection	2 years	0 or 1
Workshop use	0.5 - 1 year	1 or 2

Note) The intervals indicated above are a general guideline. Gauge blocks of a larger nominal size, of higher grades and frequently used require shorter intervals, and vice versa.

23. CERA BLOCKS

With recent advances in new materials, Mitutoyo has made extensive studies on introducing ceramics as gauge block material, and as a result, developed a new range of gauge blocks named 'Cera Blocks' which use zirconia ceramics, the most suitable ceramic material for gauge blocks. The following are some of the outstanding features of the new Cera Block.

(1) Because Cera Blocks do not corrode, they can be handled with bare hands and do not need special maintenance and rust prevention treatment.

(2) The superior abrasion resistance (10 times that of Mitutoyo steel gauge blocks) prolongs service life.

(3) The uniform and dense grain structure and the resistance to abrasion enable the blocks to be tightly wrung together.

(4) Because the thermal expansion coefficient is close to that of steel (see **Table 11**), Cera Blocks can be used under the same temperature conditions as steel gauge blocks.

(5) Zirconia ceramics have superior mechanical strength, compared to other types of ceramics, such as bending strength and toughness, which is more than sufficient for gauge blocks.

(6) Burrs on the measuring face can be easily removed using the same procedure as described in **Section 16** (page 9).

Note: Since the thermal conductivity of ceramics is relatively low, the temperature of ceramic gauge blocks does not respond as quickly to changes in the ambient temperature as steel blocks do. Therefore, care should be taken when using Cera Blocks in an environment where there are large temperature fluctuations.

Table 11 The properties of gauge block materials

Material Property	Zirconia ceramics	Steel	Carbide	Silicon nitride ceramics
Hardness (HV)	1350	800	1650	1500
Thermal expansion coefficient ($10^{-6}/°C$)	10±1	11.5±1	5	2
Bending strength (3-point bending) (kgf/mm^2)	130	200	200	60
Young's modulus ($\times 10^4 kgf/mm^2$)	2.1	2.1	6.3	2.9
Poisson's ratio	0.3	0.3	0.2	0.3
Specific gravity	6.0	7.8	14.8	3.2
Thermal conductivity (Cal/cm. sec.°C)	0.007	0.13	0.19	0.04

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