Measurement and Inspection and Testing

Chapter 35

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35.1 Introduction

- Measurement
  - Act of measuring or being measured
  - Fundamental activity of testing and inspection
- Inspection
  - Ensures what is being manufactured will meet specifications
- Testing
  - Evaluates product quality or performance

Manufacturing Principles

- Products are manufactured to standard sizes and shapes
- Interchangeable parts became common in the early 1900's
- Design engineer may have to design or alter specifications to ease manufacturing, assembly, and inspection or lower costs
  - These changes should not sacrifice functionality, product reliability, or performance

Attributes vs. Variables

- Inspection of a product can be done in two main ways
  - Attributes (Gaging)
    - Uses gages
    - Reported as YES/NO, GO/NO GO
  - Variables (Measurements)
    - Uses calibrated instruments
    - Reported in actual dimensions

35.2 Standards of Measurement

- Fundamental measures
  - Length, time, mass, temperature
  - Candela, ampere
- All other measurements can be made using a combination of the fundamental measures
- Linear standards
  - International meter is *the* standard
    - Inch is based off of the meter standard as .0254m
      - 41,929.399 wavelengths of orange-red light from krypton-86
  - The US is officially committed to convert to the International System (SI), the English system of feet and inches is still used by many manufacturing plants

TABLE 10-1 International System of Units, Founded on Seven Base Quantities on Which All Others Depend

Quantity	Name of Base	Symbol	Definition or Comment
Length	Meter (or metre)	m	Original: 1/10,000,000 of quadrant of earth's meridian passing through Barcelona and Dunkirk. Present: 1,650,763.73 wavelengths in vacuum of transition between energy levels $2p_{10}$ and $5d_5$ of krypton-86 atoms, excited at triple point of nitrogen (−210°C).
Mass	Kilogram	kg	Original: Mass of 1 cubic decimeter (1000 cubic centimeters) of water at its maximum density (4°C). Present: Mass of Prototype Kilogram No. 1 kept at International Bureau of Weights and Measures at Sèvres, France.
Time	Second	s	Original: 1/86,400t of mean solar day. Present: 9,192,631,770 cycles of frequency associated with transition between two hyperfine levels of isotope cesium-133.
Electric current	Ampere		Present: The rate of motion of charge in a circuit is called the *current*. The unit of current is the *ampere*. One ampere exists when the charge flows at a rate of 1 coulomb per second.
Thermodynamic temperature	Degree Celsius (Kelvin)	°C (K)	Present: 1/273.16 of the thermodynamic temperature of the triple point of water (0.01°C).
Amount of substance	Mole	mol	Present: A mole is an artificially chosen number ($N_0 = 6.02 \times 10^{23}$) that measures the number of molecules.
Luminous intensity	Candle		Present: One lumen per square foot is a footcandle.

Metric to English Conversions

- Table 35-2 lists common metric to English conversions
- Care should be taken when converting measurements to ensure that standard conversions have been used
- Standard sizes in the English system may not have a perfectly matching corresponding size in the metric system

Length Standards in Industry

- Gage blocks
  - Provide industry with linear standards of high accuracy
  - Small, rectangular, square, or round in cross section
  - Made with steel or carbide
  - Two flat and parallel surfaces
  - Calibrated with light-beam interferometry
  - By combining blocks, any desired dimension can be obtained

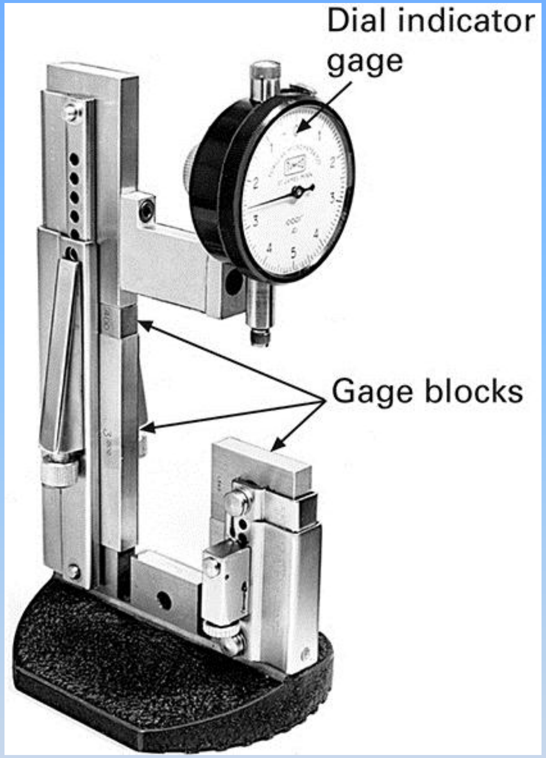
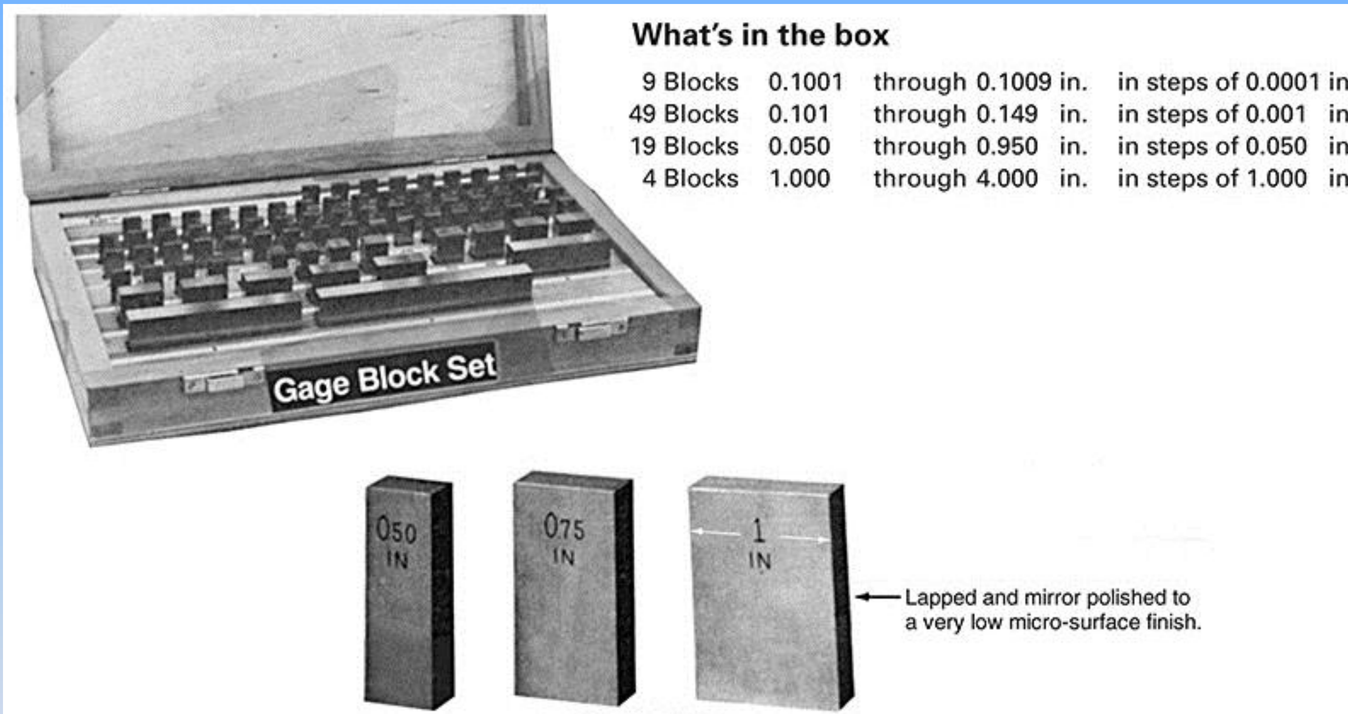


Figure 10-5 Wrung-together gage blocks in a special holder, used with a dial gage to form an accurate comparator. (Courtesy of DoALL Company.)

Gage Blocks



What's in the box

9 Blocks	0.1001	through 0.1009 in.	in steps of 0.0001 in.
49 Blocks	0.101	through 0.149 in.	in steps of 0.001 in.
19 Blocks	0.050	through 0.950 in.	in steps of 0.050 in.
4 Blocks	1.000	through 4.000 in.	in steps of 1.000 in.

Figure 10-3 Standard set of rectangular gage blocks with 0.000050-in. accuracy; three individual blocks are shown.

Standard Measuring Temperature

- Many metal instruments are used for measuring
- Metals are affected dimensionally by temperature
- Standard measuring temperature of 68°F (20°C) for precision measuring
- Gage blocks, gages, and other precision-measuring instruments are calibrated at this temperature

Accuracy Versus Precision in Processes

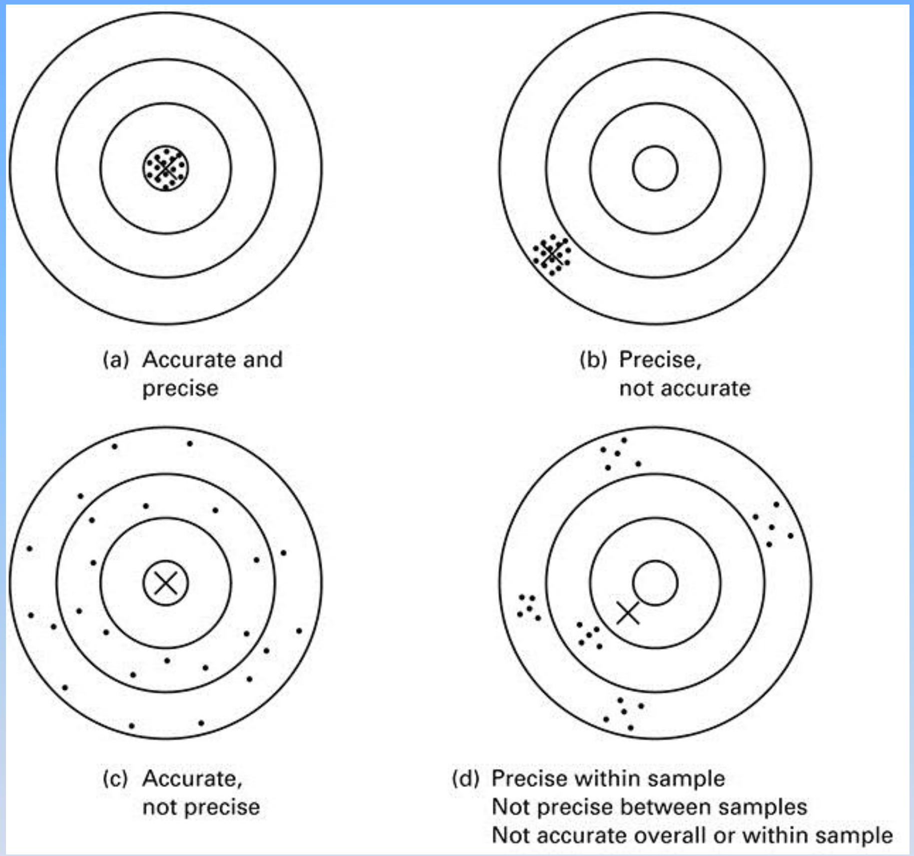


Figure 10-6 Accuracy versus precision. Dots in targets represent location of shots. Cross (X) represents the location of the average positions of all shots.

- Accuracy- ability to hit what is aimed at
- Precision- repeatability of the process
- Measuring devices must be both precise and accurate
- Skill of the operator may also have to be taken into account for measurements

35.3 Allowance and Tolerance

- Allowance- intentional, desired difference between two mating parts
  - Determines the condition of tightest fit
  - May be specified for clearance or interference
- Tolerance- undesirable but permissible deviation from a desired dimensions
  - No part can be made exactly to a specified dimension
  - Necessary to permit the actual dimension to deviate from the theoretical (nominal) dimension

Allowance and Tolerance

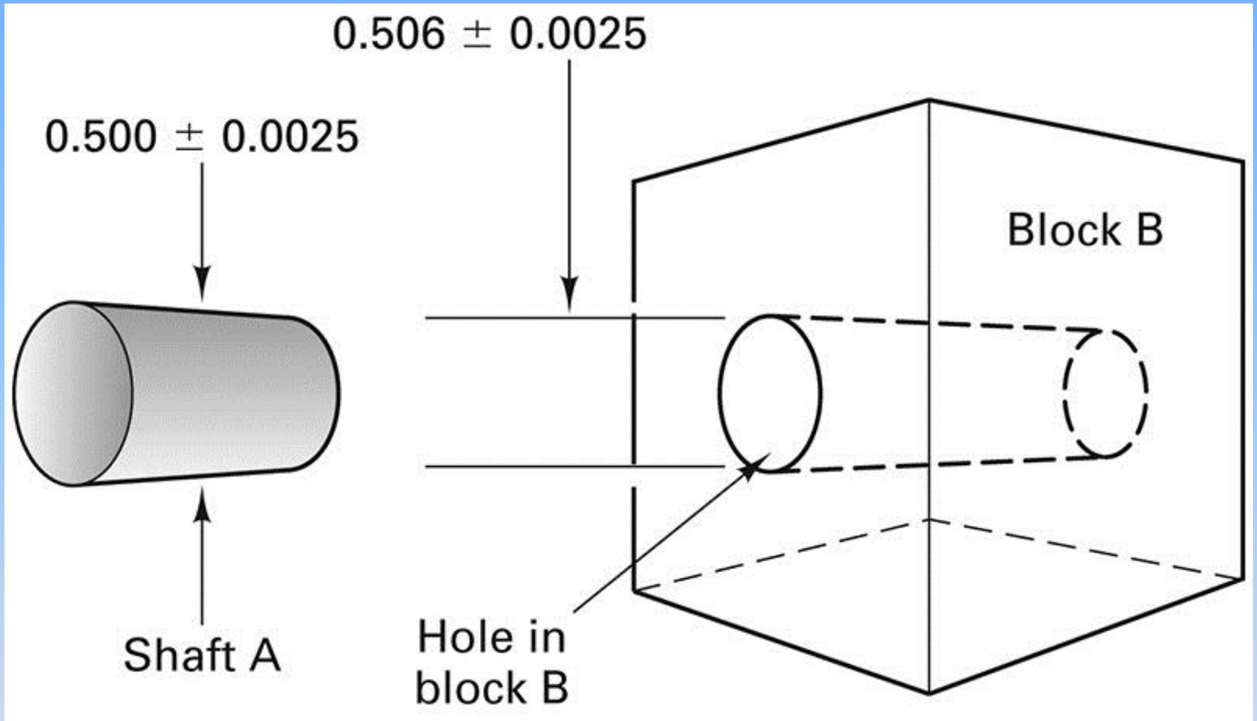


Figure 10-7 When mating parts are designed, each shaft must be smaller than each hole for a clearance fit.

Normal Distributions

- Manufacturing results in products whose geometrical features and sizes deviate in a normal distribution
  - Centered around an average dimension
  - Follows statistical analysis

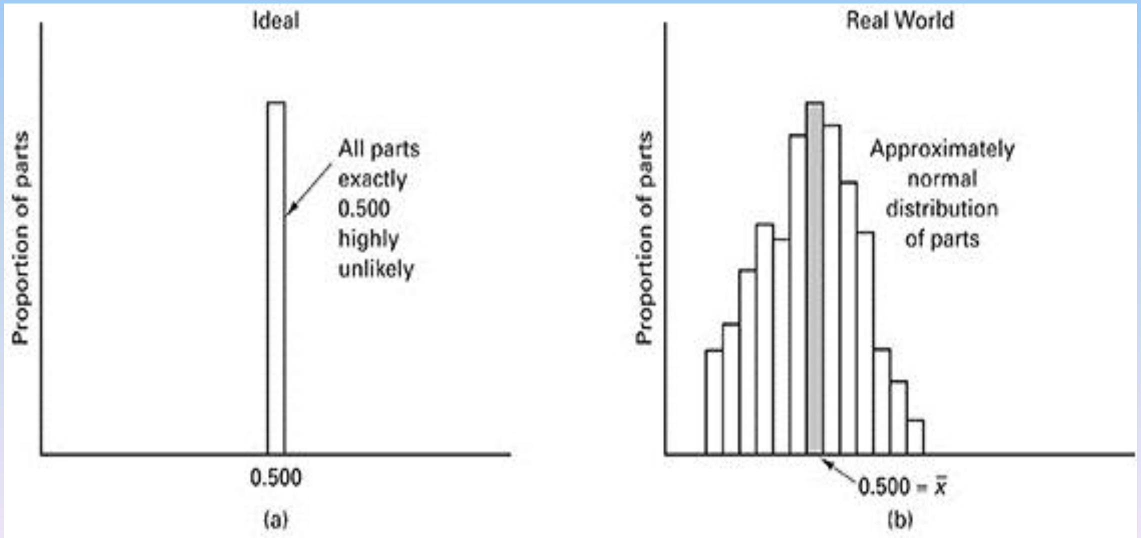


Figure 10-8 (a) In the ideal situation, the process would make all parts exactly the same size. (b) In the real world of manufacturing, parts have variability in size.

Normal Distribution

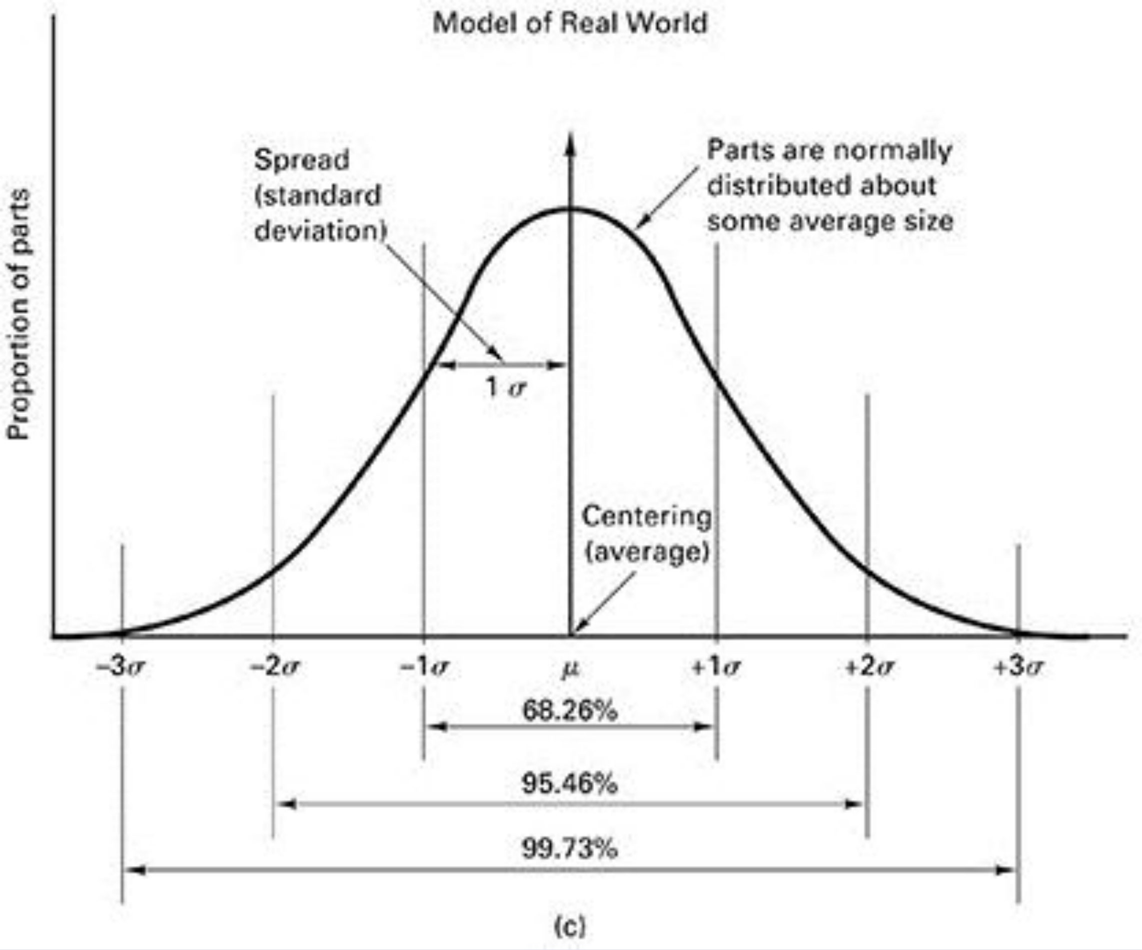


Figure 10-8 (c) The distribution of sizes can often be modeled with a normal distribution.

Specifying Tolerance and Allowances

- Tolerance can be specified in four ways
  - Bilateral, unilateral, limits and geometric
- Bilateral
  - Plus or minus deviation from the nominal size
- Unilateral
  - Deviation is in one direction from the nominal size
- Limits
  - Maximum and minimum dimensions

ANSI Classes of Fits

- Class 1: Loose fit
- Class 2: Free fit
- Class 3: Medium fit
- Class 4: Snug fit
- Class 5: Wringing fit
- Class 6: Tight fit
- Class 7: Medium force
- Class 8: Heavy force and shrink fits

ISO System of Limits and Fits

- Used in metric countries
- Each part has a basic size and each limit is defined by its limit from that size
  - Difference is called the tolerance
- Three classes of fits
  - Clearance
  - Transition
  - Interference
- Tolerances may be specified with respect to zero deviation

Geometric Tolerances

- Maximum allowable deviation of a form or position from the perfect geometry
- Maximum material condition indicates that a part is made with the maximum allowable material
- Least material condition indicates that a part is made with the minimum allowable material
- Geometric tolerances are specified with respect to a datum or reference surface
- Four tolerances
  - Flatness, straightness, roundness, and cylindricity

Geometric Tolerances

	Tolerance	Characteristic	Symbol
Individual features	Form	Straightness	—
		Flatness	⏥
		Circularity	○
		Cylindricity	⌭
Individual or related features	Profile	Line	⌒
		Surface	⌓
Related features	Orientation	Angularity	∠
		Perpendicularity	⊥
		Parallelism	//
	Location	Position	⌖
		Concentricity	○
	Runout	Circular runout	↗
		Total runout	⌰

Notes	⌀ DIA	Ⓜ MMC	Ⓛ LMC	Ⓢ RFS

(a)

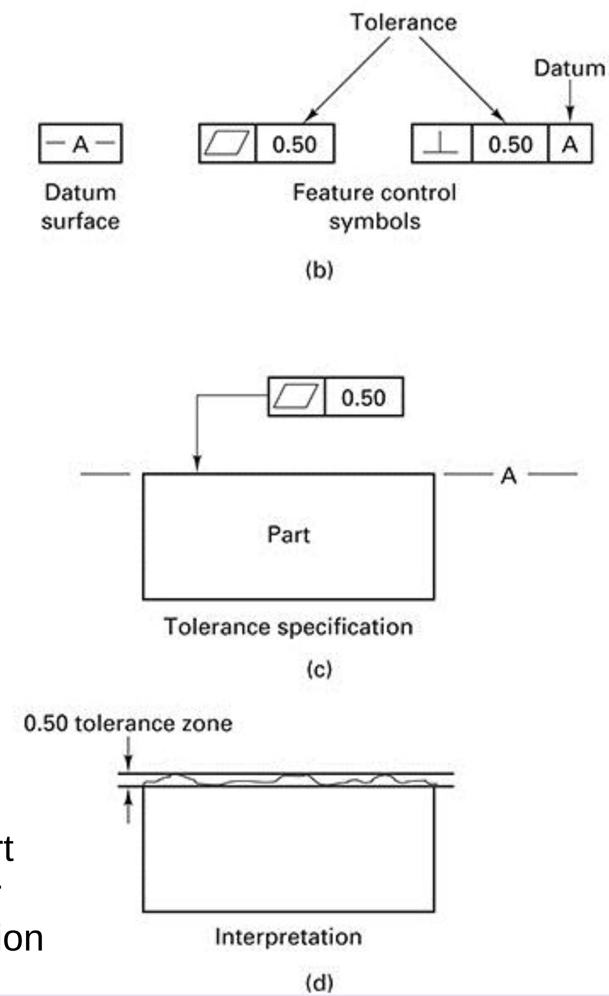
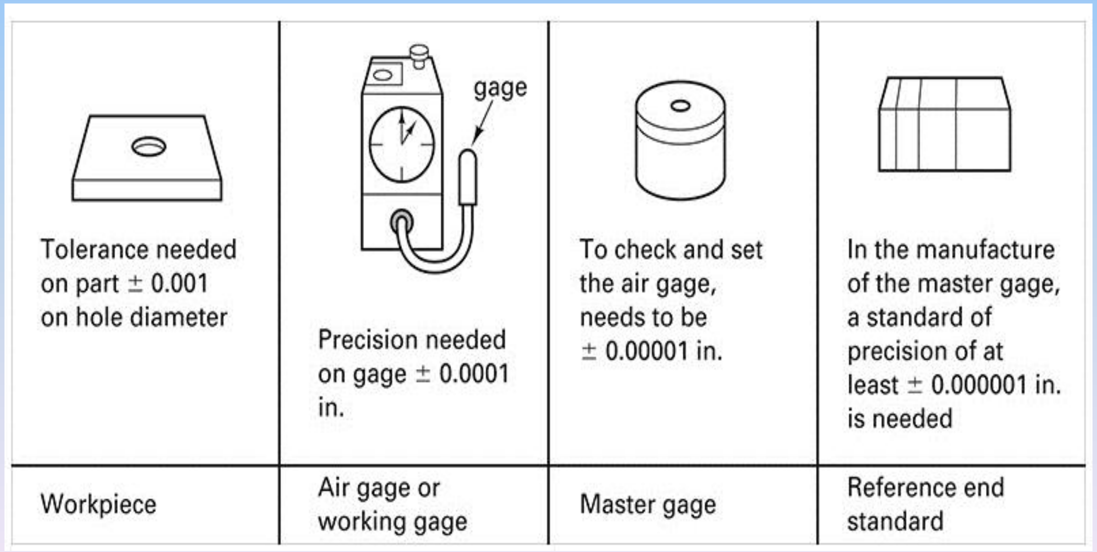


Figure 10-11 (a) Geometric tolerancing symbols; (b) feature control symbols for part drawings; (c) how a geometric tolerance for flatness is specified; (d) what the specification means.

35.4 Inspection Methods for Measurement

- Factors in selecting inspection equipment
  - Gage capability
  - Linearity
  - Repeat accuracy
  - Stability
  - Magnification
  - Resolution

Figure 10-12 The rule of 10 states that for reliable measurements each successive step in the inspection sequence should have 10 times the precision of the preceding step.



35.5 Measuring Instruments

- Manually operated instruments
  - Ease of use, precision, accuracy are affected by:
    - Least count of subdivisions
    - Line matching
    - Parallax
  - Linear measuring instruments
    - Direct
      - Line graduated so that the measurement can be read right off of the scale
    - Indirect
      - Transfers the size of the dimension to a direct reading scale

Linear Measuring Devices

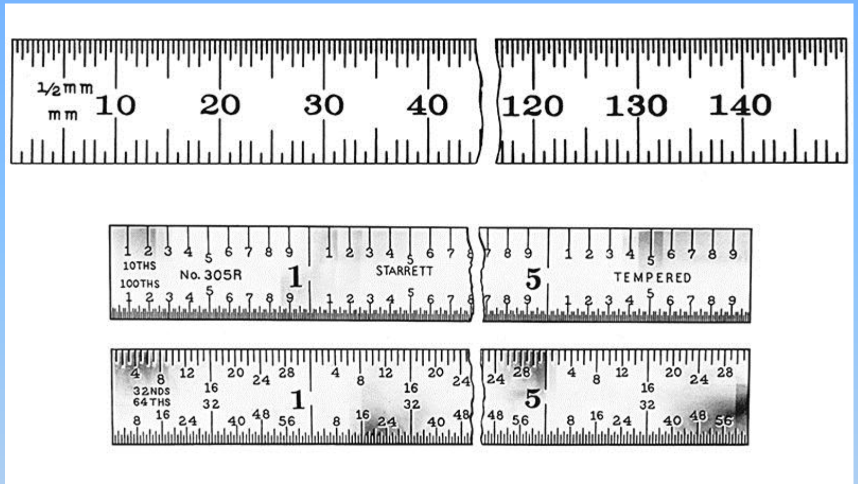
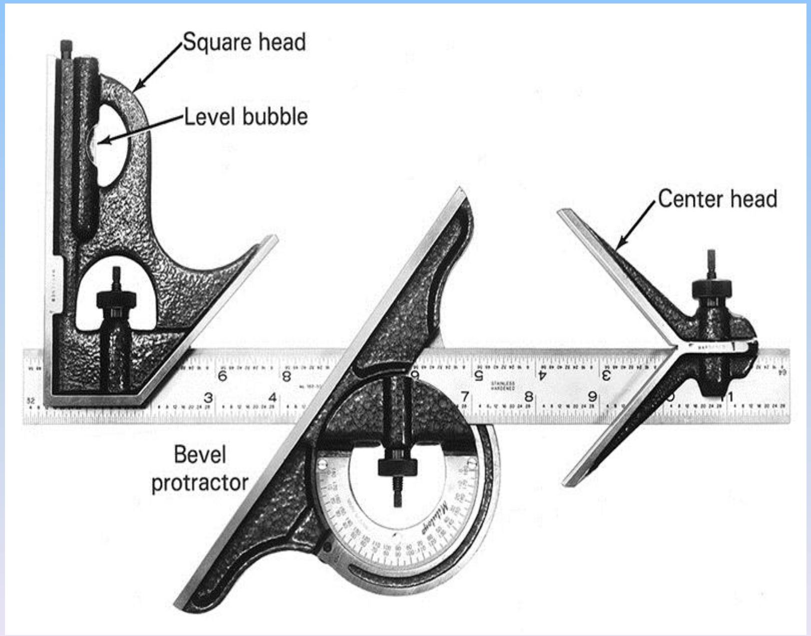


Figure 10-13 (above) Machinist's rules: (a) metric and (b) inch graduations; 10ths and 100ths on one side; 32nds and 64ths on the opposite side. (*Courtesy of L.S. Starrett Company*.)

Figure 10-14 (below) Combination set. (*Courtesy of MTI Corporation.)*



Vernier Calipers

Figure 10-17 (right) Variations in the Vernier caliper design result in other basic gages.

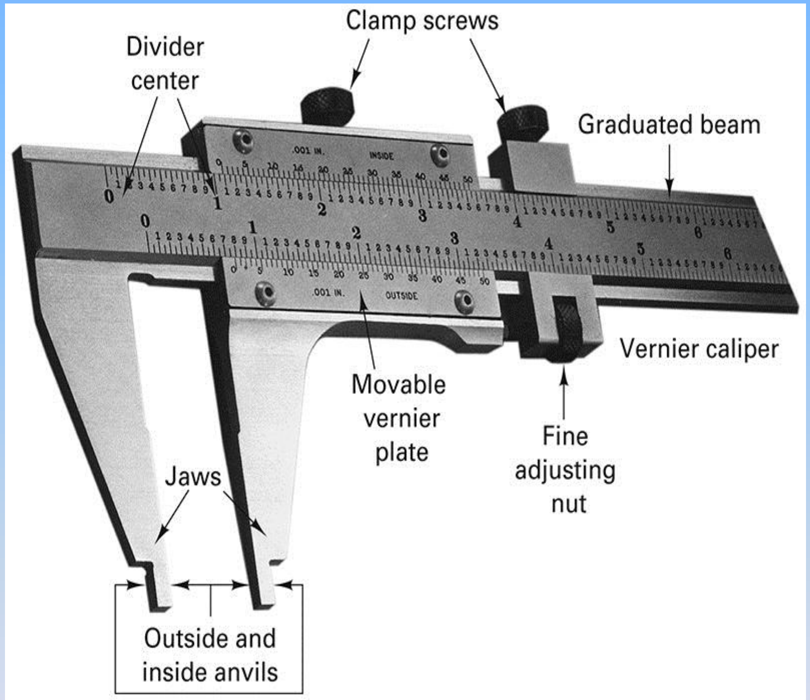
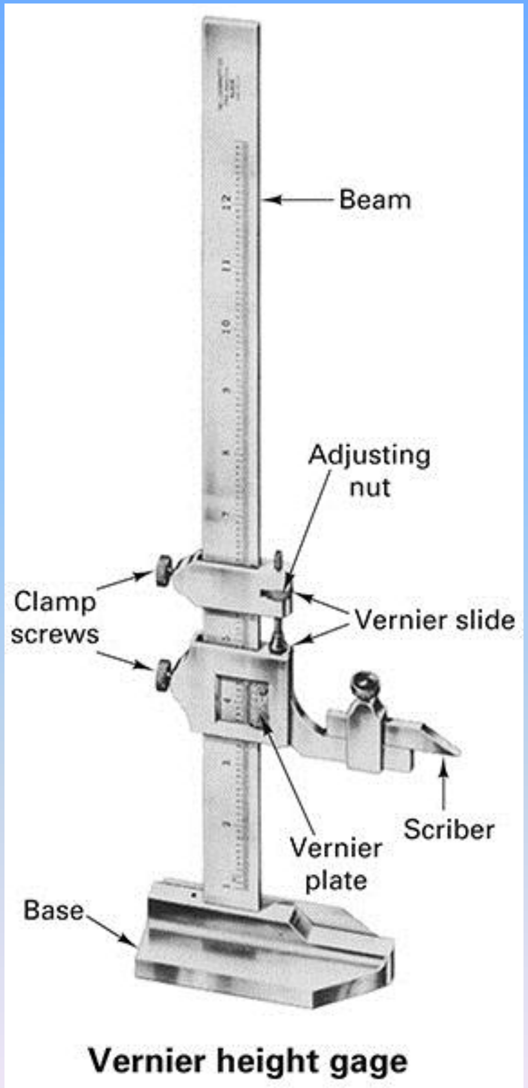
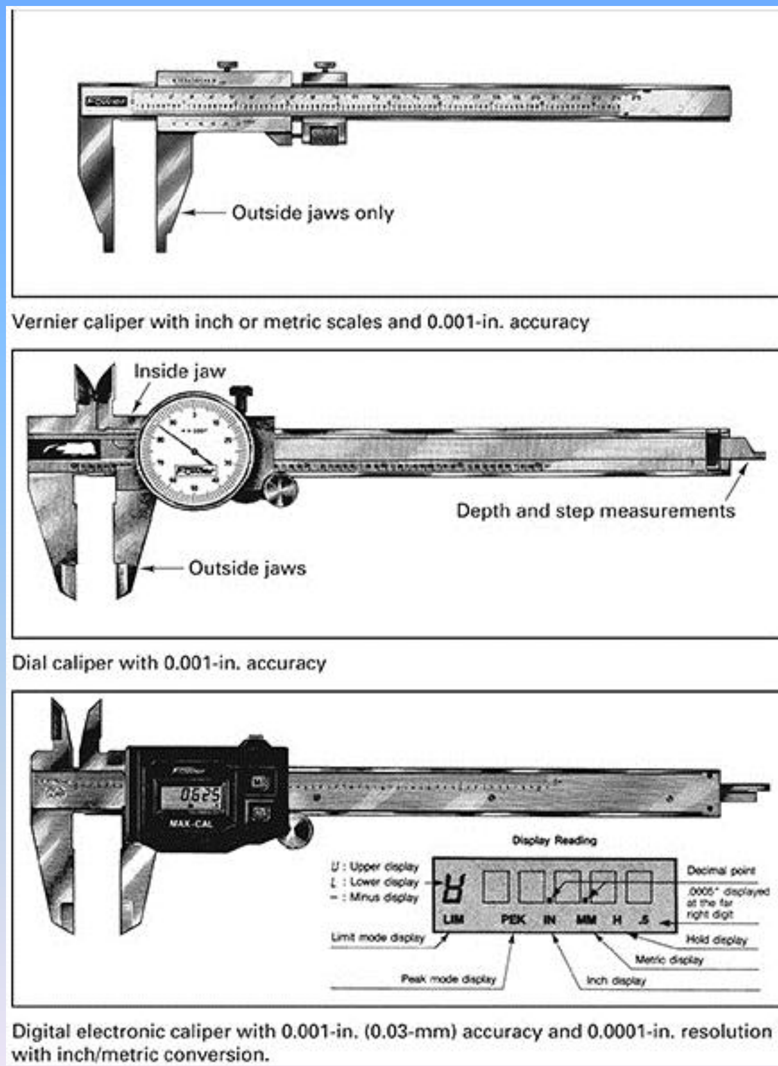


Figure 10-15 (above) The Vernier caliper can make measurements using both inside (for holes) and outside (shafts) anvils.



Other Forms of Calipers



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 with inch/metric conversion.

Figure 10-18 Three styles of calipers in common use today: (a) Vernier caliper with inch or metric scales and 0.001-in. accuracy; (b) dial caliper with 0.001-in accuracy; (c) digital electronic caliper with 0.001-in. (0.03-mm) accuracy and 0.0001-in resolution with inch/metric conversion.

Graduated and Digital Micrometers

Figure 10-19 Micrometer caliper graduated in ten-thousandths of an inch with insets A, B, and C showing two example readings. (*Courtesy Starrett Bulletin No. 1203.)*

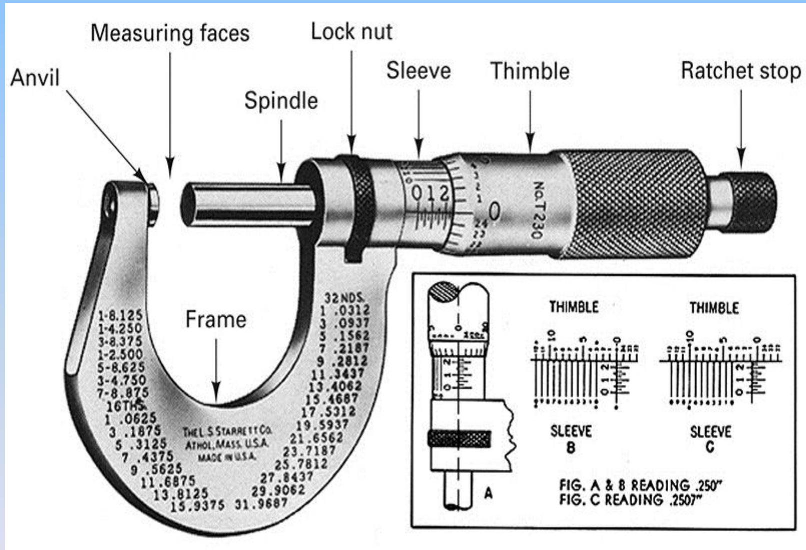


Figure 10-20 Digital micrometer for measurements from 0 to 1 in., in 0.0001-in. graduations.

Optical Instrumentation

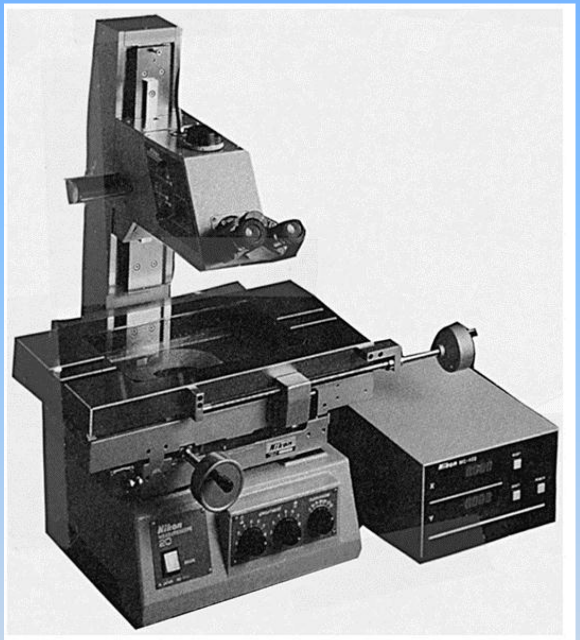
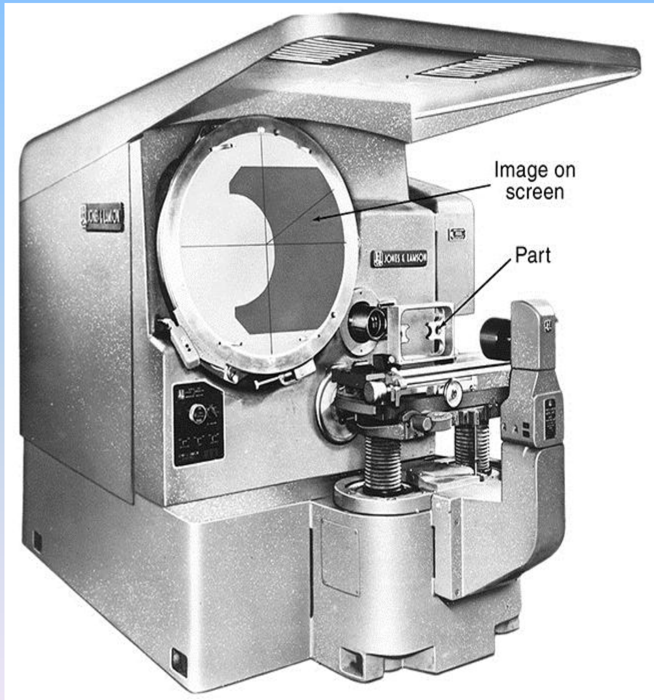


Figure 10-22 Toolmaker's microscope with digital readouts for *X* and *Y* table movements.

Figure 10-23 Optical comparator, measuring the contour on a workpiece. Digital indicators with conversions add to the utility of optical comparators.



Measuring with Lasers

- Interferometry
- Uses light interference bands to determine distance and thickness of objects
- Constructive interference- beams returning are in phase
- Destructive interference- beams returning are out of phase

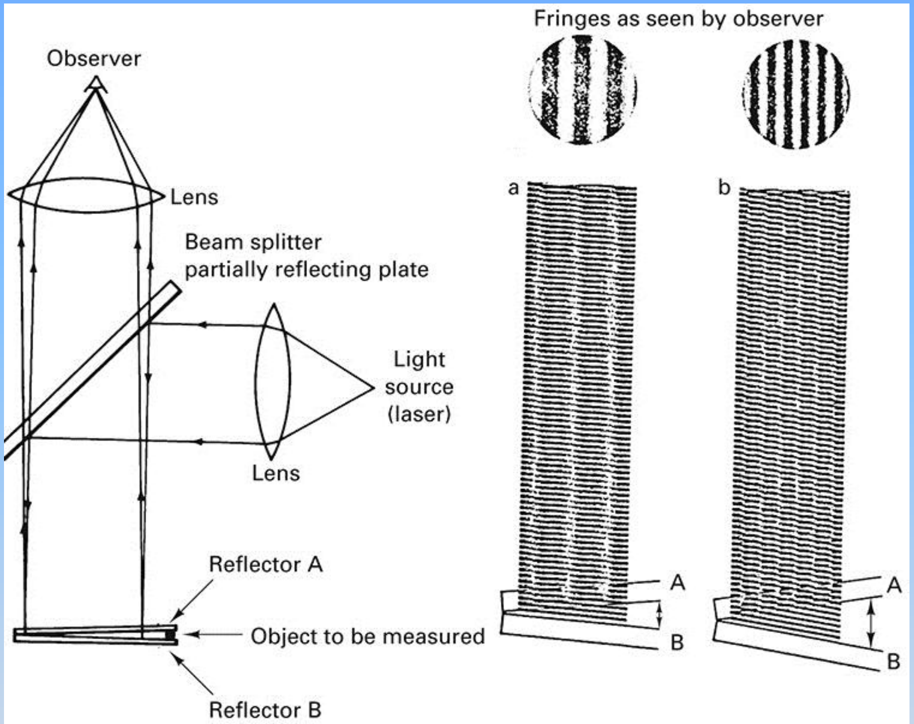


Figure 10-24 Interference bands can be used to measure the size of objects to great accuracy. (Based on the Michelson interferometer, invented in 1882.)

Digitizing Measurements

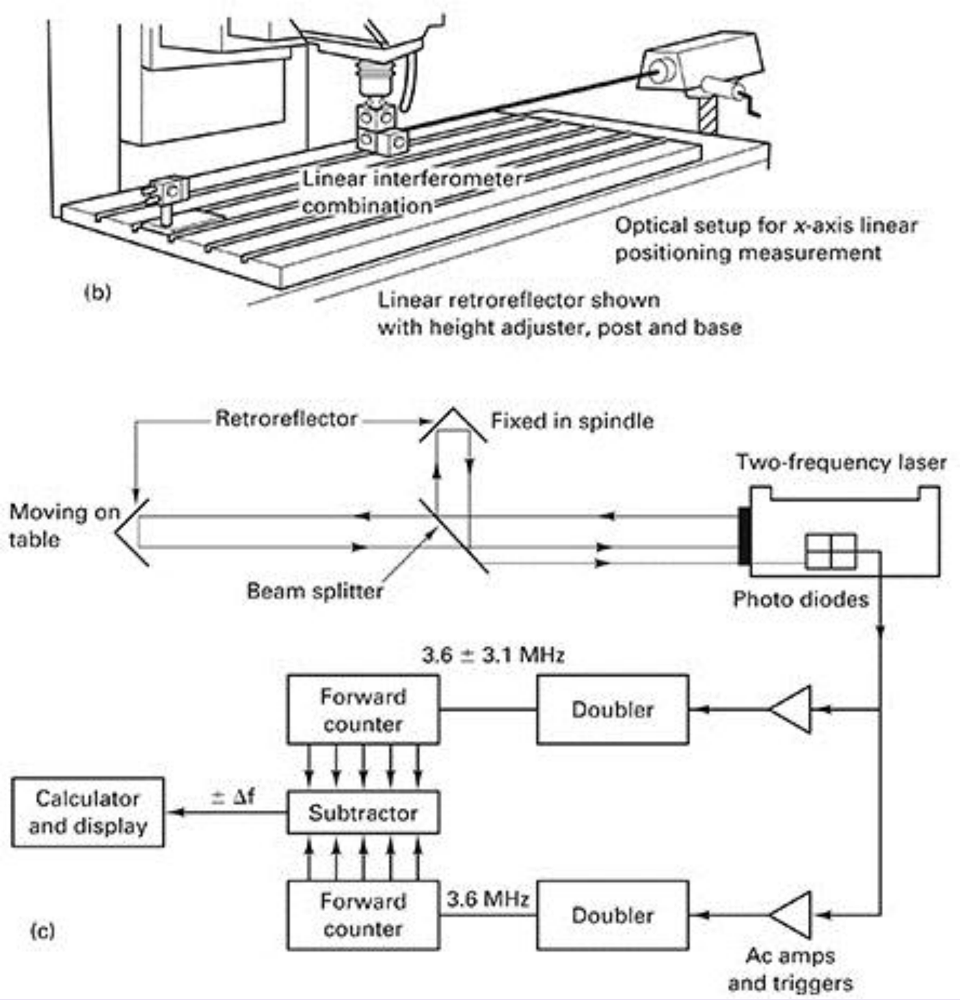


Figure 10-26 (b) Schematic of optical setup; (c) Schematic of components of a two-frequency laser interferometer. (*Courtesy of Hewlett-Packard.)*

Digitizing Measurements

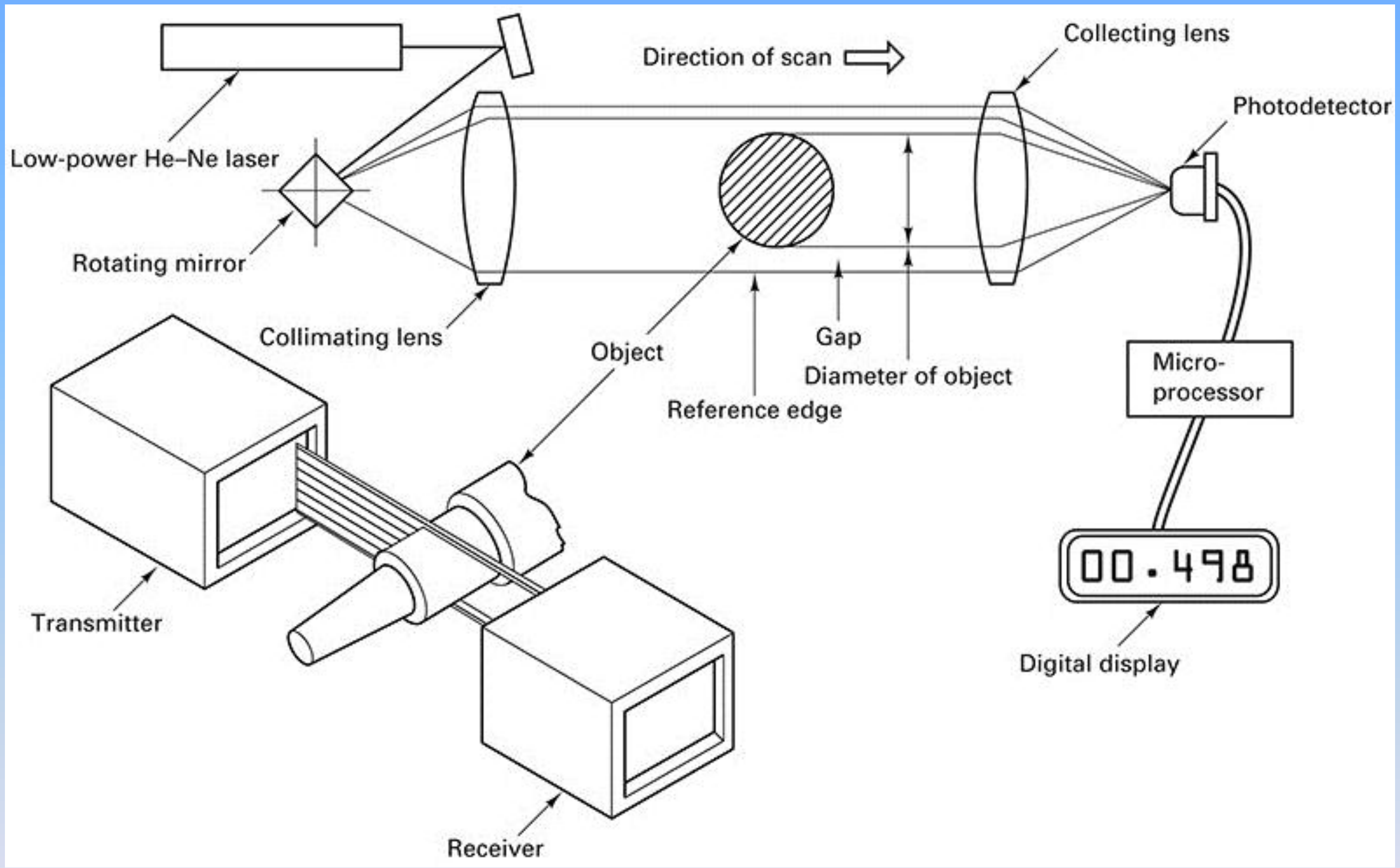


Figure 10-27 Scanning laser measuring system.
(Courtesy of ZYGO Corporation.)

35.6 Vision Systems for Measurement

- Used for visual inspection, guidance, and control
- Dissected into picture elements, pixels, which are digitized

TABLE 10-6 Laser Scanning versus Vision Systems

Variable	Laser-Scanning Systems	Video-Based Systems
Ambient lighting	Independent	Dependent
Object motion	Object usually stationary	Multiple cameras or strobe lighting may be required
Adaptability to robot systems	Readily adapted; some limitations on robot motion speed or overall system operation	Readily adapted; image-processing delays may delay system operation
Signal processing	Simple; computers often not required	Requires relatively powerful computers with sophisticated software
Cycle time	Very fast	Seconds of computer time may be needed
Applicability to simple tasks	Readily handled; edges and features produce sharp transitions in signal	Requires extensive use of sophisticated software algorithms to identify edges
Sizing capability	Can size an object in a single scan per axis	Can size on horizontal axis in one scan; other dimensions require full-frame processing
Three-dimensional capability	Limited three dimensionality; needs ranging capability	Uses two views of two cameras with sophisticated software or structured light
Accuracy and precision	Submicrometer 0.001 to 0.0001 in. or better accuracy; highly repeatable	Depends on resolution of cameras and distance between camera and object; systems with 0.004-in. precision and 0.006-in. accuracy are typical

35.7 Coordinate Measuring Machines

- Precise, three-dimensional measurements
- Measurements are made in the x, y, and z directions
- Computer routines can give the best fit to the feature

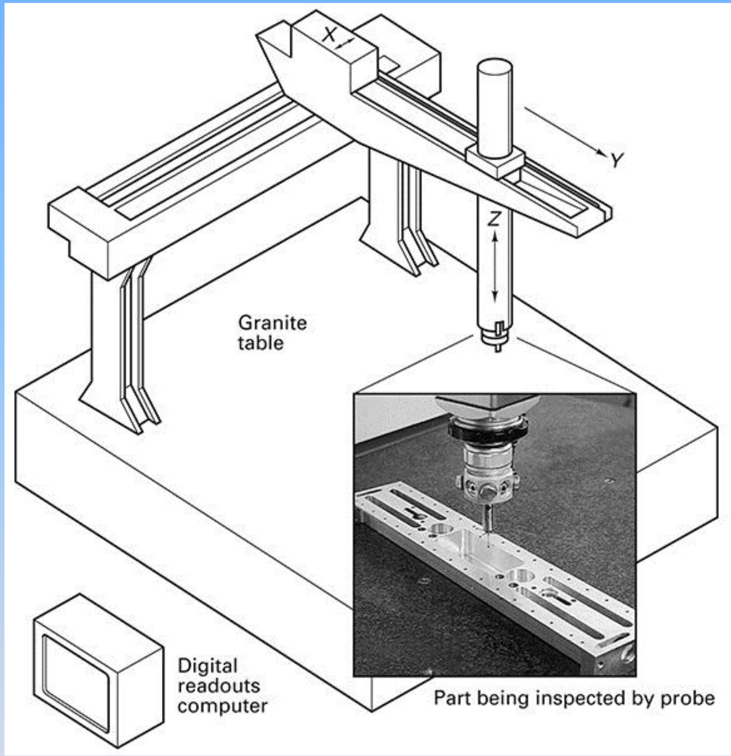


Figure 10-30 Coordinate measuring machine with inset showing probe and a part being measured.

35.8 Angle Measurements

- Angle measurements are more difficult than linear measurements
- Variety of instrumentation can be used

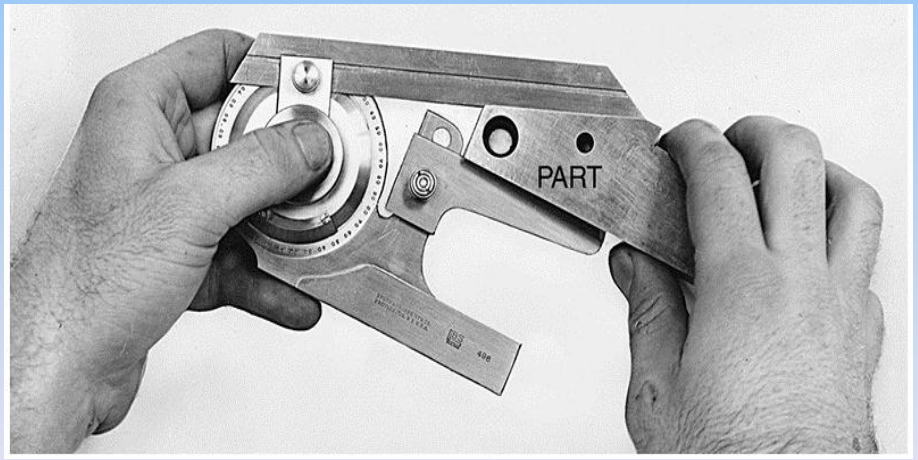


Figure 10-32 Measuring an angle on a part with a bevel protractor. (*Courtesy of Brown & Sharpe Mfg. Co.)*

Angle Measurements

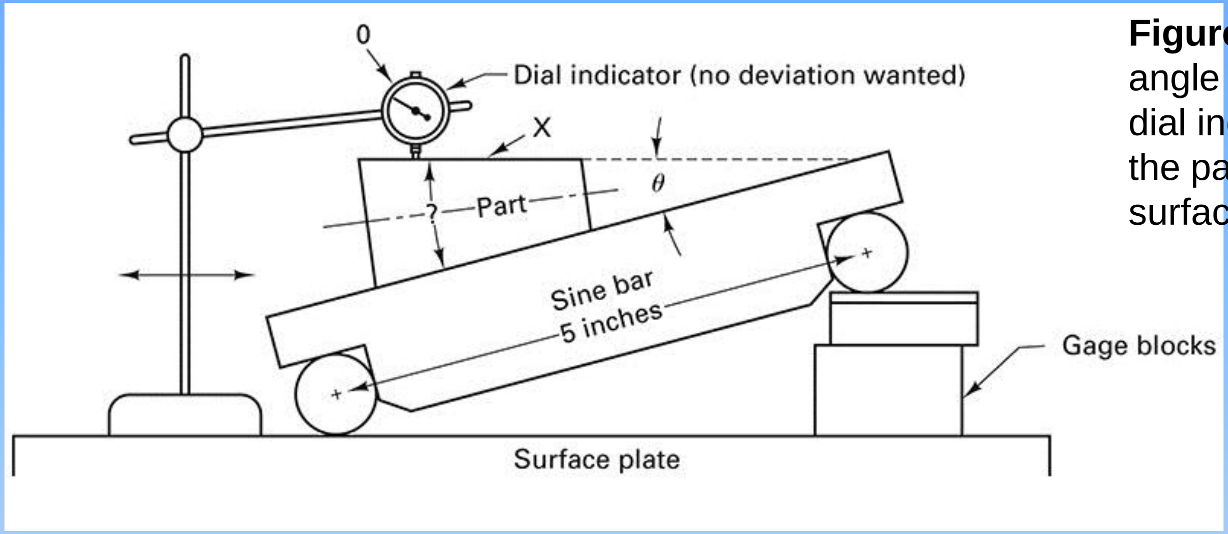


Figure 10-33 Setup to measure an angle on a part using a sine bar. The dial indicator is used to determine when the part surface X is parallel to the surface plate.

- Toolmaker's microscope can be used to make angle measurements
- Sine bar
- Angle gage blocks

35.9 Gages for Attributes Measuring

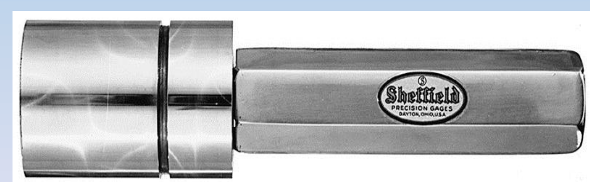
- It is not always necessary to know exact dimensions
- Attribute-type instruments are called gages
- Fixed-type gages
  - Gage only one dimension and indicate whether it is larger or smaller than some standard
  - Plug gage, go/no go gage, step-type gage, snap gage, ring gage

Fixed-Type Gages

Figure 10-36 Go and no-go (on right) ring gages for checking a shaft. (*Courtesy of Automation and Measurement Division, Bendix Corporation.)*

Figure 10-34 Plain plug gage having the go member on the left end (1.1250-in. diameter) and no-go member on the right end. (*Courtesy of Sheffield*.)

Figure 10-35 Step-type plug gage with go-no go elements on the same end. (*Courtesy of Sheffield.)*



Deviation-Type Gages

- Determines the amount by which a measured part differs from standard dimension
- Dial indicators
- Linear variable-differential transformers (LVDT)
- Air gages

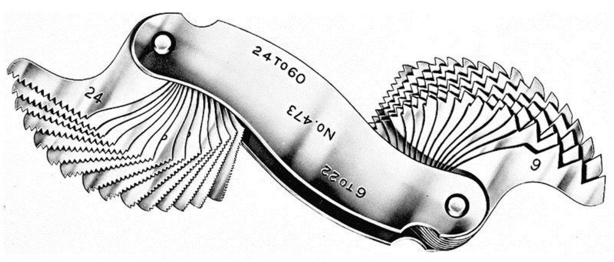


Figure 10-40 Thread pitch gages. (*Courtesy of L.S. Starrett Company.)*

Figure 10-41 Digital dial indicators with 1-in. range and 0.0001-in. accuracy. (*Courtesy of CDI.)*

Chapter 43- Testing

- Destructive testing
  - Components are subjected to conditions to induce failure
- Proof testing
  - Product is subjected to a load or pressure of some known and determined magnitude to simulate product life
- Hardness tests
- Nondestructive testing
  - Products are examined in a way that it can still be used

TABLE 10-7 Advantages and Limitations of Destructive and Nondestructive Testing

Destructive Testing

Advantages

1. Provides a direct and reliable measurement of how a material or component will respond to service conditions.
2. Provides quantitative results, useful for design.
3. Does not require interpretation of results by skilled operators.
4. Usually finds agreement as to meaning and significance of test results.

Disadvantages

1. Applied only to a sample; must show that the sample is representative of the group.
2. Tested parts are destroyed during testing.
3. Usually cannot repeat a test on the same item or use the same specimen for multiple tests.
4. May be restricted for costly or few-in-number parts.
5. Hard to predict cumulative effect of service usage.
6. Difficult to apply to parts in use; if done, testing terminates their useful life.
7. Extensive machining or preparation of test specimens is often required.
8. Capital equipment and labor costs are often high.

Nondestructive Testing

Advantages

1. Can be performed directly on production items without regard to cost or quantity available.
2. Can be performed on 100% of production lot (when high variability is observed) or a representative sample (if sufficient similarity is noted).
3. Different tests can be applied to the same item, and a test can be repeated on the same specimen.
4. Can be performed on parts that are in service; the cumulative effects of service life can be monitored on a single part.
5. Little or no specimen preparation is required.
6. The test equipment is often portable.
7. Labor costs are usually low.

Disadvantages

1. Results often require interpretation by skilled operators.
2. Different observers may interpret the test results differently.
3. Properties are measured indirectly, and results are often qualitative or comparative.
4. Some test equipment requires a large capital investment.

Visual and Liquid Penetration Inspection

TABLE 10-8 Visual Inspection

Principle	Illuminate the test specimen and observe the surface. Can reveal a wide spectrum of surface flaws and geometric discontinuities. Use of optical aids or assists (such as magnifying glass, microscopes, illuminators, and mirrors) is permitted. While most inspection is by human eye, video cameras and computer-vision systems can be employed.
Advantages	Simple, easy to use, relatively inexpensive.
Limitations	Depend on skill and knowledge of inspector. Limited to detection of surface flaws.
Material limitations	None.
Geometrical limitations	Any size or shape providing viewing accessibility of surfaces to be inspected.
Permanent record	Photographs or videotapes are possible. Inspectors' reports also provide valuable records.
Remarks	Should always be the initial and primary means of inspection and is the responsibility of everyone associated with parts manufacture.

TABLE 10-9 Liquid Penetrant Inspection

Principle	A liquid penetrant containing fluorescent material or dye is drawn into surface flaws by capillary action and subsequently revealed by developer material in conjunction with visual inspection.
Advantages	Simple, inexpensive, versatile, portable, easily interpreted, and applicable to complex shapes.
Limitations	Can only detect flaws that are open to the surface; surfaces must be cleaned before and after inspection; deformed surfaces and surface coatings may prevent detection; and the penetrant may be wiped or washed out of large defects. Cannot be used on hot products.
Material limitations	Applicable to all materials with a nonporous surface.
Geometrical limitations	Any size or shape permitting accessibility of surfaces to be inspected.
Permanent record	Photographs, videotapes, and inspectors' reports provide the most common records.

Magnetic Particle Inspection

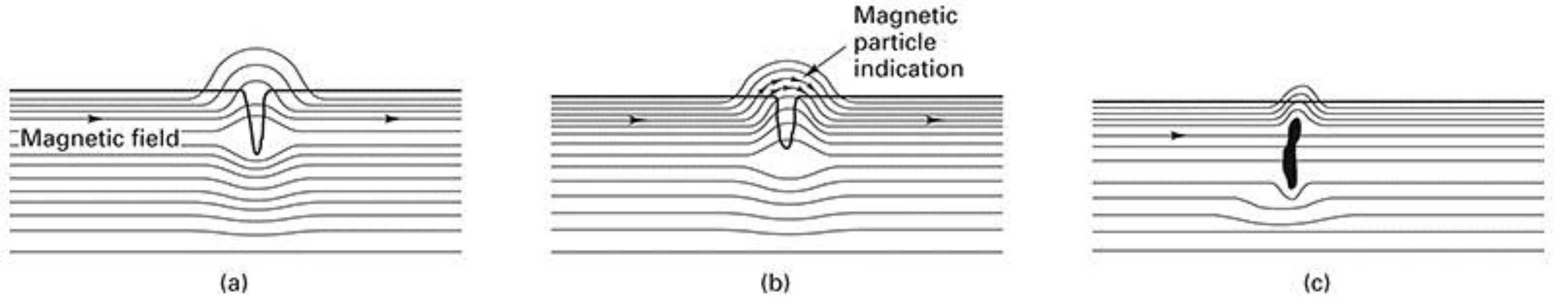


Figure 10-43 (a) Magnetic field showing disruption by a surface crack; (b) magnetic particles are applied and are preferentially attracted to field leakage; (c) subsurface defects can also produce surface-detectable disruptions if they are sufficiently close to the surface.

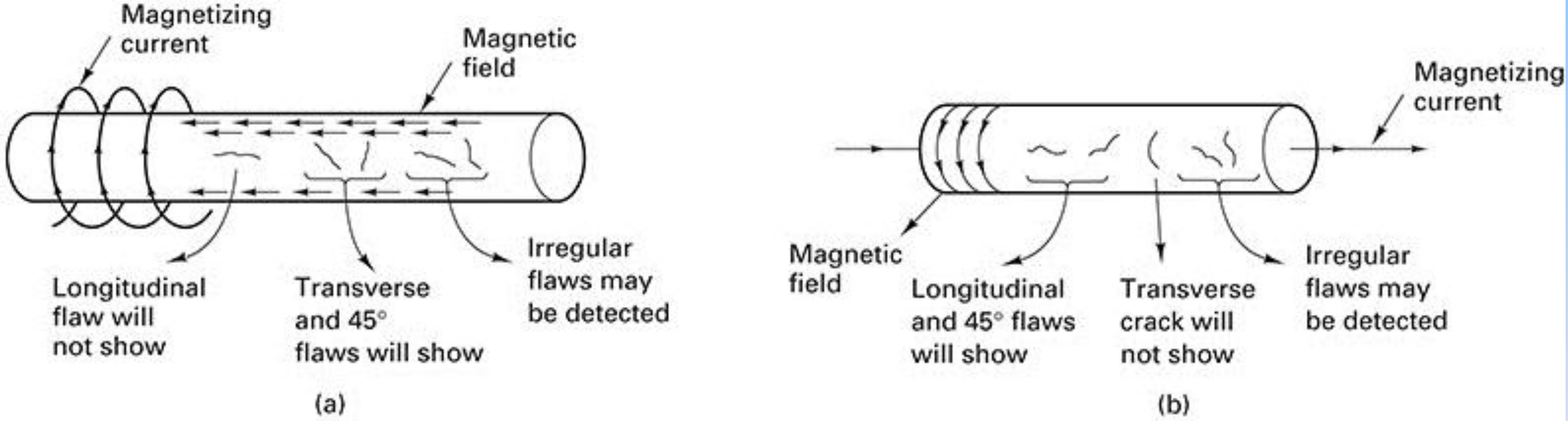


Figure 10-44 (a) A bar placed within a magnetizing coil will have an axial magnetic field. Defects parallel to this field may go unnoticed, while those that disrupt the field and are sufficiently close to a surface are likely to be detected. (b) When magnetized by a current passing through it, the bar has a circumferential magnetic field and the geometries of detectable flaws are reversed.

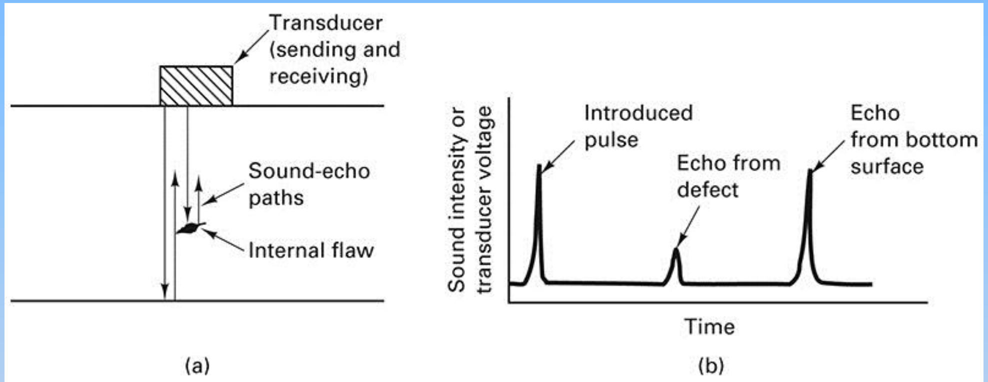
Magnetic Particle Inspection

TABLE 10-10 Magnetic Particle Inspection

Principle	When magnetized, ferromagnetic materials will have a distorted magnetic field in the vicinity of flaws and defects. Magnetic particles will be strongly attracted to regions where the magnetic flux breaks the surface.
Advantages	Relatively simple, fast, easy-to-interpret; portable units exist; can reveal both surface and subsurface flaws and inclusions (as much as 6-mm deep) and small, tight cracks.
Limitations	Parts must be relatively clean; alignment of the flaw and the field affects the sensitivity so that multiple inspections with different magnetizations may be required; can only detect defects at or near surfaces; must demagnetize part after test; high current source is required; some surface processes can mask defects; postcleaning may be required.
Material limitations	Must be ferromagnetic; nonferrous metals such as aluminum, magnesium, copper, lead, tin, and titanium and the ferrous (but not ferromagnetic) austenitic stainless steels cannot be inspected.
Geometrical limitations	Size and shape are almost unlimited; most restrictions relate to the ability to induce uniform magnetic fields within the piece; hard to use on rough surfaces.
Permanent record	Photographs, videotapes, and inspectors' reports are most common. In addition, the defect pattern can be preserved on the specimen by an application of transparent lacquer or transferred to a piece of transparent tape that has been applied to the specimen and peeled off.

Ultrasonic Inspection

- Several different inspection methods
  - Pulse-echo
  - Through-transmission
  - Resonance testing



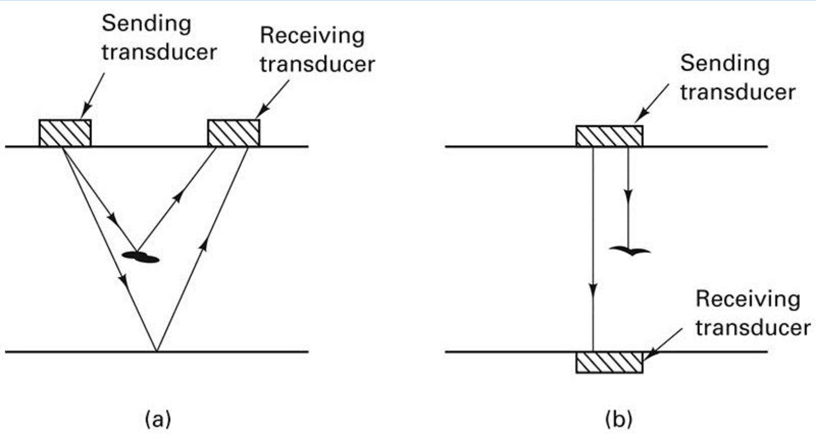


Figure 10-46 (above) (a) Ultrasonic inspection of a flat plate with a single transducer; (b) plot of sound intensity or transducer voltage versus time showing the initial pulse and echoes from the bottom surface and intervening defect.

Figure 10-47 (left) (a) Dual-transducer ultrasonic inspection in the pulse-echo mode; (b) dual transducers in through-transmission configuration.

Ultrasonic Inspection

TABLE 10-11 Ultrasonic Inspection

Principle	High-frequency sound waves are propagated through a test specimen, and the transmitted or reflected signal is monitored and interpreted.
Advantage	Can reveal internal defects; high sensitivity to most cracks and flaws; high-speed test with immediate results; can be automated and recorded; portable; high penetration in most important materials (up to 60 ft in steel); indicates flaw size and location; access to only one side is required; can also be used to measure thickness, Poisson's ratio, or elastic modulus; presents no radiation or safety hazard.
Limitations	Difficult to use with complex shapes; external surfaces and defect orientation can affect the test (may need dual transducer or multiple inspections); a couplant is required; the area of coverage is small (inspection of large areas requires scanning); trained, experienced, and motivated technicians may be required.
Material limitations	Few can be used on metals, plastics, ceramics, glass, rubber, graphite, and concrete, as well as joints and interfaces between materials.
Geometric limitations	Small, thin, or complex-shaped parts or parts with rough surfaces and nonhomogeneous structure pose the greatest difficulty.
Permanent record	Ultrasonic signals can be recorded for subsequent playback and analysis. Strip charts can also be used.

Radiography

TABLE 10-12 Radiography

Principle	Some form of radiation (X-ray, gamma ray, or neutron beam) is passed through the sample and is differentially absorbed depending on the thickness, type of material, and the presence of internal flaws or defects.
Advantages	Probes the internal regions of a material; provides a permanent record of the inspection; can be used to determine the thickness of a material; very sensitive to density changes.
Limitations	Most costly of the NDT methods (involves expensive equipment); radiation precautions are necessary (potentially dangerous to human health); the defect must be at least 2% of the total section thickness to be detected (thin cracks can be missed if oriented perpendicular to the beam); film processing requires time, facilities, and care; the image is a two-dimensional projection of a three-dimensional object, so the location of an internal defect requires a second inspection at a different angle; complex shapes can present problems; a high degree of operator training is required.
Material limitations	Applicable to most engineering materials.
Geometric limitations	Complex shapes can present problems in setting exposure conditions and obtaining proper orientation of source, specimen, and film. Two-side accessibility is required.
Permanent record	A photographic image is part of the standard test procedure.

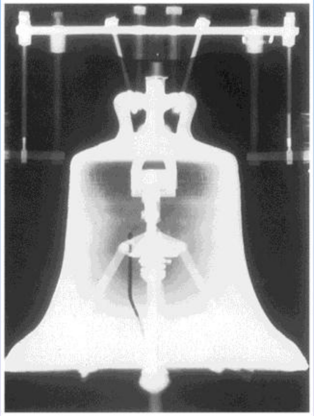


Figure 10-48 Radiograph of the Liberty Bell. The photo reveals the famous crack, as well as the iron spider installed in 1915 to support the clapper and the steel beam and supports, which were set into the yoke in 1929. (*Courtesy of Eastman Kodak Company.)*

Eddy-Current Testing

TABLE 10-13 Eddy-Current Testing

Principle	When an electrically conductive material is brought near an alternating-current coil that produces an alternating magnetic field, surface currents (eddy currents) are generated in the material. These surface currents generate their own magnetic field, which interacts with the original, modifying the impedance of the originating coil. Various material properties and/or defects can affect the magnitude and direction of the induced eddy currents and can be detected by the electronics.
Advantage	Can detect both surface and near-surface irregularities; applicable to both ferrous and nonferrous metals; versatile—can detect flaws; variations in alloy or heat treatment; variations in plating or coating thickness, wall thickness, and crack depth; intimate contact with the specimen is not required; can be automated; electrical circuitry can be adjusted to select sensitivity and function; pass–fail inspection is easily conducted; high speed; low cost; no final cleanup required.
Limitations	Response is sensitive to a number of variables, so interpretation may be difficult; sensitivity varies with depth, and depth of inspection depends on the test frequency; reference standards are needed for comparison; trained operators are generally required.
Material limitations	Only applicable to conductive materials, such as metals; some difficulties may be encountered with ferromagnetic materials.
Geometric limitations	Depth of penetration is limited; must have accessibility of coil or probe; constant separation distance between coils and specimen is required for good results.
Permanent record	Electronic signals can be recorded using devices such as strip-chart recorders.

Eddy-Current Testing

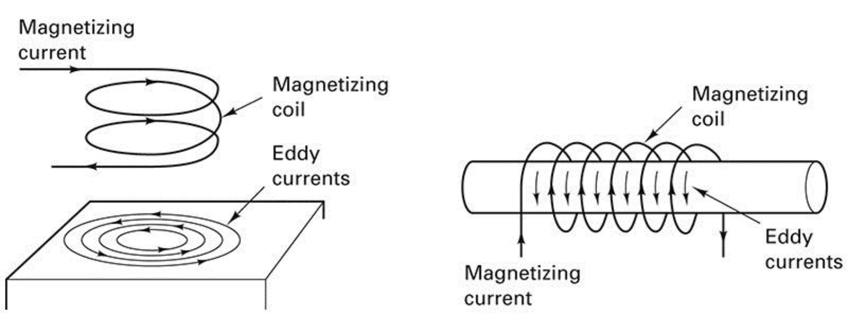
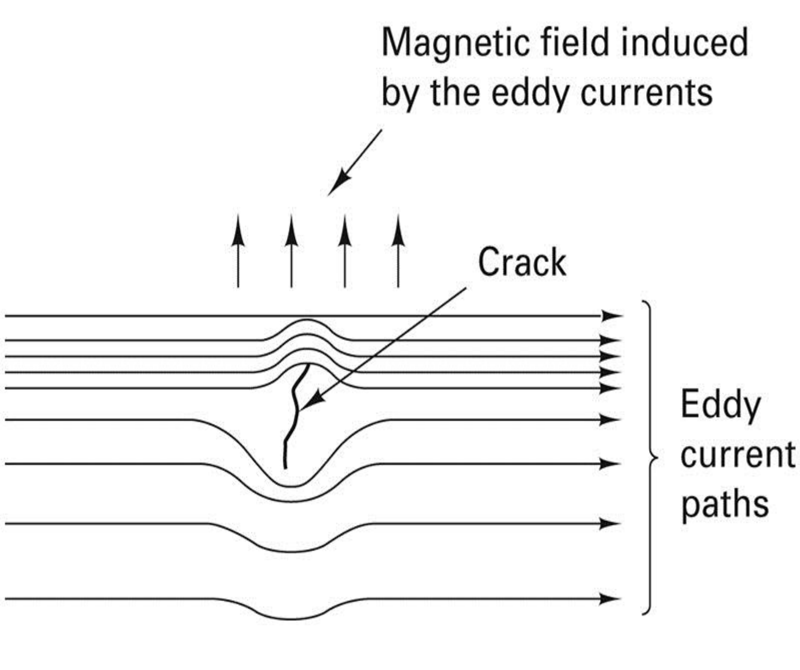


Figure 10-49 (above) Relation of the magnetizing coil, magnetizing current, and induced eddy currents. The magnetizing current is actually an alternating current, producing a magnetic field that forms, collapses, and re-forms in the opposite direction. This dynamic magnetic field induces the eddy currents, and the changes in the eddy currents produce a secondary magnetic field that interacts with the sensor coil or probe.

Figure 10-50 (below) Eddy currents are constrained to travel within the conductive material, but the magnitude and path of the currents will be affected by defects and changes in material properties. By focusing on the magnitude of the eddy currents, features such as differences in heat treatment can be detected.



Acoustic Emission Monitoring

TABLE 10-14 Acoustic Emission Monitoring

Principle	Almost all materials will emit high-frequency sound (acoustic emissions) when stressed, deformed, or undergoing structural changes, such as the formation or growth of a crack or defect. These emissions can now be detected and provide an indication of dynamic change within the material.
Advantages	The entire structure can be monitored with near-instantaneous detection and response; continuous surveillance is possible; defects inaccessible to other methods can be detected; inspection can be in harsh environments; and the location of the emission source can be determined.
Limitations	Only growing or "active" flaws can be detected (the mere presence of defects is not detectable); background signals may cause difficulty; there is no indication of the size or shape of the flaw; expensive equipment is required; and experience is required to interpret the signals.
Material limitations	Virtually unlimited, provided that they are capable of transmitting sound.
Geometric limitations	Requires continuous sound-transmitting path between the source and the detector. Size and shape of the component affect the strength of the emission signals that reach the detector.

Other Methods of Nondestructive Testing and Inspection

- Leak testing
  - Determine the existence or absence of leak sites and the rate of material loss
- Thermal methods
  - Temperature-sensing devices evaluate abnormal temperature distributions
- Strain sensing
- Advanced optical methods
- Resistivity methods
- Computed tomography
- Chemical analysis and surface topography

Dormant versus Critical Flaws

- Most materials have flaws of some magnitude
- The extent and possible severity of flaws is important in determining if the flaws in the product can be tolerated
- Larger defects may grow or propagate under cyclic loading
- Identify the conditions below which the flaw remains dormant and above which it becomes critical

Summary

- Measurement and inspection is an important aspect of quality control
- There is a wide variety of techniques that can be employed to make measurements
- The correct technique depends on the application, available equipment, and necessary accuracy
- Cost may play a role in determining which technique is appropriate