ENGINEERING METROLOGY
(DIMENSIONAL METROLOGY)

TRADITIONAL MEASURING METHODS FOR LENGTH AND ANGLE

DEPARTMENT OF MECHANICAL ENGINEERING
ISFAHAN UNIVERSITY OF TECHNOLOGY

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Dimensional Metrology Needs

- Linear measurements
- Angular measurements
- Geometric form measurements
  - Roundness
  - Straightness
  - Cylindricity
  - Flatness, etc

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Dimensional Metrology Needs

- Geometric relationships
  - Parallel, perpendicular, etc.
  - Concentric, runout, etc.
- Controlled surface texture

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GEOMETRIC FEATURES OF PARTS

- Common measured quantities and geometric features:
  - ✓ Length _ including all linear dimensions of parts
  - ✓ Diameter _ outside and inside
  - ✓ Roundness _ including out of roundness, eccentricity
  - ✓ Depth _ such as drilled or bored holes and cavities in dies
  - ✓ Straightness _ such as shafts, bars and tubing
  - ✓ Flatness _ such as machined and ground surfaces
  - ✓ Perpendicularity_ such as a threaded bar inserted into a plate
  - ✓ Parallelism_ such as two shafts or slideways in machines
  - ✓ Angles_ including internal and external angles
  - ✓ Profile_ such as curvatures in castings, forgings

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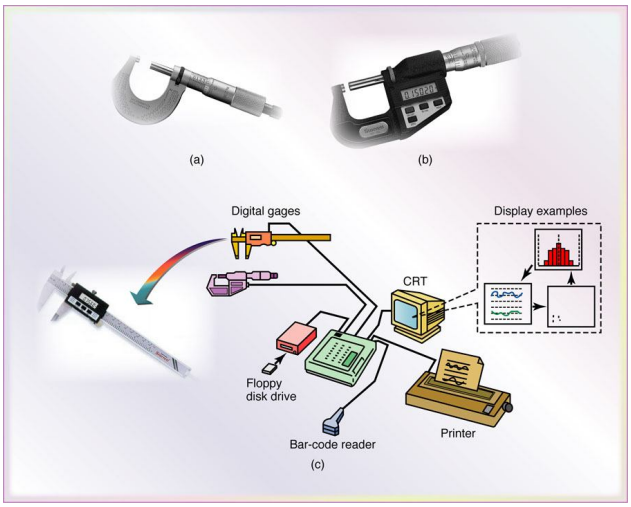

Analog and Digital Measuring Devices

(a) A vernier (analog) micrometer. (b) A digital micrometer with a range of 0 to 25 mm and a resolution of 1.25μm. It is generally easier to read dimensions on this instrument compared to the analog micrometer. (c) Schematic illustration showing the integration of digital gages with microprocessors for real-time data acquisition for statistical process control.

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TRADITIONAL MEASURING METHODS AND INSTRUMENTS

- Line-graduated (means “marked to indicate a certain quantity)instruments:
  - Linear measurement
    - Direct readings
      - Rules
      - Vernier Calipers
      - Micrometers
    - Indirect reading: without any graduated scales
      - Calipers and dividers
      - Telescoping gages

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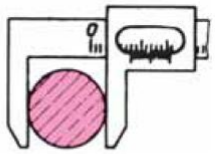
Direct and indirect measuring



الف- اندازه گیری مستقیم

ب- اندازه گیری غیرمستقیم

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HISTORY OF MEASURING LENGTH UNIT

✓~4000 B.C	King's Elbow	Elbow (0.4633m): 1.5 feet/ 2 hand-spans
✓ 1101 A.D	King Henry I	Yard (0.9144m): distance from his nose to the tip of his thumb
✓ 1528	J. Fernel	Reference: Distance between Paris & Amiens
✓17th century		The length of certain pendulum
✓ 1661	Sir C. Wren	Pendulum with a period of ½ second
✓	C. Huygens	Pendulum with a period of 1 second
✓ 1790	France	Métre: one ten-millionth of the distance between the north pole and the equator (pure platinum rectangle in 1799)
✓ 1870-1872		*meter*: 90% platinum & 10% iridium, X-shaped bar
✓ 1960	SI	1,650,763.73 wavelengths of the orange light given off by electrically excited krypton 86

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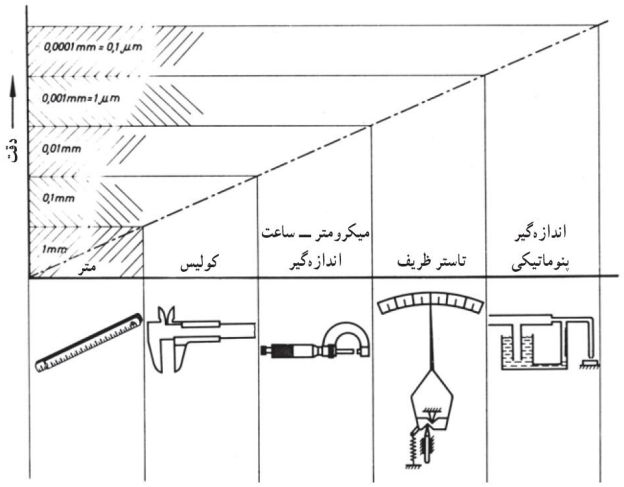
دقت تعدادی از وسایل اندازه‌گیری و کنترل اندازه



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MEASURING LENGTH
DIRECT READING: RULES

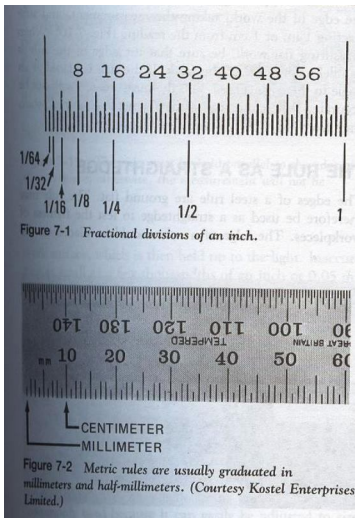

Figure 7-1 *Fractional divisions of an inch.*

Figure 7-2 *Metric rules are usually graduated in millimeters and half-millimeters. (Courtesy Kostel Enterprises Limited.)*

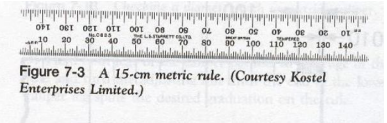

Figure 7-3 *A 15-cm metric rule. (Courtesy Kostel Enterprises Limited.)*

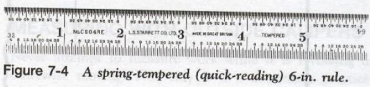

Figure 7-4 *A spring-tempered (quick-reading) 6-in. rule.*

Figure 7-5 *A hook rule is used to make accurate measurements from an edge or shoulder. (Courtesy The L. S. Starrett Company.)*

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DIRECT READING: RULES

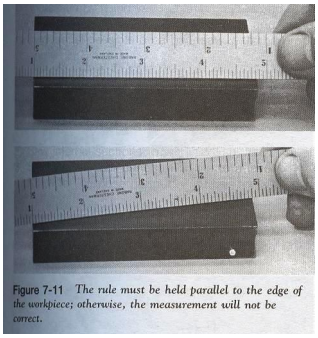

Figure 7-11 *The rule must be held parallel to the edge of the workpiece; otherwise, the measurement will not be correct.*

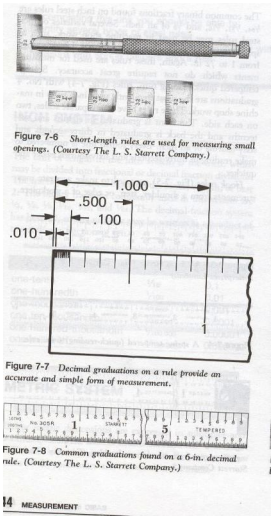

Figure 7-6 *Short-length rules are used for measuring small openings. (Courtesy The L. S. Starrett Company.)*

Figure 7-7 *Decimal graduations on a rule provide an accurate and simple form of measurement.*

Figure 7-8 *Common graduations found on a 6-in. decimal rule. (Courtesy The L. S. Starrett Company.)*

14 MEASUREMENT

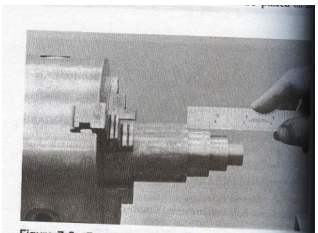

Figure 7-9 *Butting a rule against a shoulder.*

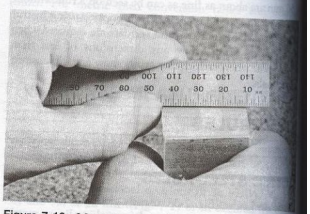

Figure 7-10 *Measuring with a rule starting at the 1-cm line. (Courtesy Kostel Enterprises Limited.)*

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DIRECT READING: VERNIER CALIPER

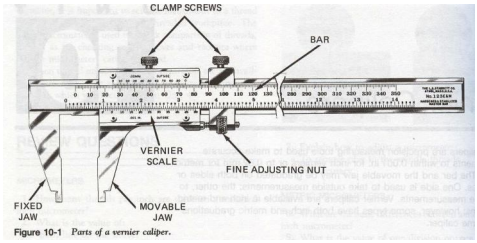
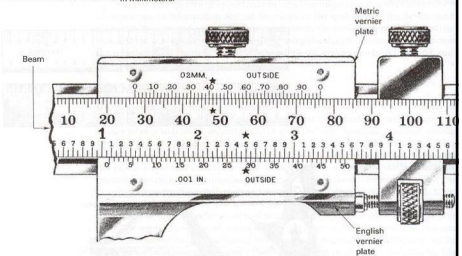


Figure 10-1 *Parts of a vernier caliper.*

FIGURE 10-16 Vernier caliper graduated for English and metric (direct) reading. The metric reading is 27 + 0.42 = 27.42 mm.

Refer to the upper bar graduations and metric vernier plate. Each bar graduation is 1.00 mm. Every tenth graduation is numbered in sequence–10 mm, 20 mm, 30 mm, 40 mm, etc. over the full range of the bar. This provides for direct reading in millimeters.



In the picture, the vernier plate zero line is one inch (1.000") plus one twentieth (0.50") beyond the zero line on the bar, or 1.050". The 29th graduation on the vernier plate coincides with a line on the bar (as indicated by stars). 29 × 0.001 (.029") is therefore added to the 1.050" bar reading, and the total is 1.079".

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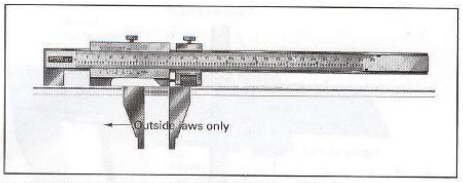
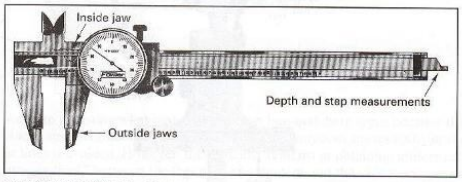
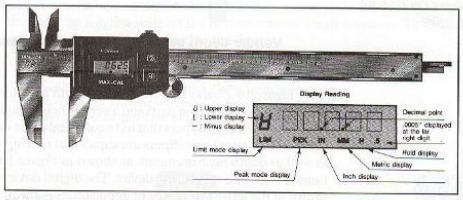
DIRECT READING: VERNIER CALIPER



Vernier caliper with inch or metric scales and 0.001 in. accuracy



Dial caliper with 0.001 in. accuracy



Digital electronic caliper with 0.001 in. (0.03 mm) accuracy and 0.0001 in. resolution

FIGURE 10-18 Three styles of calipers in common use today: (a) Vernier caliper with inch or metric scales and .001-in. accuracy; (b) dial caliper with .001-in. accuracy; (c) digital electronic caliper with .001-in. (.03-mm) accuracy and .0001-in. resolution with inch/metric conversion.

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DIRECT READING: VERNIER CALIPER

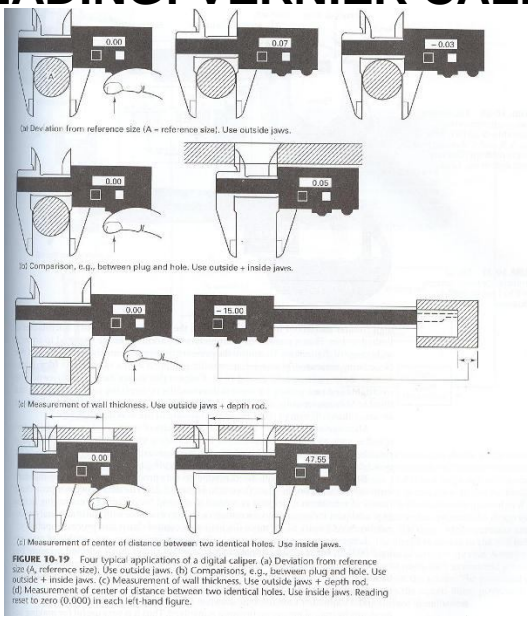

FIGURE 10-19 Four typical applications of a digital caliper. (a) Deviation from reference size (A, reference size). Use outside jaws. (b) Comparisons, e.g., between plug and hole. Use outside + inside jaws. (c) Measurement of wall thickness. Use outside jaws + depth rod. (d) Measurement of center of distance between two identical holes. Use inside jaws. Reading reset to zero (0.000) in each left-hand figure.

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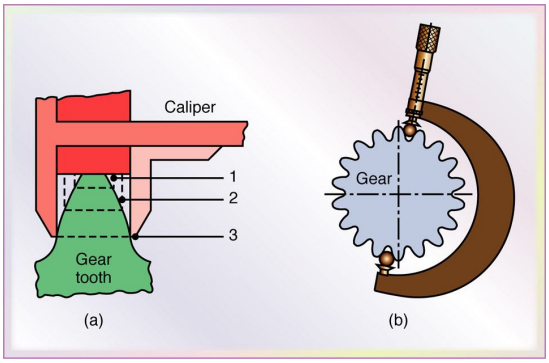
MEASURING GEAR-TOOTH TICKNESS & PROFILE



Measuring gear-tooth thickness and profile with (a) a gear-tooth caliper and (b) pins or balls and a micrometer. *Source:* Courtesy of American Gear Manufacturers Association.

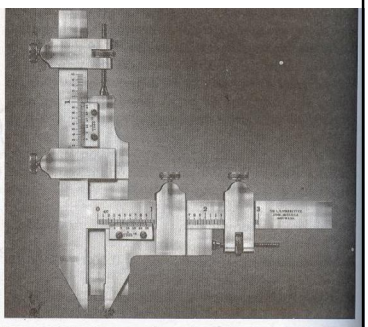


Figure 10-7 *A gear-tooth vernier caliper.*

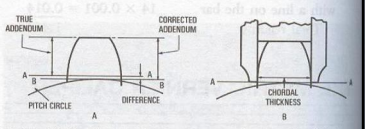


Figure 10-8 *Gear-tooth measurement showing the (A) true and (B) corrected addendum.*

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DIRECT READING: MICROMETER

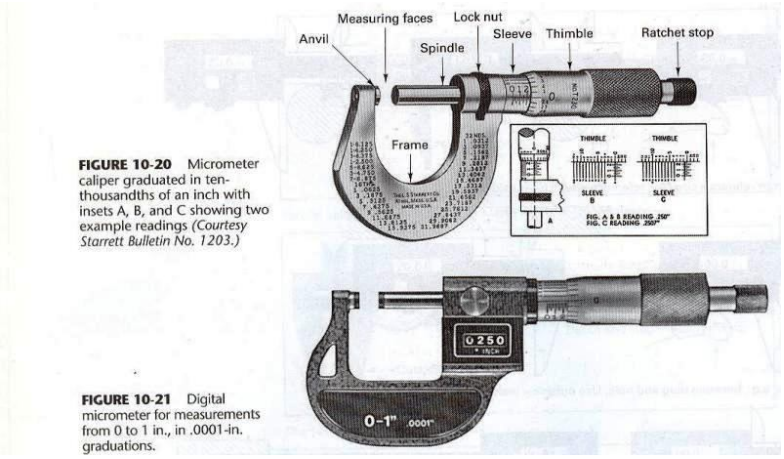

FIGURE 10-20 Micrometer caliper graduated in ten-thousandths of an inch with insets A, B, and C showing two example readings *(Courtesy Starrett Bulletin No. 1203.)*

FIGURE 10-21 Digital micrometer for measurements from 0 to 1 in., in .0001-in. graduations.

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DIRECT READING: MICROMETER

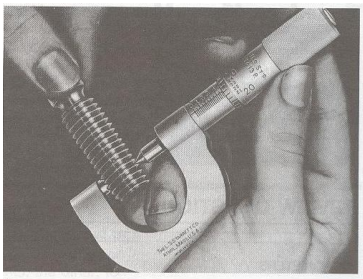

Figure 9-17 *A screw thread micrometer measures the pitch diameter of a thread. (Courtesy The L. S. Starrett Company.)*

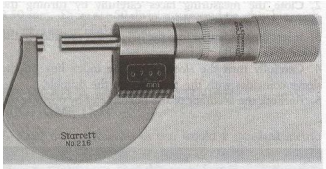

Figure 9-11 *A direct-reading micrometer has graduations like those in a standard micrometer and a digital readout built into the frame. (Courtesy The L. S. Starrett Company.)*

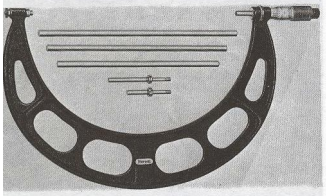

Figure 9-12 *A large-frame micrometer has interchangeable anvils that increase the range of the micrometer. (Courtesy The L. S. Starrett Company.)*

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DIGITAL-MICROMETER Depth Gage

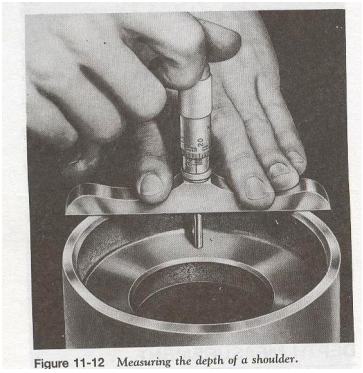

Figure 11-12 *Measuring the depth of a shoulder.*

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INSIDE MICROMETER

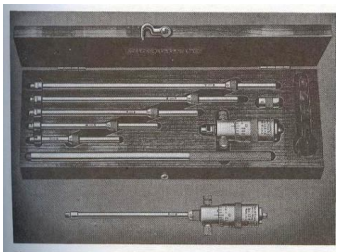

Figure 11-2 *An inside micrometer set can measure a large range of sizes.*

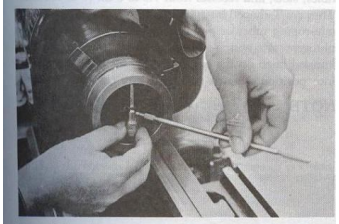

Figure 11-3 *Using an inside micrometer to measure the size of a hole.*

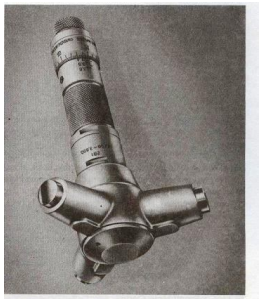

Figure 11-4 *The Intrimik, which has three contact points, measures holes accurately. (Courtesy Brown & Sharpe Co.)*

Figure 11-5 *Construction of the Intrimik head. (Courtesy Brown & Sharpe Co.)*

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INDIRECT READING:

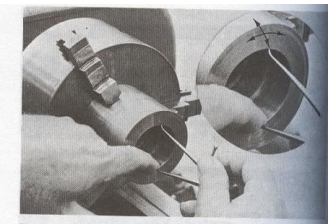

Figure 7-14 *Adjusting an inside caliper to the size of a hole.*

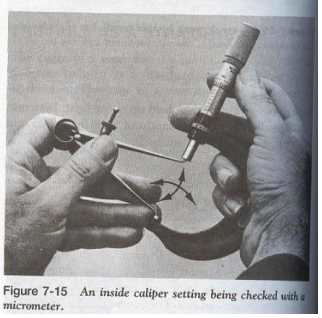

Figure 7-15 *An inside caliper setting being checked with a micrometer.*

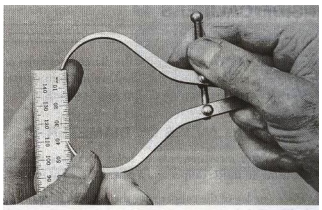

Figure 7-12 *Setting an outside caliper to size with a rule.*

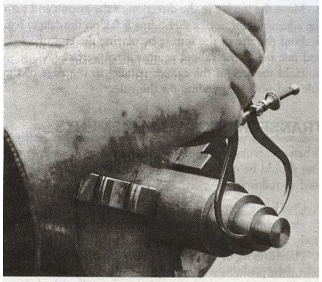

Figure 7-13 *Checking a diameter with an outside caliper.*

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INDIRECT READING:

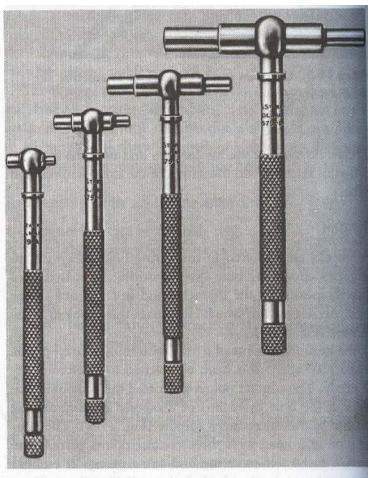

Figure 11-7 *A set of telescope gages. (Courtesy The L. S. Starrett Company.)*

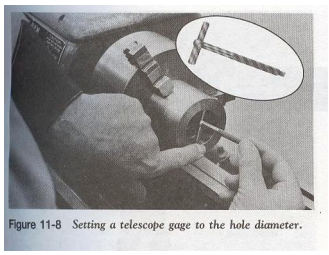

Figure 11-8 *Setting a telescope gage to the hole diameter.*

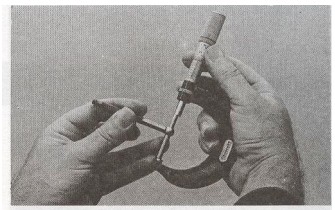

Figure 11-9 *Measuring the telescope gage setting with a micrometer.*

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TRADITIONAL MEASURING METHODS AND INSTRUMENTS

- Line-graduated instruments:
  - Measuring length
    - Direct readings
      - Rules
      - Vernier Calipers
      - Micrometers
    - Indirect reading
      - Calipers
      - Telescoping gages

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Measuring length

- **Vernier micrometer**
  - A vernier scale on the sleeve
  - Improving reading accuracy
  - Reading scale 0.0001 in and 0.002 mm
  - Not trustable read values for 0.002 mm (0.0001 in) [not in accordance with rule of 10]- to be discussed later

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Vernier micrometer

metric **inch**

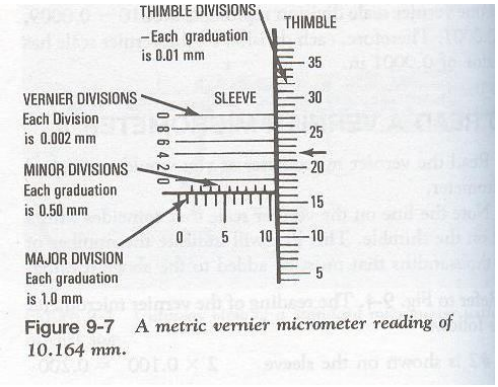

Figure 9-7 *A metric vernier micrometer reading of 10.164 mm.*

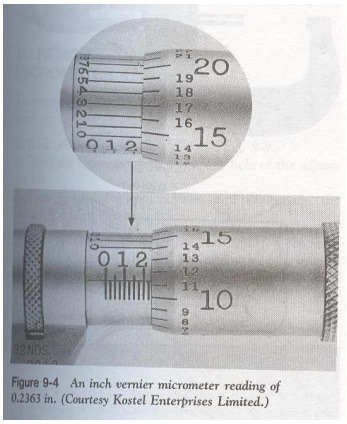

Figure 9-4 *An inch vernier micrometer reading of 0.2363 in. (Courtesy Kostel Enterprises Limited.)*

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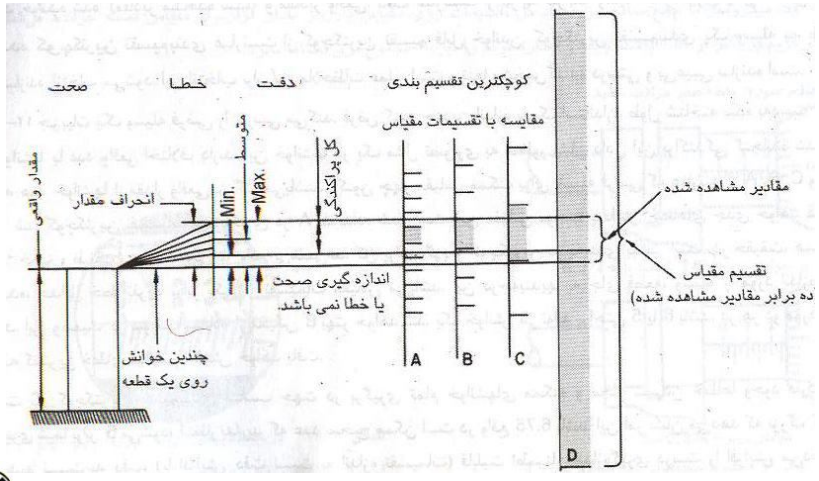
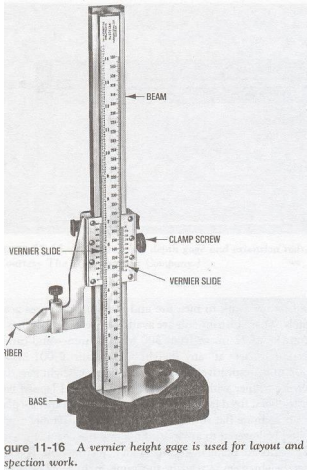
Accuracy and measuring scale



Measuring height

- **Vernier height gage**
  - Used in toolrooms and inspection departments on layout and jig and fixture work to measure and mark off distances accurately
  - Size 300 to 1000 mm (12 to 72 in)
  - Resolution 0.02 mm (0.001 in)



gure 11-16 *A vernier height gage is used for layout and spection work.*

Measuring height

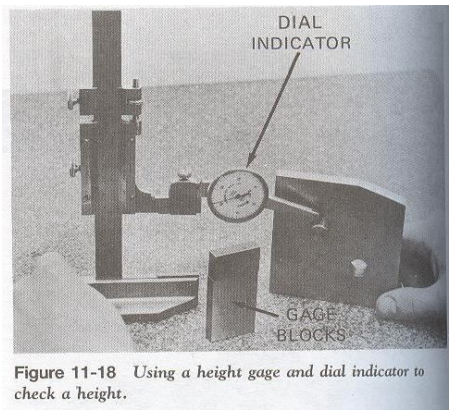
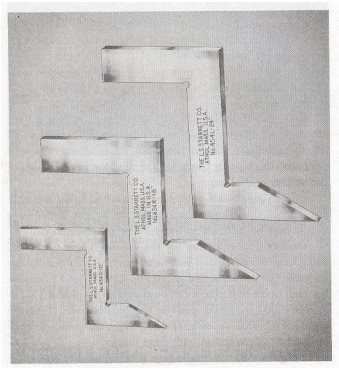


Figure 11-18 *Using a height gage and dial indicator to check a height.*



Offset scribers are used with a vernier height gage for accurate layout work

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TRADITIONAL MEASURING METHODS AND INSTRUMENTS

Angle measurement

- Usually are more difficult to make than linear measurements
- Angles are measured in degrees
  - Decimal subdivisions of a degree: minutes and seconds [sometimes decimal portions of degree)
  - For plane angles radian in SI (degrees permissible)
  - Two methods of measurements:
  - Direct
  - Indirect

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TRADITIONAL MEASURING METHODS AND INSTRUMENTS

- Line-graduated instruments:
  - Angle measurement instruments
    - Precision squares
    - Combination square
    - Bevel protractor
    - Sine bar
    - Surface plate

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PRECESION SQUARES

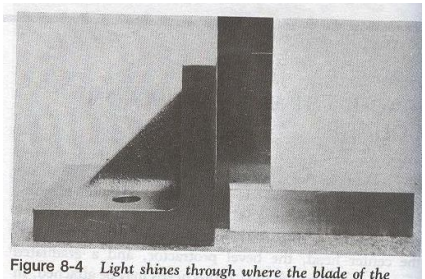

Figure 8-4 *Light shines through where the blade of the square does not make line contact with the surface.*

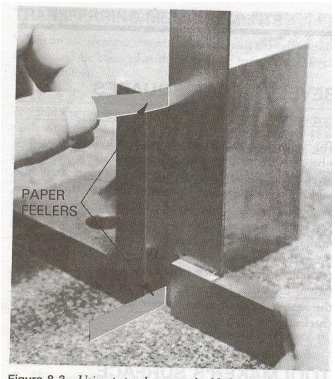

Figure 8-3 *Using paper between the blade of the square and the workpiece to check for squareness.*

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PRECESION SQUARES

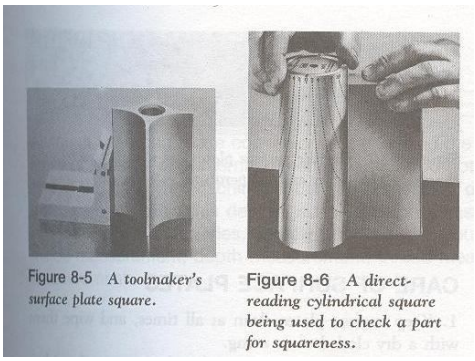

Figure 8-5 *A toolmaker's surface plate square.*

Figure 8-6 *A direct-reading cylindrical square being used to check a part for squareness.*

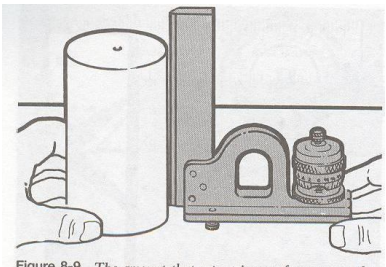

Figure 8-9 *The amount that a part is out of square can be read on an adjustable micrometer square. (Courtesy Ash Precision Equipment Inc.)*

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PRECESION SQUARES

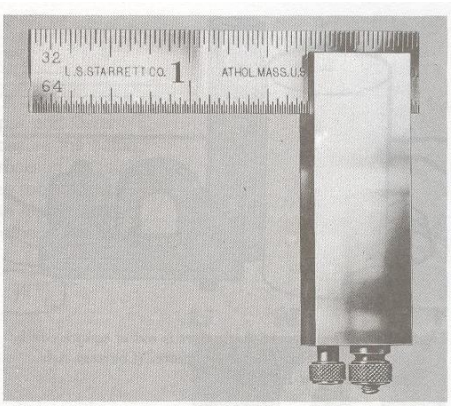

Figure 8-7 *A diemaker's square is useful for checking die clearance.*

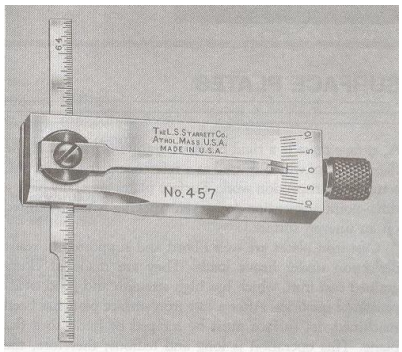

Figure 8-8 *The direct-reading diemaker's square indicates the angle at which the blade is set.*

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COMBINATION SET

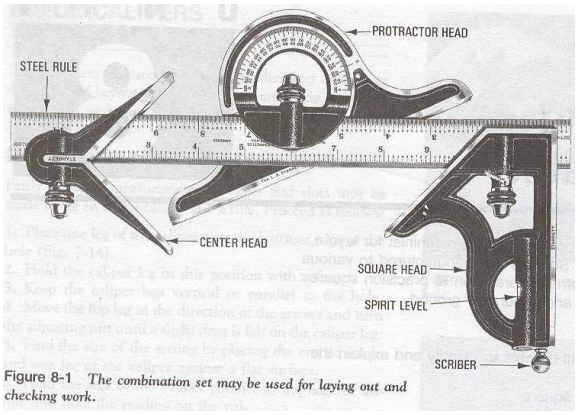

Figure 8-1 *The combination set may be used for laying out and checking work.*

Figure 8-2 *The combination (adjustable) square being used as a depth gage.*

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BEVEL PROTRACTOR

- A precision instrument capable of measuring angles to within 5’ (0.083°)
- A base & vernier scale

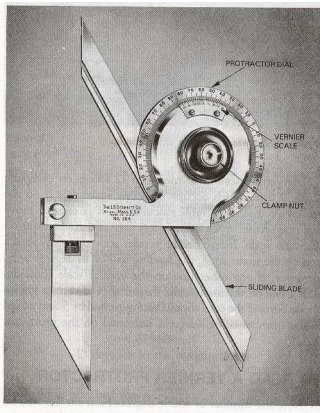

Figure 13-1 *The universal bevel protractor can measure angles accurately.*

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BEVEL PROTRACTOR

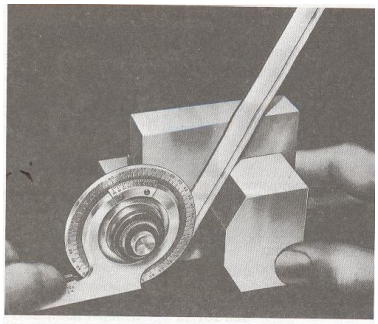

Figure 13-2 *Measuring an obtuse angle using a universal bevel protractor.*

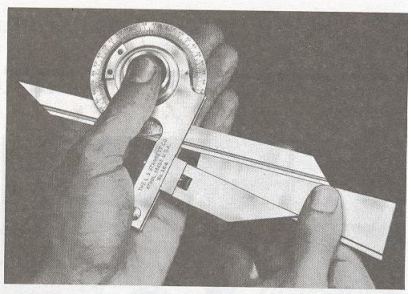

Figure 13-3 *Measuring an acute angle.*

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Surface plates

- Rigid block of granite or cast iron
- The flat surface is used as a reference plane for layout, setup, and inspection work
- Generally have a three-point suspension to prevent rocking when mounted on an uneven surface

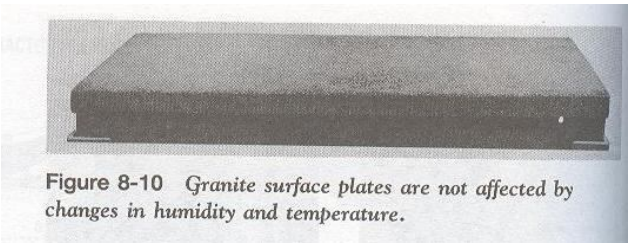

Figure 8-10 *Granite surface plates are not affected by changes in humidity and temperature.*

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Surface plates

- Cast-iron plates are well ribbed and supported to resist deflection under heavy loads
  - Made of close-grained cast iron
  - High strength and good wear
- Surface scraped by hand to a flat plane after machining
- Granite surface plates may be made from grey, pink, or black granite
  - Obtainable in several degrees of accuracy
  - Lapped for flat finished

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Surface plates

- Advantages of granite surface plates may be made from grey, pink, or black granite
  - Will not burr; therefore the accuracy is not impaired
  - Not appreciably affected by temperature changes
  - Nonmagnetic
  - Rustproof
  - Abrasives will not embed themselves as easily in the surface; thus they may be used near grinding machines

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THE SINE BAR

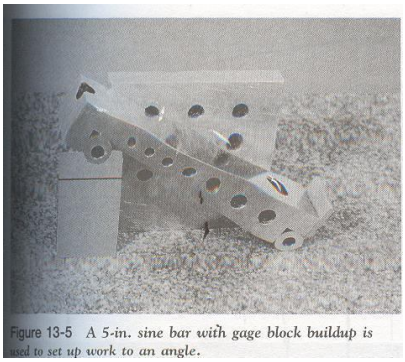
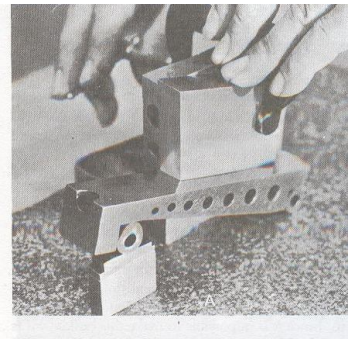


Figure 13-5 A 5-in. sine bar with gage block buildup is used to set up work to an angle.



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Sine bar

- Used when the accuracy of an angle must be checked to less than 5’ or work must be located to a given angle within close limits
- Consists of a steel bar with two cylinders of equal diameter fastened near the ends
- The distance between the centers 125 or 250mm (5 in ± 0.0002; accuracy of the face of the sine bar 0.000 05 in)
- Made from a hardened, stabilized, ground, and lapped tool steelmay be used near grinding machines

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Measuring with Sine bar

- Placing the part on the sine bar or plate
- Adjusting the angle by placing blocks on a surface plate
- Using a dial indicator to scan the top surface of the part
- Adding or removing gage blocks as necessary until the top surface is parallel to the surface plate
- Calculating the angle using trigonometric:

$$\text{Sine of the angle} = \frac{\text{side opposite}}{\text{hypotenuse}} = \frac{\text{gage block buildup}}{\text{length of sine bar}}$$

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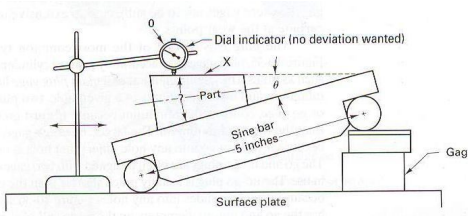
Measuring with sine bar- sine plate



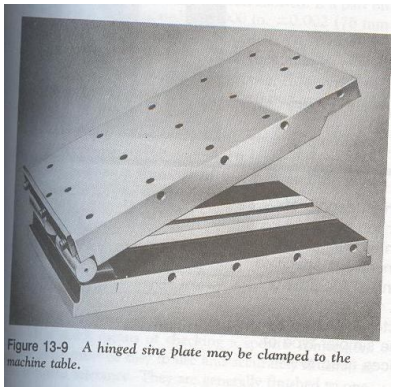


Figure 13-9 *A hinged sine plate may be clamped to the machine table.*

Sine plate

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Comparative length measurement

- Instruments used for measuring comparative lengths
- Amplify and measure variations or deviations in the distance between two or more surfaces
- The most common example is dial indicator with accuracies as high as 1μm

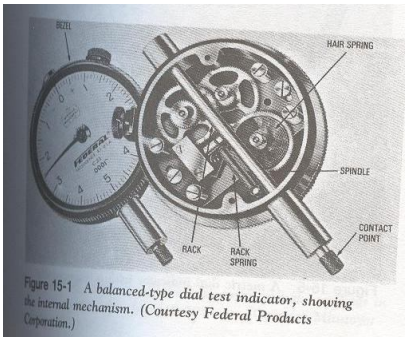

Figure 15-1 *A balanced-type dial test indicator, showing the internal mechanism. (Courtesy Federal Products Corporation.)*

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Dial indicator

- Mechanical devices that convert linear displacements of a pointer to the amount of rotation of an indicator on a circular dial
- To compare sizes and measurements to a known standard
- To check the alignment of a machine tools, fixtures, and workpieces prior to machining

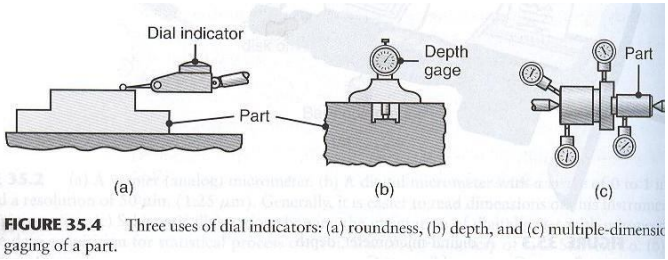

FIGURE 35.4 Three uses of dial indicators: (a) roundness, (b) depth, and (c) multiple-dimensio gaging of a part.

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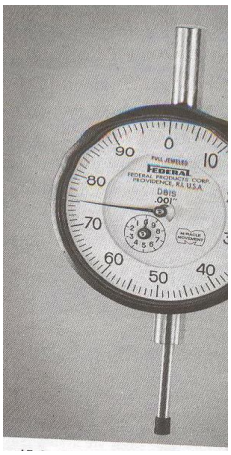
Types of dial indicators



continuous-reading dial indicator

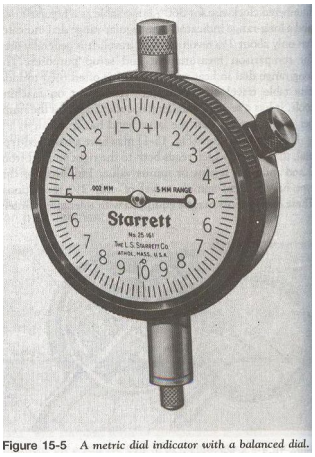
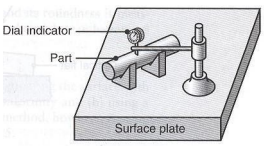


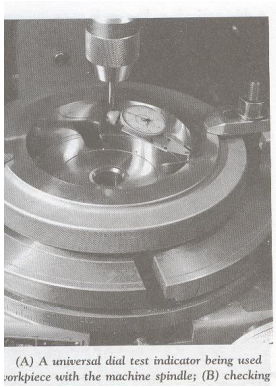
Figure 15-5 *A metric dial indicator with a balanced dial.*

Dial test indicator (balanced)

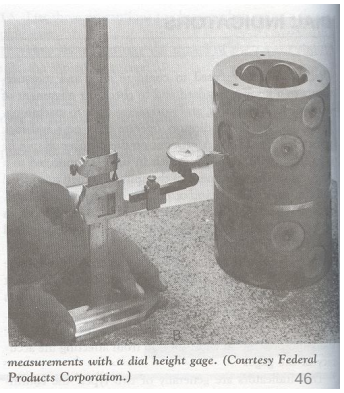
Working with dial indicator

- The indicator is set to zero at a certain reference surface
- The instrument or the surface to be measured is brought into contact with the pointer
- The movement of the indicator is read directly on the circular dial (either plus or minus)





(A) A universal dial test indicator being used workpiece with the machine spindle; (B) checking



measurements with a dial height gage. (Courtesy Federal Products Corporation.)

Gages

- Interchangeable manufacture requires an accurate standard of measurements in order to function efficiently
- Gages provide industry with a means of maintaining sizes to specific standards and tolerances
- Gages may include gage blocks, fixed gages, air gages, or sophisticated electronic or laser devices

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Gage blocks

- Individual square, rectangular, or round blocks of various sizes
- Made from hardened and ground alloy steel which have been heat treated and stress relived
- The two measuring surfaces are lapped and polished to an optically flat surface and to a specific size accurate within 2 to 8 millionths of an inch (50 to 200 millionths of a millimeter)
- The size of each block is stamped on one of its surface

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Gage blocks

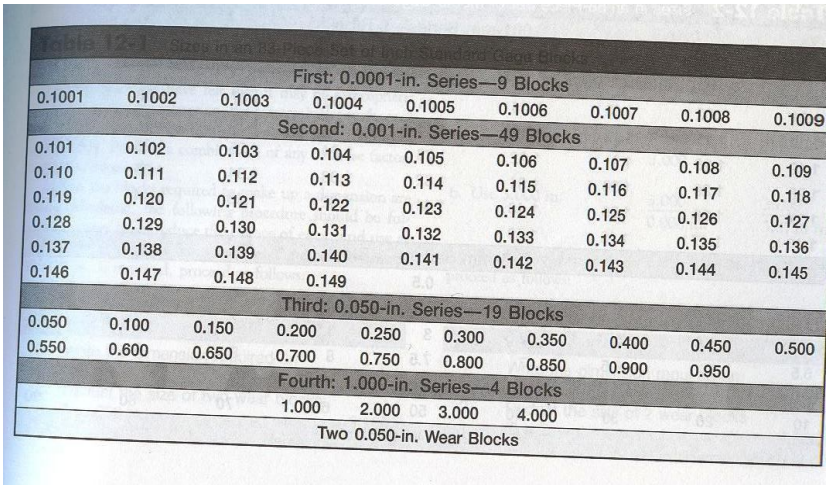
- Chrome plated gage blocks are also available
- Carbide blocks when long wear is desirable
- Ceramics (often zirconia) blocks are available because of:
  - Corrosion resistance
  - No detrimental effect as a result of handling
  - Superior abrasion resistance
  - Thermal expansion coefficient close to steel
  - Resistance to impact
  - Free from burr

Figure 12-1 An 83-piece set of gage blocks.

Application of gage blocks

- To check the dimensional accuracy of fixed gages to determine the extent of wear, growth, or shrinkage
- To calibrate adjustable gages, such as micrometers and vernier calipers, imparting accuracies to theses instruments
- To set comparators, dial indicators, and height gages to exact dimensions
- To set sine bars and sine plates when extreme accuracy is required in angular setups
- For precision layout with the use of attachments
- To make machine tool setups
- To measure and inspect the accuracy of finished parts

Sizes in an 83-piece set of Inch gage block



First: 0.0001-in. Series—9 Blocks								
0.1001	0.1002	0.1003	0.1004	0.1005	0.1006	0.1007	0.1008	0.1009
Second: 0.001-in. Series—49 Blocks								
0.101	0.102	0.103	0.104	0.105	0.106	0.107	0.108	0.109
0.110	0.111	0.112	0.113	0.114	0.115	0.116	0.117	0.118
0.119	0.120	0.121	0.122	0.123	0.124	0.125	0.126	0.127
0.128	0.129	0.130	0.131	0.132	0.133	0.134	0.135	0.136
0.137	0.138	0.139	0.140	0.141	0.142	0.143	0.144	0.145
0.146	0.147	0.148	0.149					
Third: 0.050-in. Series—19 Blocks								
0.050	0.100	0.150	0.200	0.250	0.300	0.350	0.400	0.450	0.500
0.550	0.600	0.650	0.700	0.750	0.800	0.850	0.900	0.950	
Fourth: 1.000-in. Series—4 Blocks								
			1.000	2.000	3.000	4.000		
Two 0.050-in. Wear Blocks								

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Sizes in an 88-piece set of Metric gage block

Table 12-2 Sizes in an 88-Piece Set of Metric Gage Blocks

0.001-mm Series—9 Blocks							
1.001	1.002	1.003	1.004	1.005	1.006	1.007	1.008
0.01-mm Series—49 Blocks							
1.01	1.02	1.03	1.04	1.05	1.06	1.07	1.08
1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.17
1.19	1.20	1.21	1.22	1.23	1.24	1.25	1.26
1.28	1.29	1.30	1.31	1.32	1.33	1.34	1.35
1.37	1.38	1.39	1.40	1.41	1.42	1.43	1.44
1.46	1.47	1.48	1.49				
0.5-mm Series—1 Block							
0.5							
0.5-mm Series—18 Blocks							
1	1.5	2	2.5	3	3.5	4	4.5
5.5	6	6.5	7	7.5	8	8.5	9
10-mm Series—9 Blocks							
10	20	30	40	50	60	70	80
Two 2-mm Wear Blocks							

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