# CHAPTER 35

## Engineering Metrology and Instrumentation

# Slideway Cross-Section

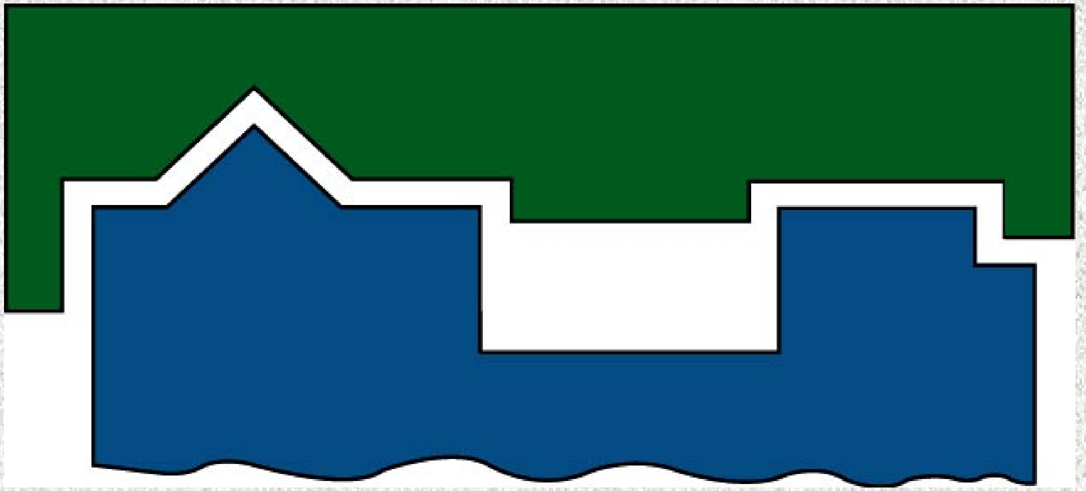


Figure 35.1 Cross-section of a machine tool slideway. The width, depth, angles, and other dimensions must be produced and measured accurately for the machine tool to function as expected.

# Types of Measurement and Instruments Used

TABLE 35.1

| Measurement | Instrument | Sensitivity μm | Sensitivity μin. |
|---|---|---|---|
| Linear | Steel rule | 0.5 mm | 1/64 in. |
| | Vernier caliper | 25 | 1000 |
| | Micrometer, with vernier | 2.5 | 100 |
| | Diffraction grating | 1 | 40 |
| Angle | Bevel protractor, with vernier | 5 min | |
| | Sine bar | | |
| Comparative length | Dial indicator | 1 | 40 |
| | Electronic gage | 0.1 | 4 |
| | Gage blocks | 0.05 | 2 |
| Straightness | Autocollimator | 2.5 | 100 |
| | Transit | 0.2 mm/m | 0.002 in./ft |
| | Laser beam | 2.5 | 100 |
| Flatness | Interferometry | 0.03 | 1 |
| Roundness | Dial indicator Circular tracing | 0.03 | 1 |
| Profile | Radius or fillet gage | | |
| | Dial indicator | 1 | 40 |
| | Optical comparator | 125 | 5000 |
| | Coordinate measuring machines | 0.25 | 10 |
| GO-NOT GO | Plug gage | | |
| | Ring gage | | |
| | Snap gage | | |
| Microscopes | Toolmaker's | 2.5 | 100 |
| | Light section | 1 | 40 |
| | Scanning electron | 0.001 | 0.04 |
| | Laser scan | 0.1 | 5 |

# Caliper and Vernier

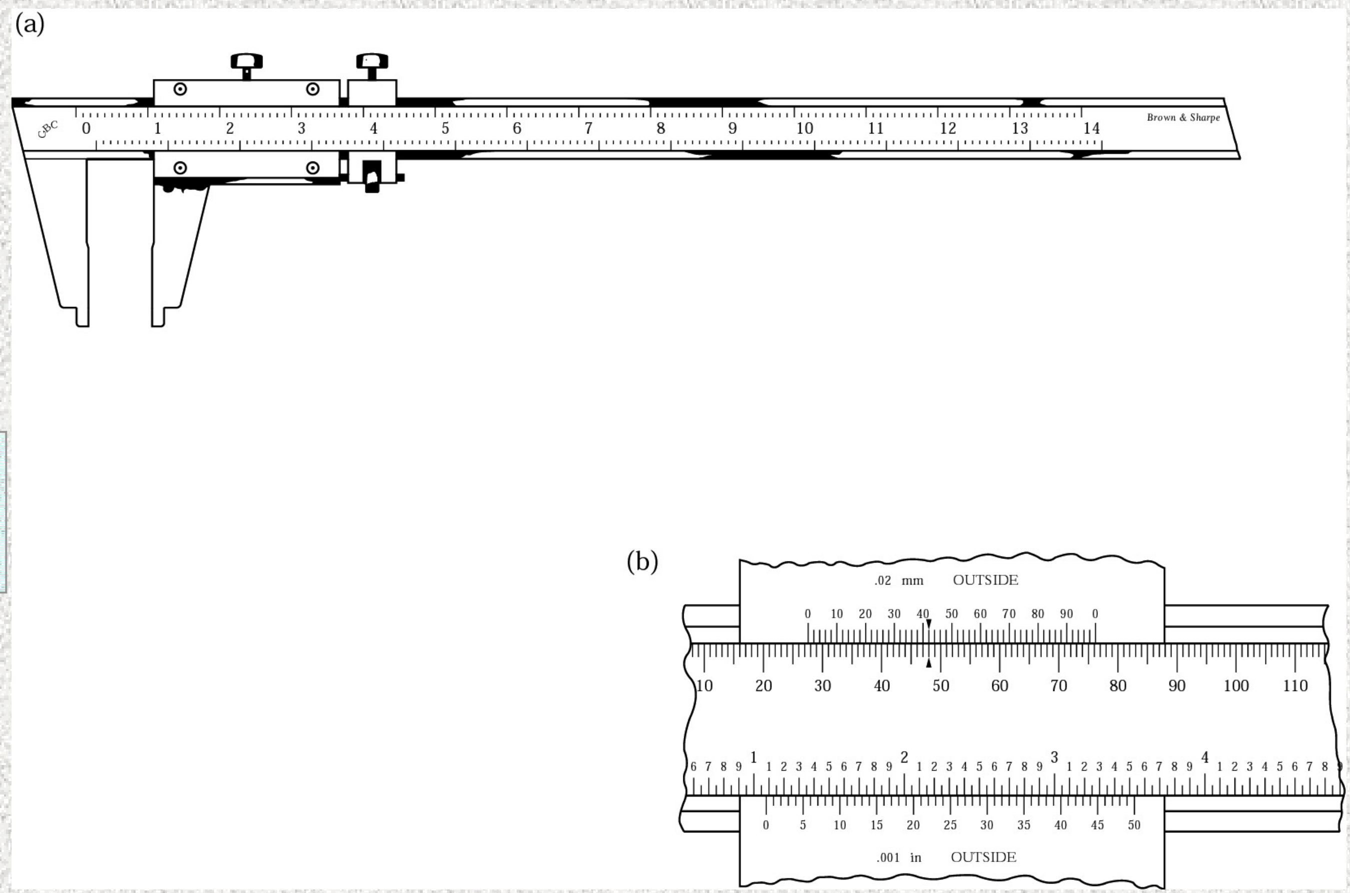



Figure 35.2 (a) A caliper gage with a vernier. (b) A vernier, reading 27.00 + 0.42 = 27.42 mm, or 1.000 + 0.050 + 0.029 = 1.079 in. We arrive at the last measurement as follows: First note that the two lowest scales pertain to the inch units. We next note that the 0 (zero) mark on the lower scale has passed the 1-in. mark on the upper scale. Thus, we first record a distance of 1.000 in. Next we note that the 0 mark has also passed the first (shorter) mark on the upper scale. Noting that the 1-in. distance on the upper scale is divided into 20 segments, we hve passed a distance of 0.050 in. Finally note that the marks on the two scales coincide at the number 29. Each of the 50 graduations on the lower scale indicates 0.001 in., so we also have 0.029 in. Thus the total dimension is 1.000 in. + 0.050 in. + 0.029 in. = 1.079 in.

# Analog and Digital Micrometers

(a)


(c)

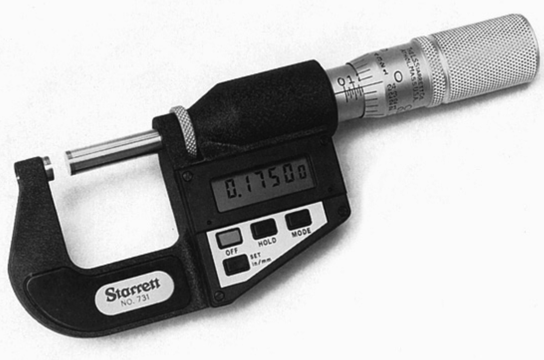



Figure 35.3 (a) A micrometer being used to measure the diameter of round rods. *Source*: L. S. Starrett Co. (b) Vernier on the sleeve and thimble of a micrometer. Upper one reads 0.200 + 0.075 + 0.010 = 0.285 in.; lower one reads 0.200 + 0.050 + 0.020 + 0.0003 = 0.2703 in. These dimensions are read in a manner similar to that described in the caption for Fig. 35.2. (c) A digital micrometer with a range of 0-1 in. (0-25 mm) and a resolution of 0.00005 in. (0.001 mm). Note how much easier it is to read dimensions on this instrument than on the analog micrometer shown in (a). However, such instruments should be handled carefully. *Source*: Mitutoyo Corp.

# Angle-Measuring Instruments

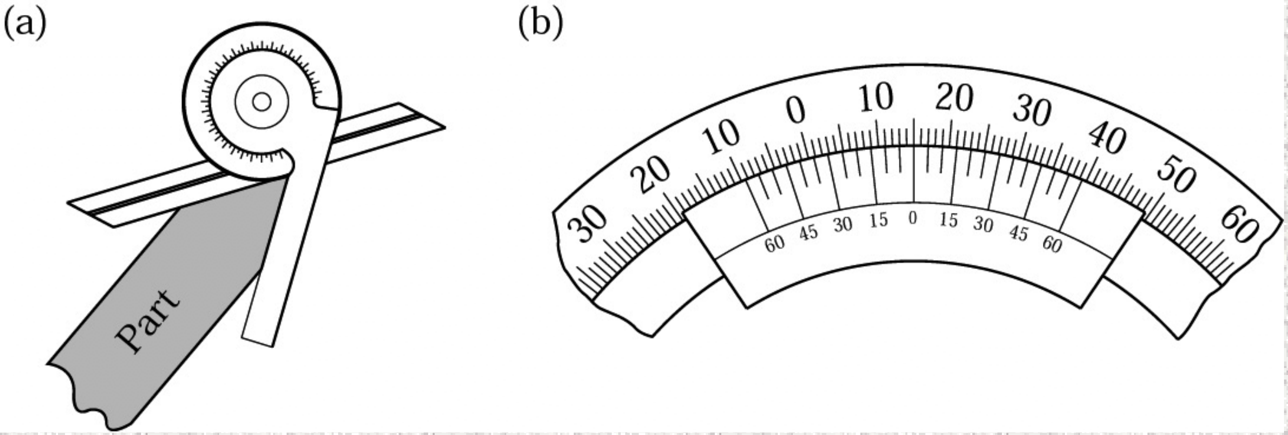
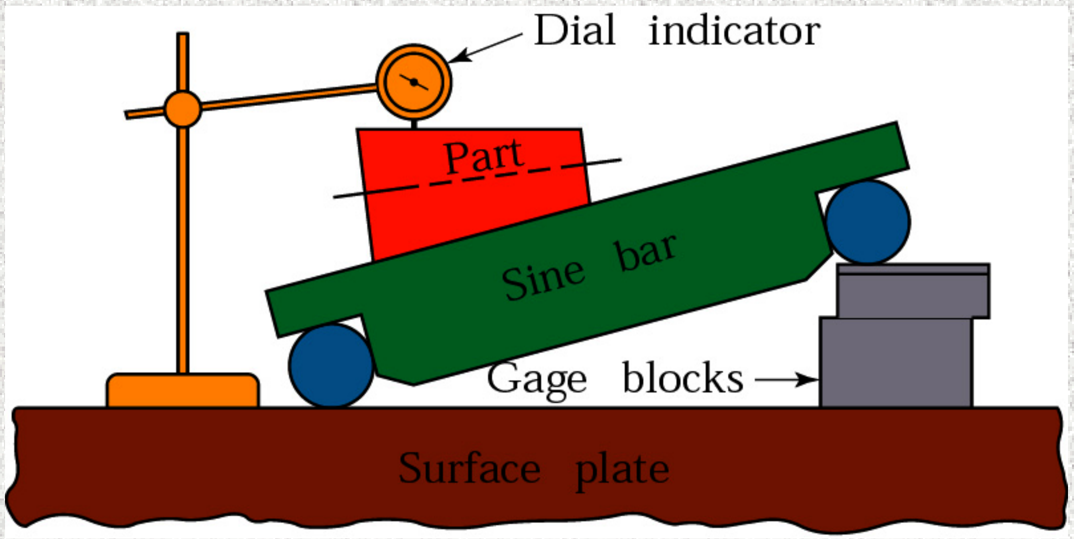



Figure 35.4 (a) Schematic illustration of a bevel protractor for measuring angles. (b) Vernier for angular measurement, indicating 14° 30´.

Figure 35.5 Setup showing the use of a sine bar for precision measurement of workpiece angles.



# Dial Indicators

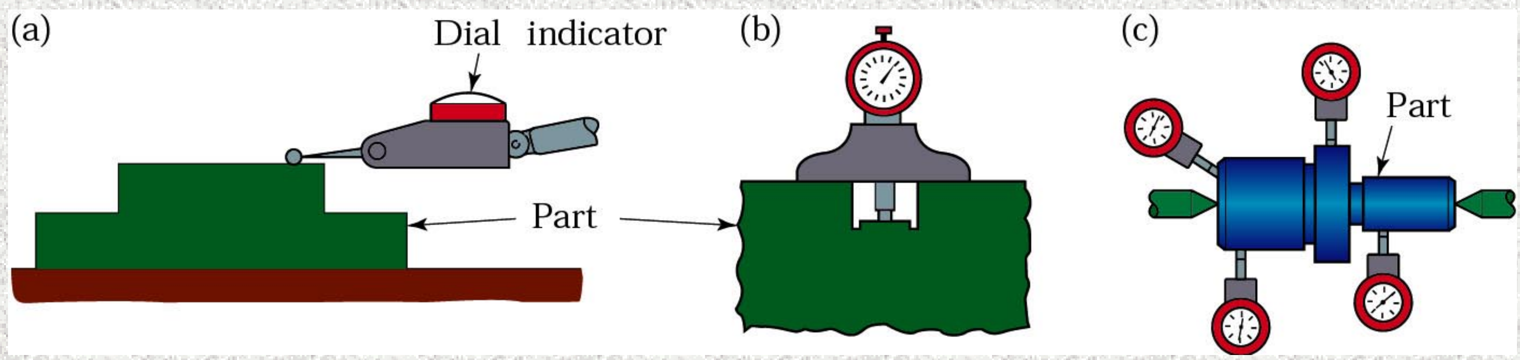



Figure 35.5 Setup showing the use of a sine bar for precision measuremnet of workpiece angles.

# Electronic Gages


Figure 35.7  An electronic gage for measuring bore diameters.  The measuring head is equipped with three carbide-tipped steel pins for wear resistance.  The LED display reds 29.158 mm.  *Courtesy of* TESA SA.

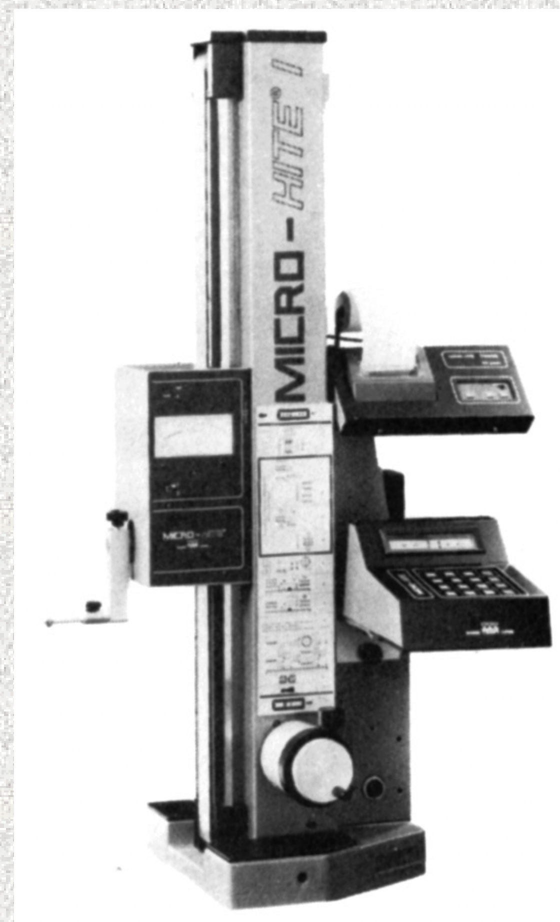
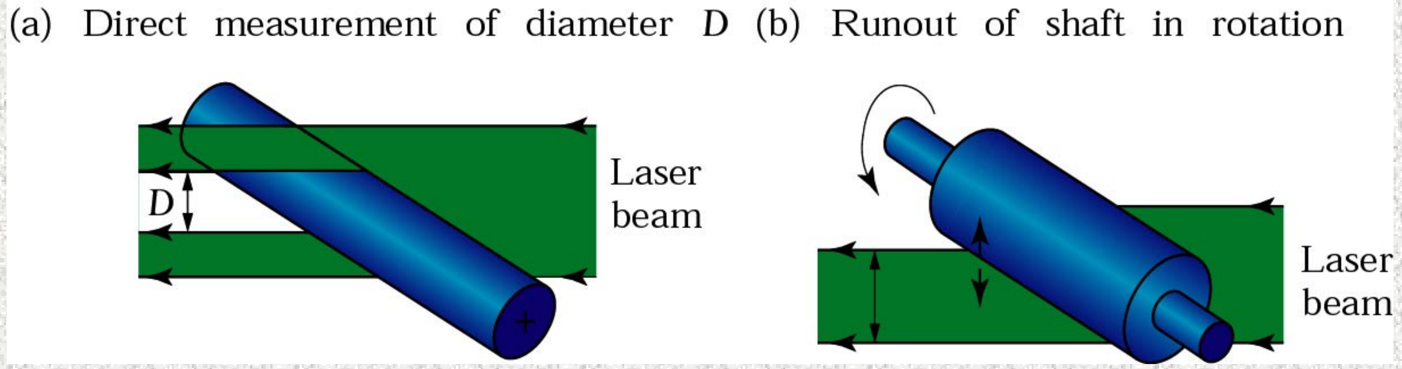



Figure 35.8 An electronic vertical length mesauring instrument, with a sensitivity of 1 $\mu$m (40 $\mu$in.). *Courtesy of* TESA SA.

# Laser Scan Micrometer and Straightness Measurement

Figure 35.9 Two types of measurement made with a laser scan micrometer. *Source*: Mitutoyo Corp.



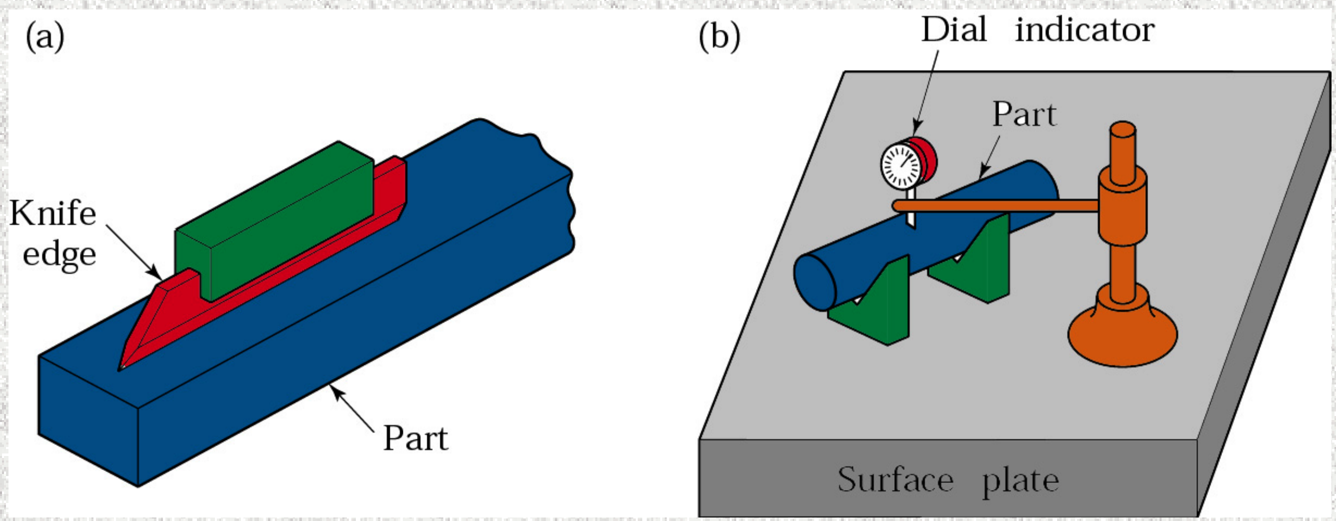




Figure 35.10 Measuring straightness with (a) a knife-edge rule and (b) a dial indicator attached to a movable stand resting on a surface plate. *Source*: F. T. Farago.

# Interferometry

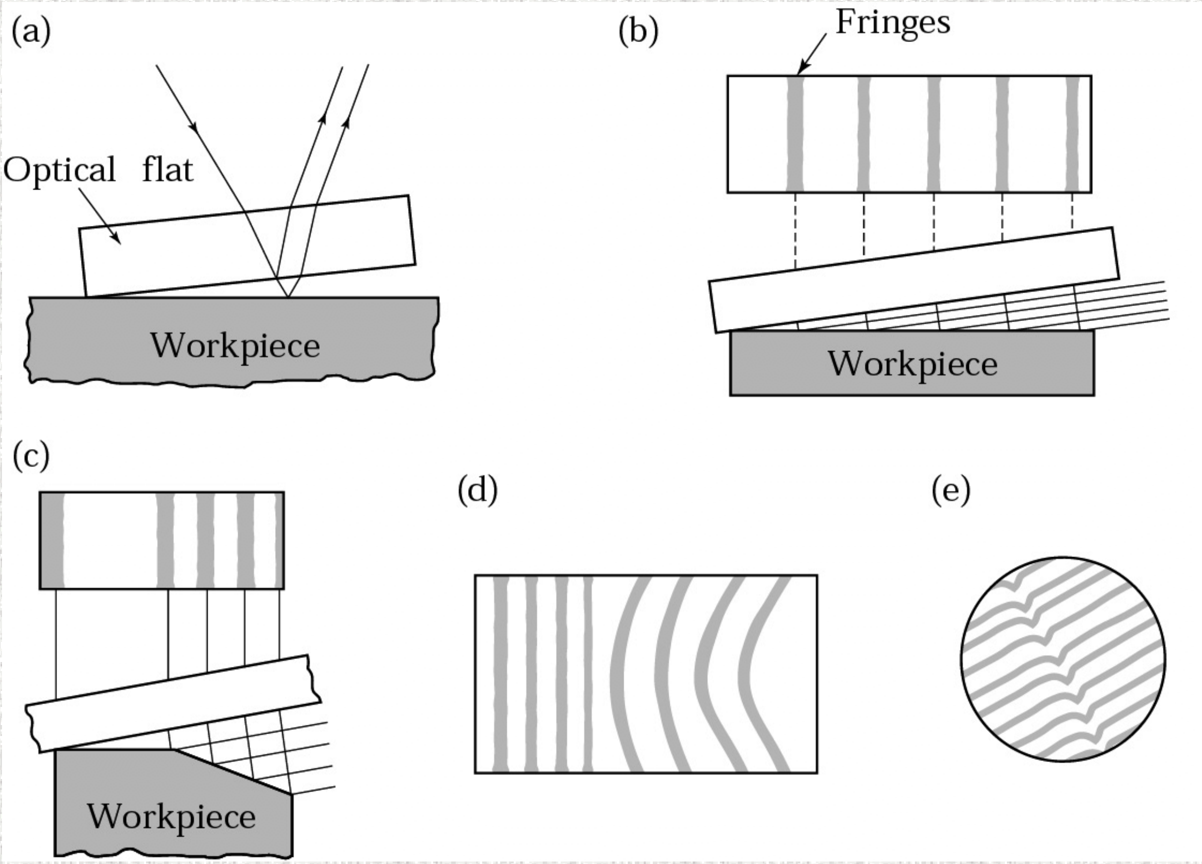
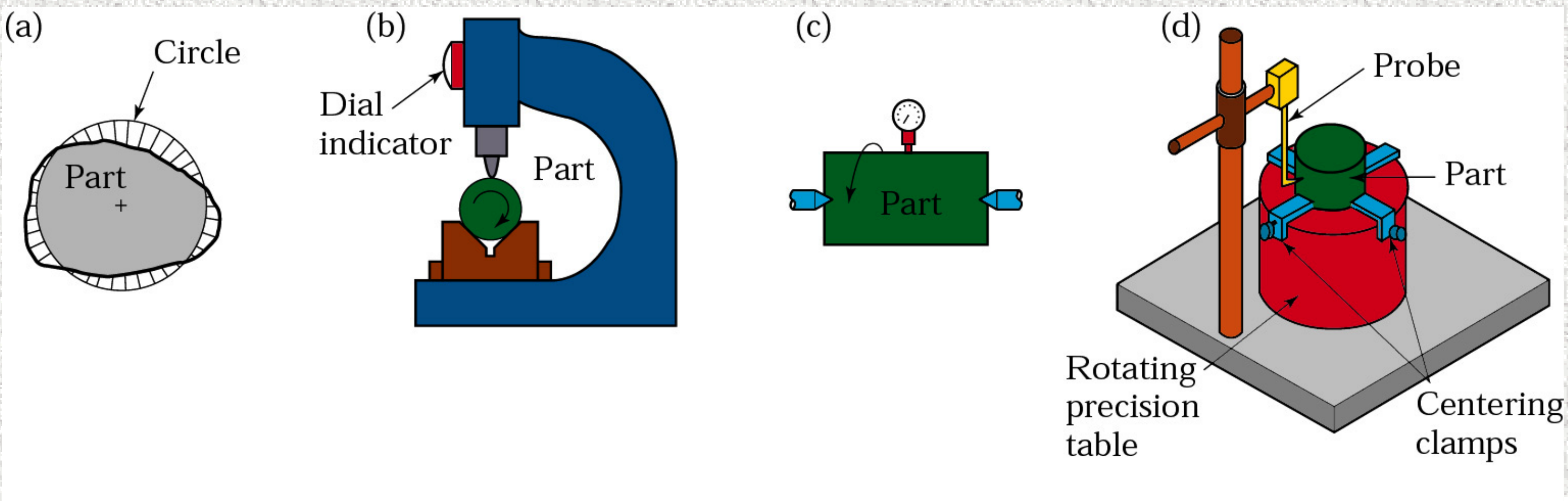



Figure 35.11 (a) Interferometry method for measuring flatness using an optical flat. (b) Fringes on a flat inclined surface. An optical flat resting on a perfectly flat workpiece surface will not split the light beam, and no fringes will be present. (c) Fringes on a surface with two inclinations. *Note*: the greater the incline, the closer the fringes. (d) Curved fringe patterns indicate curvatures on the workpiece surface. (e) Fringe pattern indicating a scratch on the surface.

# Measuring Roundness

Figure 35.12 (a) Schematic illustration of "out of roundness" (exaggerated). Measuring roundness using (b) V-block and dial indicator, (c) part supported on centers and rotated, and (d) circular tracing, with part being rotated on a vertical axis. *Source*: After F. T. Farago.



# Measuring Profiles

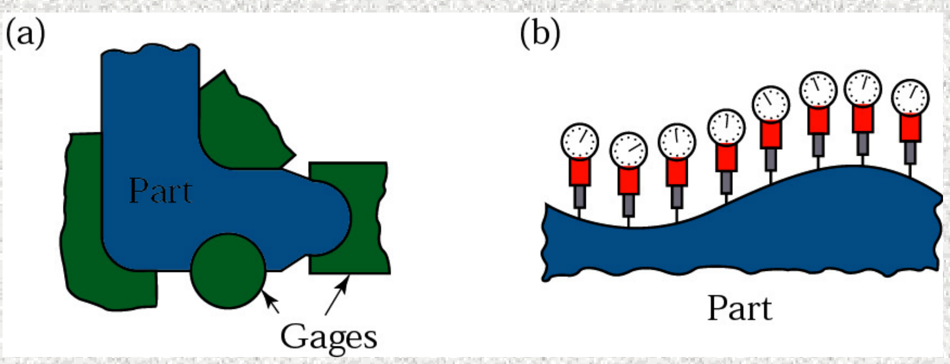



Figure 35.13 Measuring profiles with (a) radius gages and (b) dial indicators.

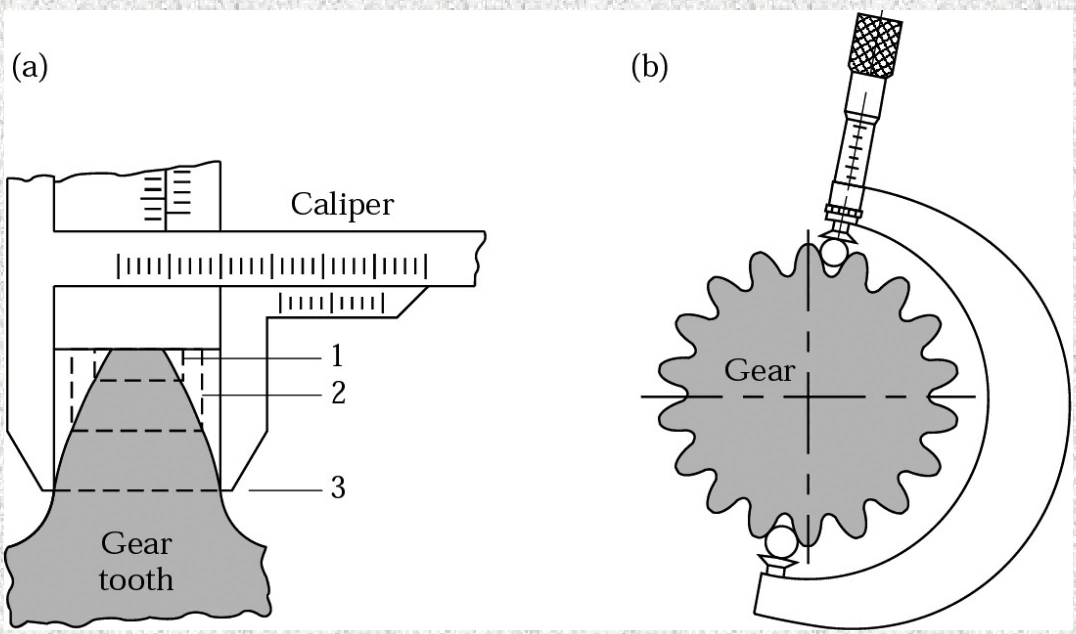



Figure 35.13 Measuring profiles with (a) radius gages and (b) dial indicators.

# Horizontal-Beam Contour Projector


Figure 35.15 A bench model horizontal-beam contour projector with a 16 in.-diameter screen with 150-W tungsten halogen illumination. *Courtesy of* L. S. Starrett Company, Precision Optical Division.

# Coordinate Measuring Machine

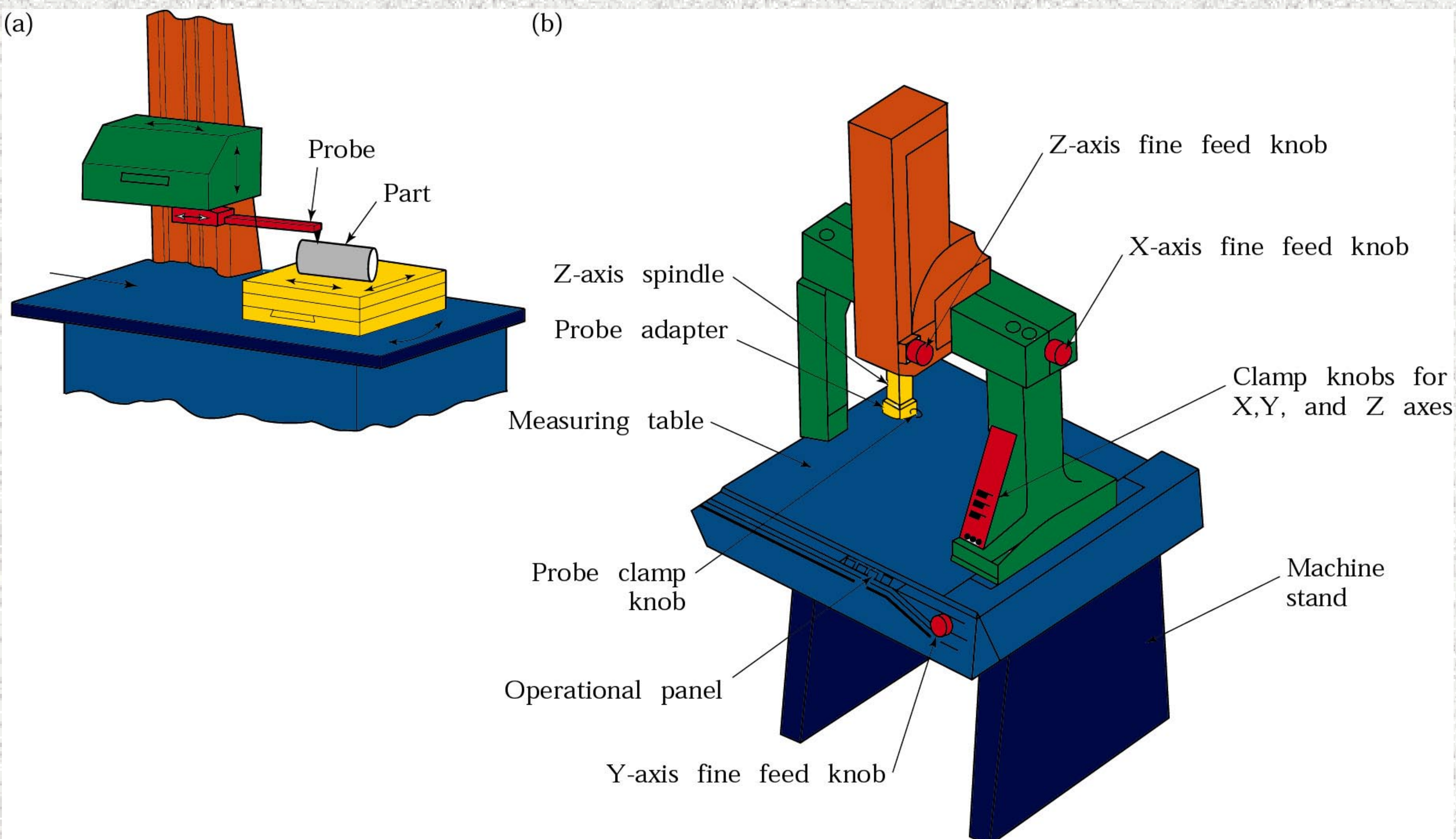
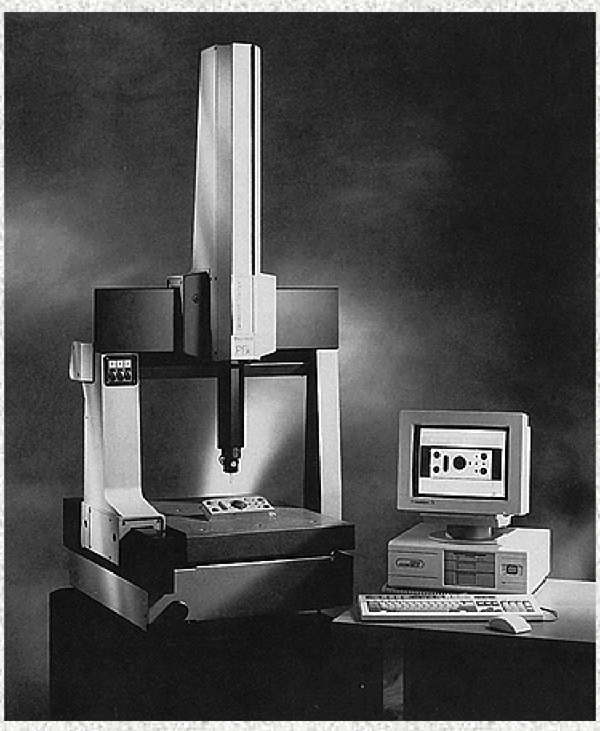



Figure 35.16 (a) Schematic illustration of one type of coordinate measuring machine. (b) Components of another type of coordinate measuring machine. These machines are available in various sizes and levels of automation and with a variety of probes (attached to the probe adapter), and are capable of measuring several features of a part. *Source*: Mitutoyo Corp.

# Coordinate Measuring Machine

Figure 35.17 A coordinate measuring machine. Brown & Sharpe Manufacturing.



# Gages

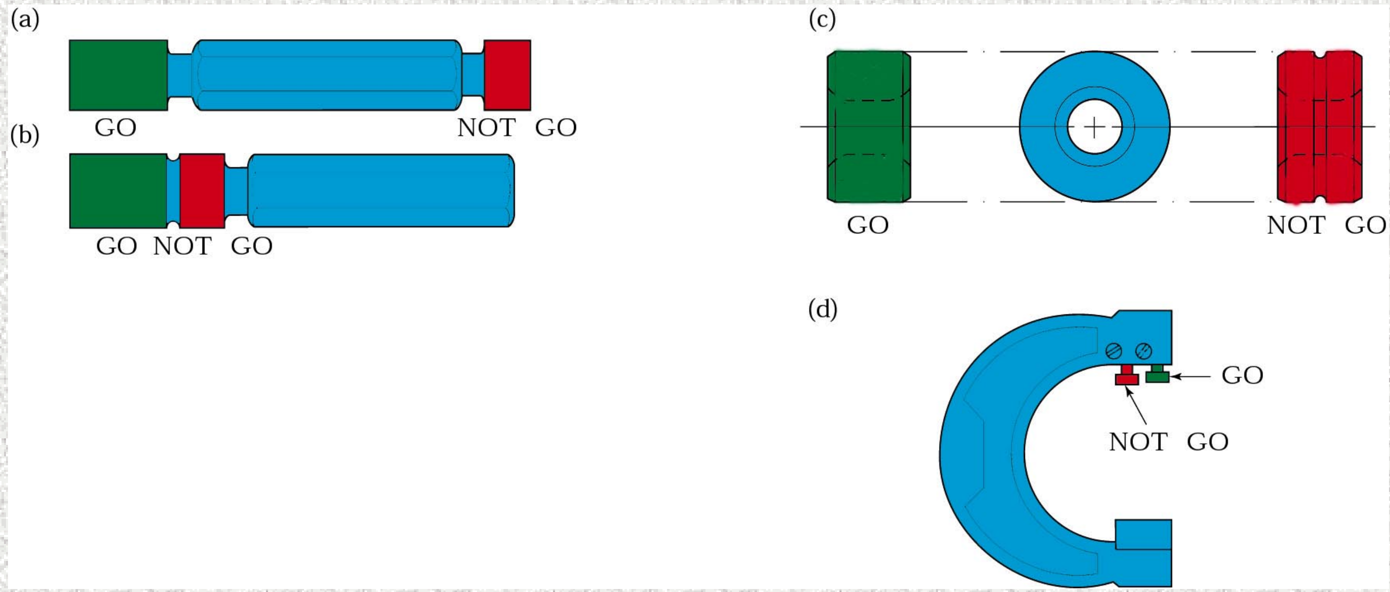



Figure 35.18 (a) Plug gage for holes, with GO-NOT GO on opposite ends. (b) Plug gage with GO-NOT GO on one end. (c) Plain ring gages for gagin round rods. Note the difference in knurled surfaces to identify the two gages. (d) Snap gage with adjustable anvils.

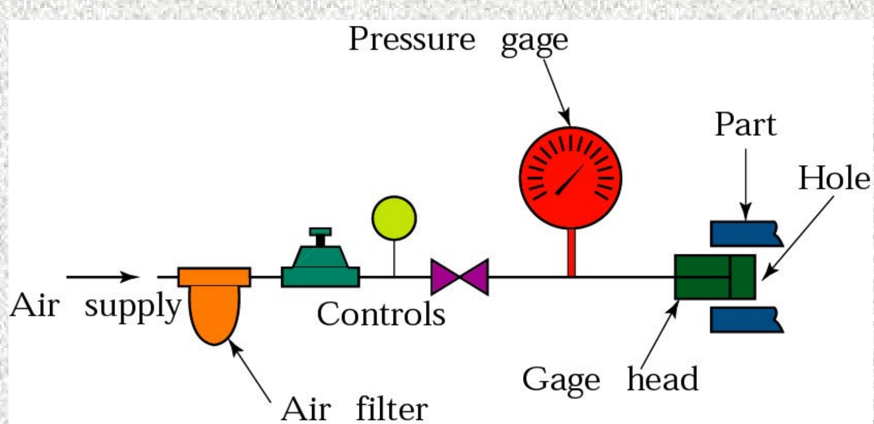



Figure 35.19 Schematic illustration of one type of pneumatic gage.

# Tolerance Control

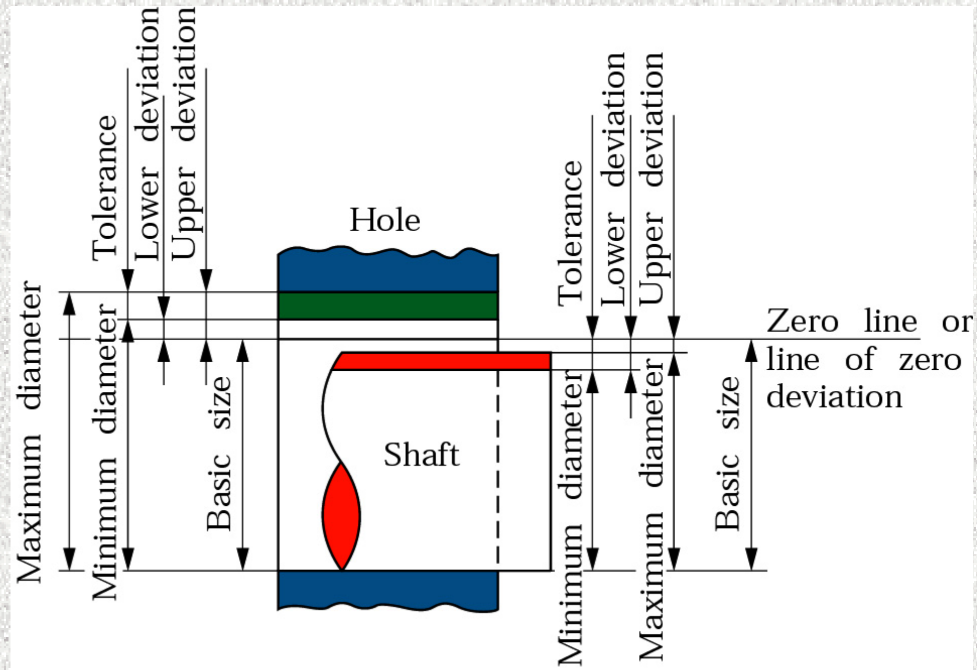



Figure 35.20 Basic size, deviation, and tolerance on a shaft, according to the ISO system.

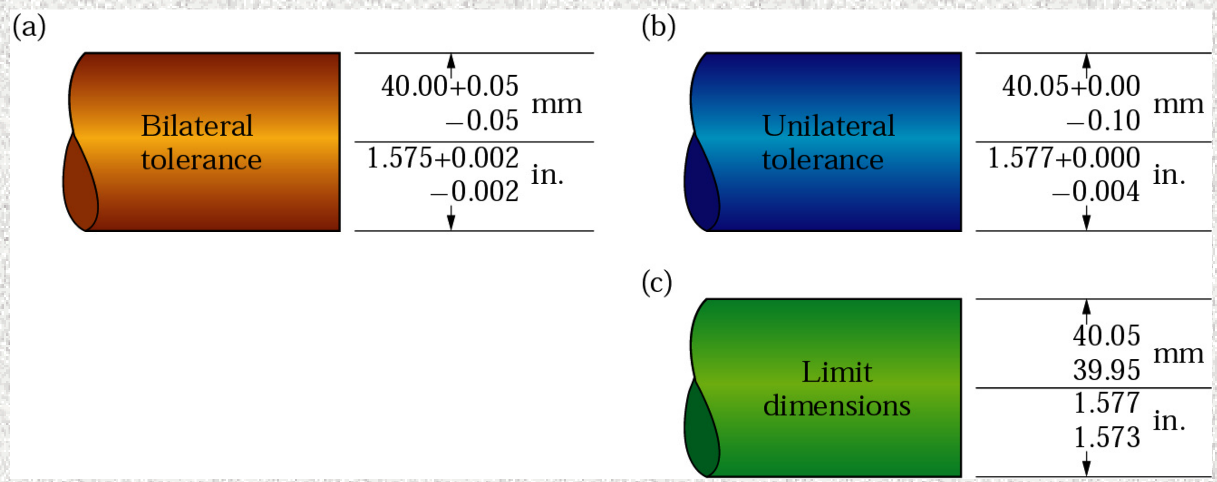



Figure 35.21 Various methods of assigning tolerances on a shaft. *Source*: L. E. Doyle.

# Tolerances as a Function of Size

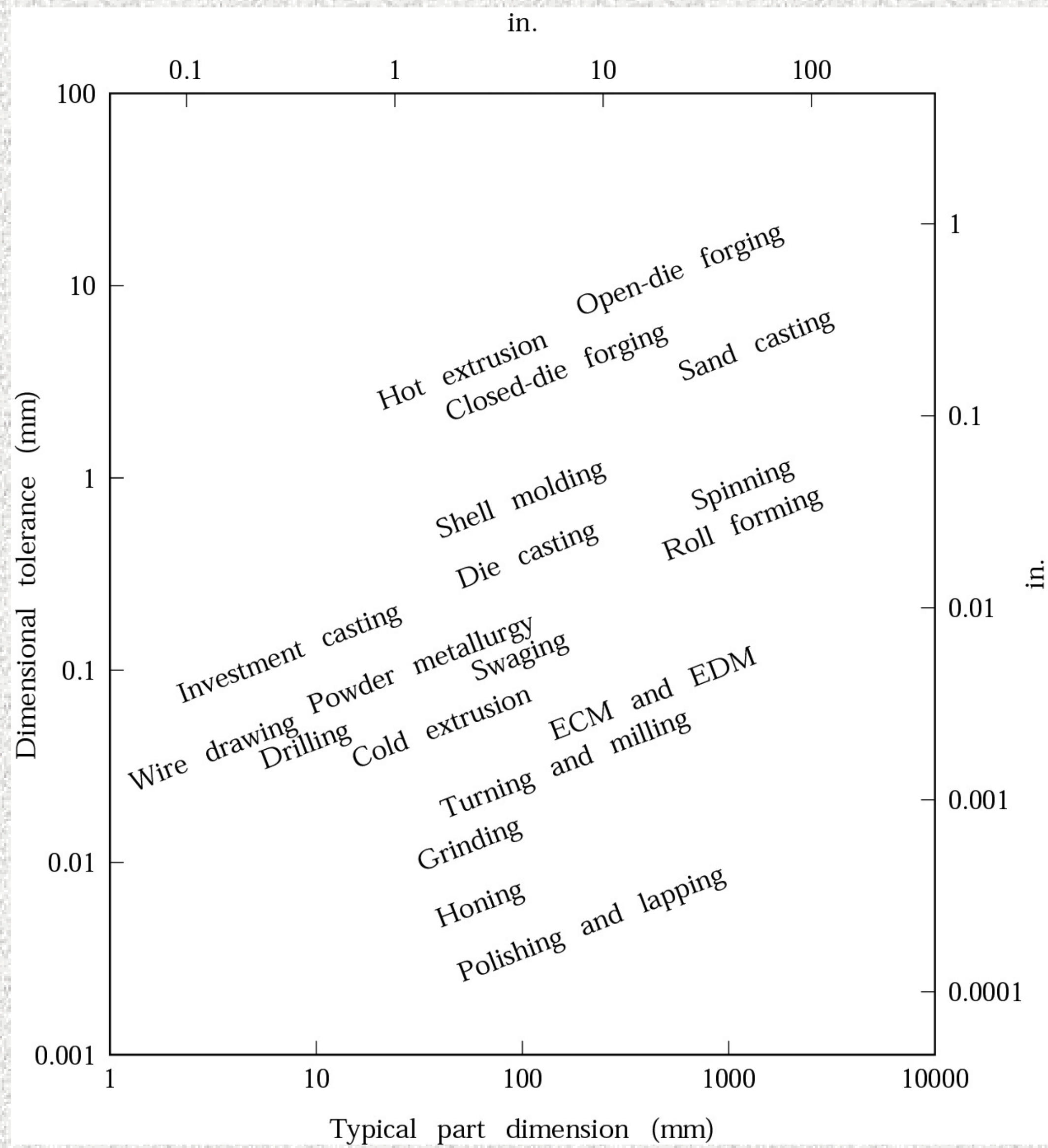
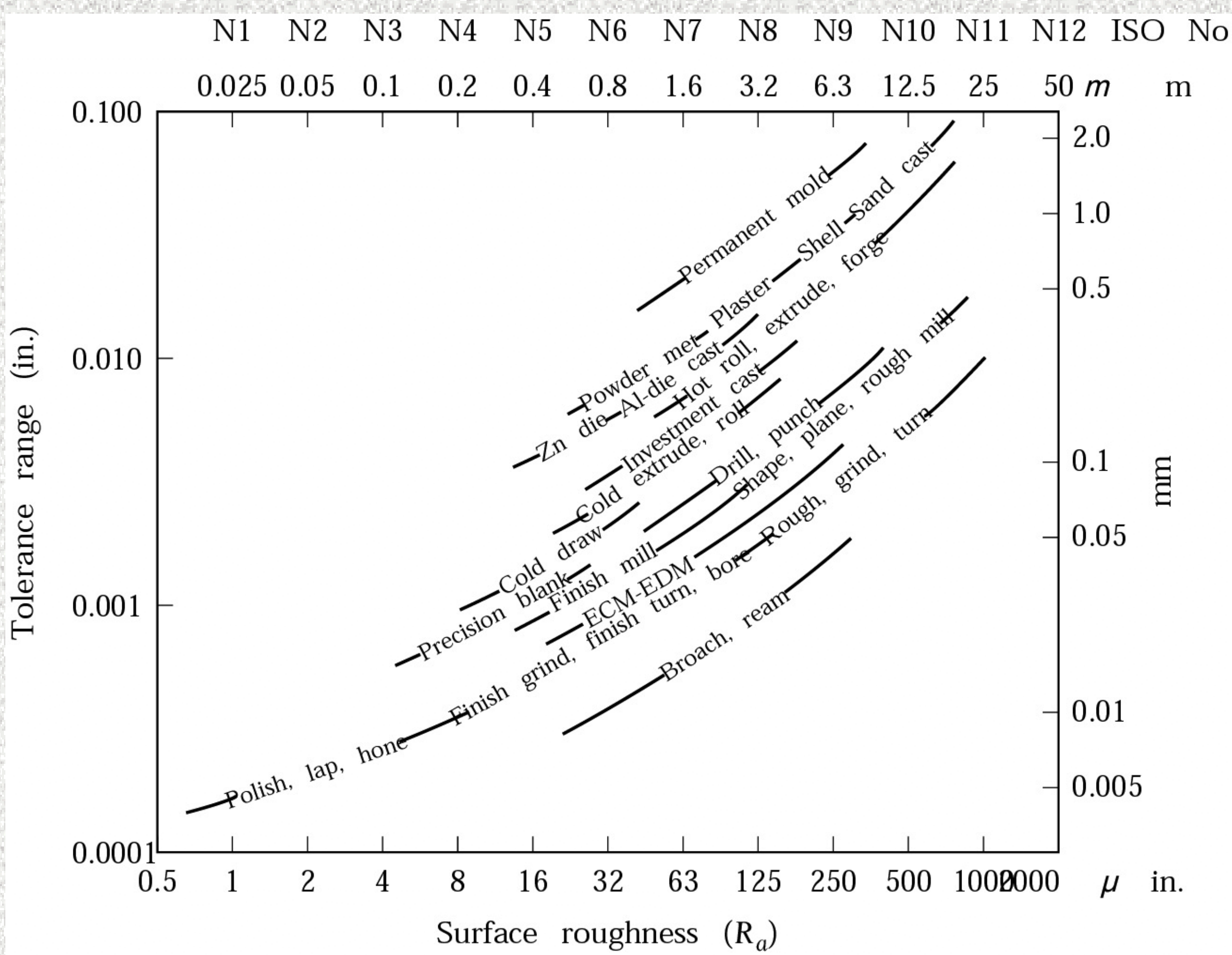



Figure 35.22 Tolerances as a function of part size for various manufacturing processes. *Note*: Because many factors are involved, there is a broad range for tolerances.

# Tolerances and Surface Roughnesses

Figure 35.23 Tolerances and surface roughness obtained in various manufacturing processes. These tolerances apply to a 25-mm (1-in.) workpiece dimension. *Source*: J. A. Schey.



# Engineering Symbols

Figure 35.24 Geometric characteristic symbols to be indicated on engineering drawings of parts to be manufactured. *Source*: The American Society of Mechanical Engineers.

(a)

| Type of feature | Type of tolerance | Characteristic | Symbol |
|---|---|---|---|
| Individual (no datum reference) | Form | Flatness | ⏥ |
| | | Straightness | ⏤ |
| | | Circularity (roundness) | ○ |
| | | Cylindricity | ⌭ |
| Individual or related | Profile | Profile of a line | ⌒ |
| | | Profile of a surface | ⌓ |
| Related (datum reference required) | Orientation | Perpendicularity | ⊥ |
| | | Angularity | ∠ |
| | | Parallelism | // |
| | Location | Position | ⌖ |
| | | Concentricity | ◎ |
| | Runout | Circular runout | ↗ |
| | | Total runout | ⌰ |

(b)

.605
Basic, or exact, dimension

-A-
Datum feature symbol

Ⓜ
Maximum material condition

Ⓢ
Regardless of feature size

Ⓛ
Least material condition

Ⓟ
Projected tolerance zone

∅
Diametrical (cylindrical) tolerance zone or feature

⌖ | ∅.005 Ⓜ | A
Feature control frame

A1
Datum target symbol