MEASUREMENT AND INSPECTION

1. Metrology
2. Inspection Principles
3. Conventional Measuring Instruments and Gages
4. Measurement of Surfaces
5. Advanced Measurement and Inspection Techniques

Measurement

Procedure in which an unknown quantity is compared to a known standard, using an accepted and consistent system of units

- The measurement may involve a simple linear rule to scale the length of a part
- Or it may require a sophisticated measurement of force versus deflection during a tension test
- Measurement provides a numerical value of the quantity of interest, within certain limits of accuracy and precision

Inspection

Procedure in which a part or product feature, such as a dimension, is examined to determine whether or not it conforms to design specification

- Many inspections rely on measurement techniques, while others use gaging methods
  - *Gaging* determines simply whether the part characteristic meets or does not meet the design specification
  - Gaging is usually faster than measuring, but not much information is provided about feature of interest

Metrology

Defined as the science of measurement

- Concerned with seven fundamental quantities (standard units shown in parentheses):
  - Length (meter)
  - Mass (kilogram)
  - Time (second)
  - Electric current (ampere)
  - Temperature (degree Kelvin)
  - Light intensity (candela)
  - Matter (mole)

Metrology

- From these basic quantities, most other physical quantities are derived, such as:
  - Area
  - Volume
  - Velocity and acceleration
  - Force
  - Electric voltage
  - Heat energy

Manufacturing Metrology

- In manufacturing metrology, we are usually concerned with measuring a length quantity of a part or product
  - Length and width
  - Depth
  - Diameter
  - Straightness, flatness, and roundness, etc.
  - Surface roughness

Accuracy and Precision

Accuracy - degree to which a measured value agrees with the true value of the quantity of interest

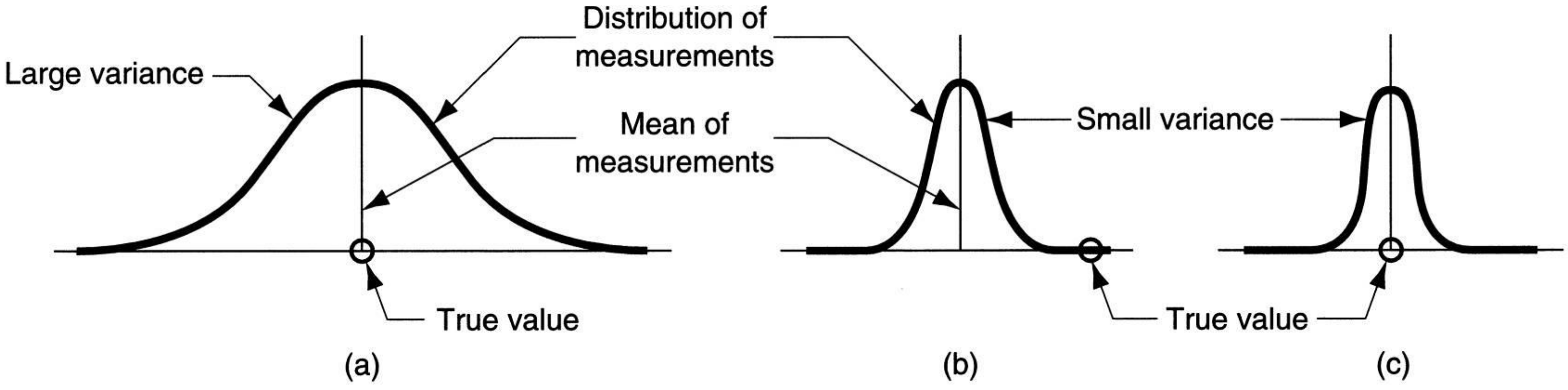
- A measurement procedure is accurate when it is absent of systematic errors
  - *Systematic errors* - positive or negative deviations from true value that are consistent from one measurement to the next

Precision - degree of repeatability in the measurement process

- Good precision means that random errors in the measurement procedure are minimized

Accuracy and Precision

Figure 45.1 Accuracy versus precision in measurement: (a) high accuracy but low precision; (b) low accuracy but high precision; and (c) high accuracy and high precision.



Two Dominant Systems of Units

- Two systems of units have evolved into predominance in the world:
  1. U.S. customary system (U.S.C.S.)
  2. SI (for Systeme Internationale d'Unites) - the “metric system”

Types of Inspection

- Inspection involves the use of measurement and gaging techniques to determine whether a product, its components, subassemblies, or materials conform to design specifications
- Inspections divide into two types:

1. Inspection by variables - product or part dimensions of interest are *measured* by the appropriate measuring instruments
2. Inspection by attributes – product or part dimensions are *gaged* to determine whether or not they are within tolerance limits

Manual Inspection

- Inspection procedures are often performed manually
- The work is boring and monotonous, yet the need for precision and accuracy is high
- Hours may be required to measure the important dimensions of only one part
- Because of the time and cost of manual inspection, statistical sampling procedures are often used to reduce the need to inspect every part

Sampling Inspection

- When sampling inspection is used, the number of parts in the sample is usually small compared to the quantity of parts produced
  - Sample size may be 1% of production run
- Because not all of the items in the population are measured, there is a risk in any sampling procedure that defective parts will slip through
  - The risk can be reduced by taking a larger sample size
  - Fact is that less than 100% good quality must be tolerated as the price of using sampling

100% Inspection

- Theoretically, the only way to achieve 100% good quality is by 100% inspection
  - All defects are screened and only good quality parts are passed

Measuring Instruments and Gages

- Conventional measuring instruments and gages include:
  - Precision gage blocks
  - Measuring instruments for linear dimensions
  - Comparative instruments
  - Fixed gages
  - Angular measurements

Precision Gage Blocks

The standards against which other dimensional measuring instruments and gages are compared

- Usually square or rectangular blocks
- Surfaces are finished to be dimensionally accurate and parallel to $\pm$ several millionths of an inch and are polished to a mirror finish
- Precision gage blocks are available in certain standard sizes or in sets, the latter containing a variety of different sized blocks

Measurement of Linear Dimensions

- Measuring instruments are divided into two types:
  - *Graduated measuring devices* include a set of markings on a linear or angular scale to which the object's feature of interest can be compared for measurement
  - *Nongraduated measuring devices* have no scale and are used to compare dimensions or to transfer a dimension for measurement by a graduated device

Micrometer

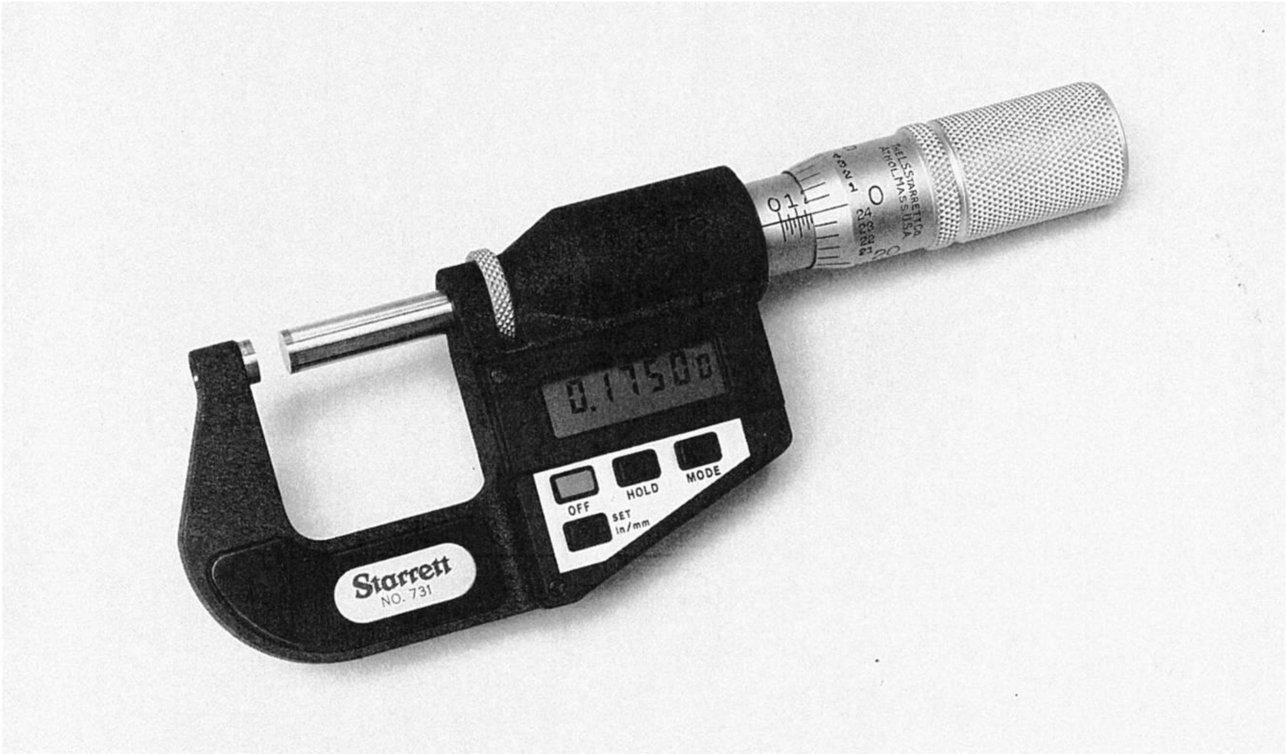


Figure 45.5 External micrometer, standard one-inch size with digital readout (photo courtesy of L. S. Starret Co.).

Calipers

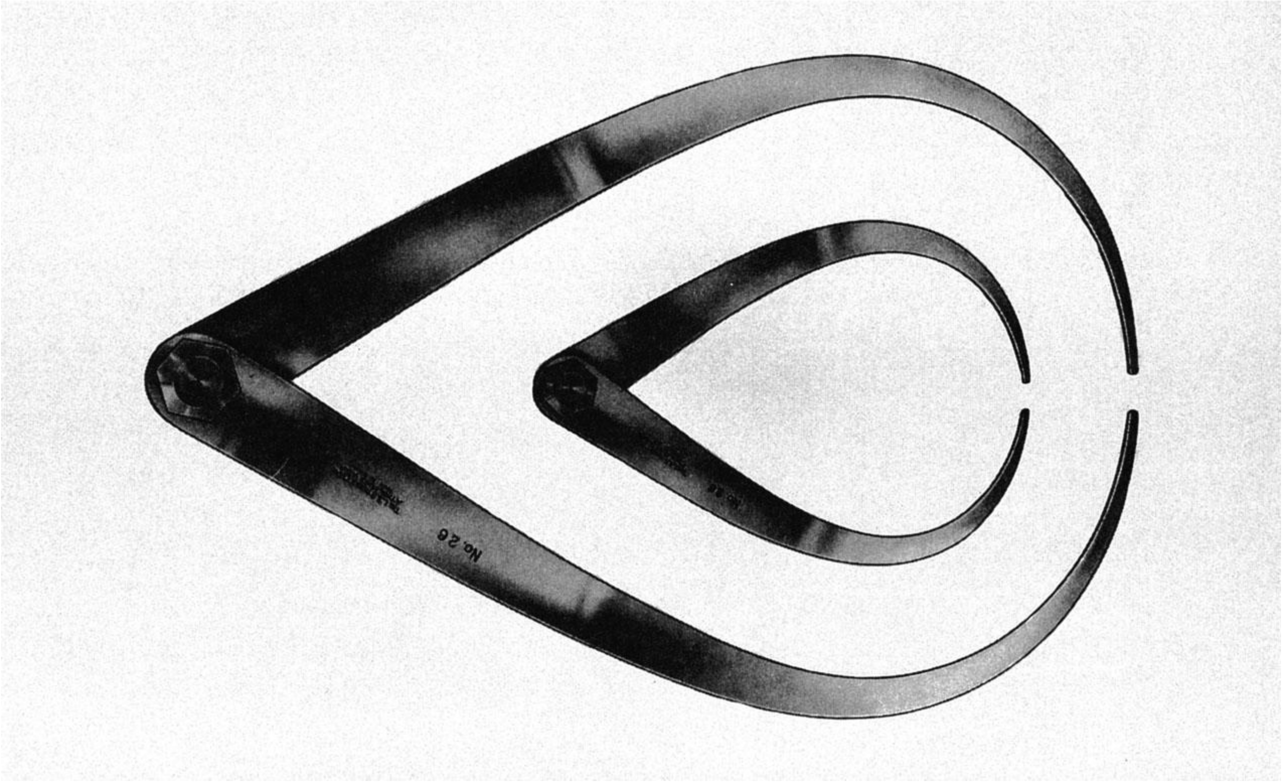


Figure 45.2 Two sizes of outside calipers (photo courtesy of L. S. Starret Co.).

Mechanical Gages: Dial Indicators

- Mechanical gages are designed to mechanically magnify the deviation to permit observation
- Most common instrument in this category is the *dial indicator*, which converts and amplifies the linear movement of a contact pointer into rotation of a dial
  - The dial is graduated in small units such as 0.01 mm or 0.001 inch
  - Applications: measuring straightness, flatness, parallelism, squareness, roundness, and runout

Dial Indicator

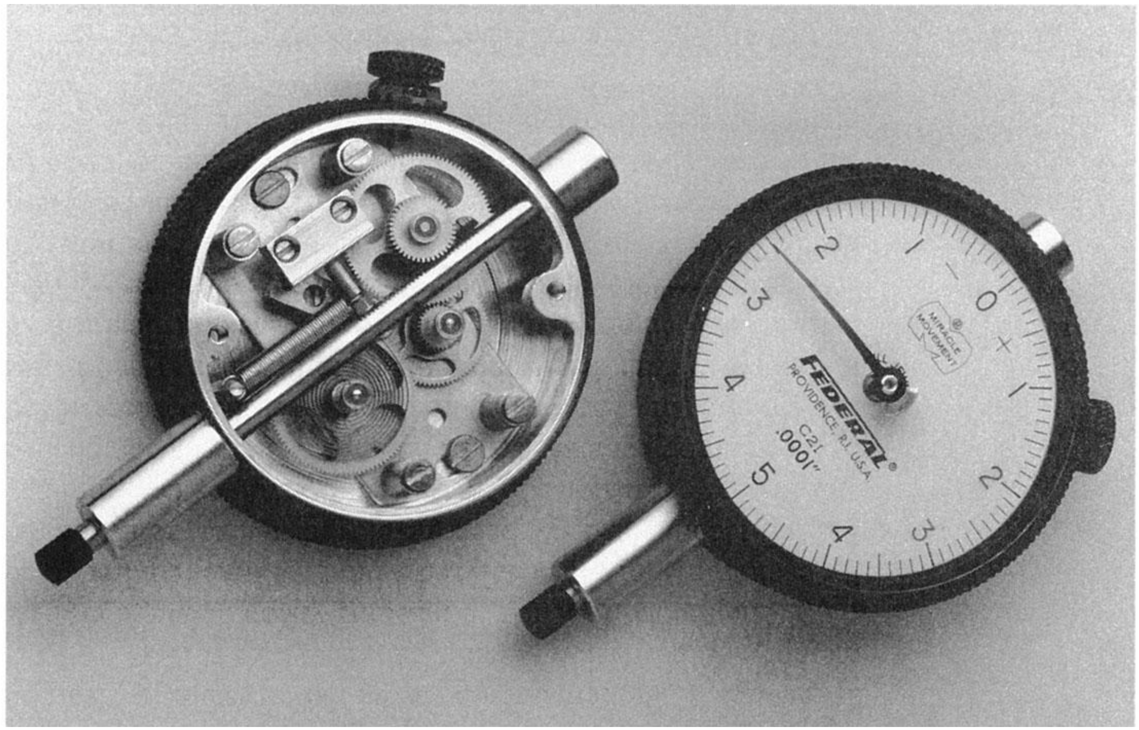


Figure 45.6 Dial indicator: front view shows dial and graduated face; back view shows rear of instrument with cover plate removed (photo courtesy of Federal Products Co.).

Dial Indicator to Measure Runout

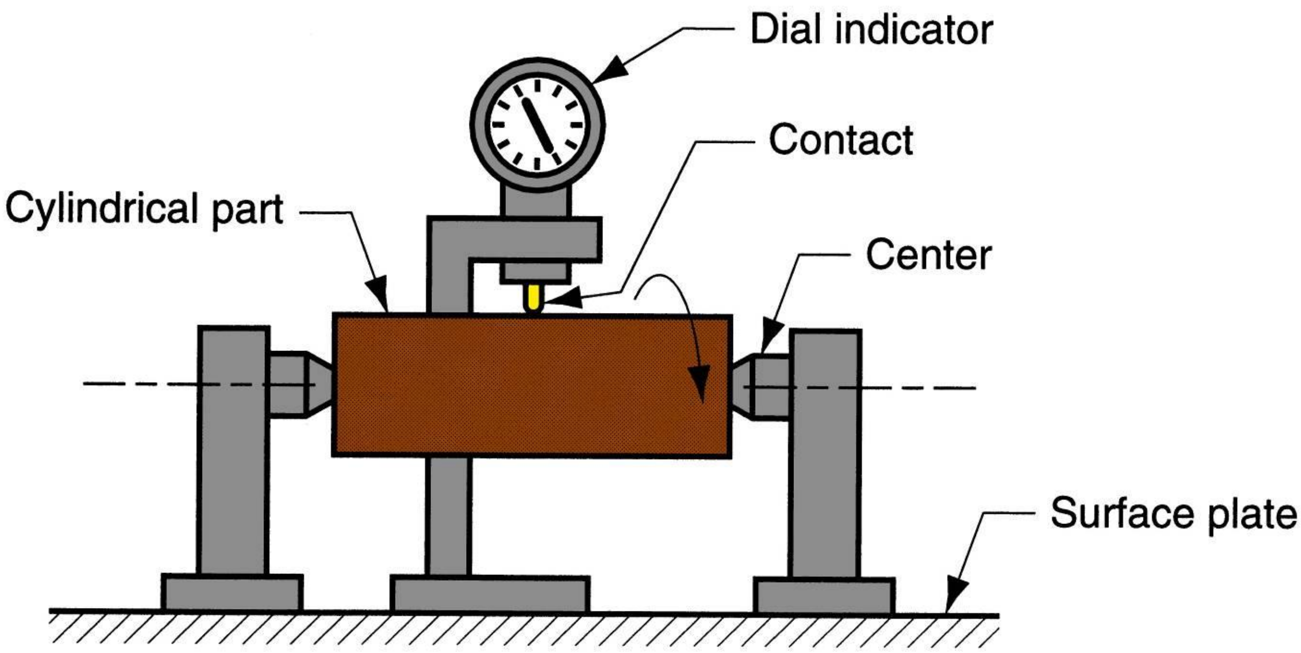


Figure 45.7 Dial indicator setup to measure runout; as part is rotated about its center, variations in outside surface relative to center are indicated on the dial.

Electronic Gages

Family of measuring and gaging instruments based on transducers capable of converting a linear displacement into an electrical signal

- Electrical signal is amplified and transformed into suitable data format such as a digital readout
- Applications of electronic gages have grown rapidly in recent years, driven by advances in microprocessor technology
- They are gradually replacing many of the conventional measuring and gaging devices

GO/NO-GO gages

So-called because one gage limit allows the part to be inserted while the other limit does not

- GO limit - used to check the dimension at its maximum material condition
  - This is the minimum size for an internal feature such as a hole
  - It is the maximum size for an external feature such as an outside diameter
- NO-GO limit - used to inspect the minimum material condition of the dimension in question

Snap Gage

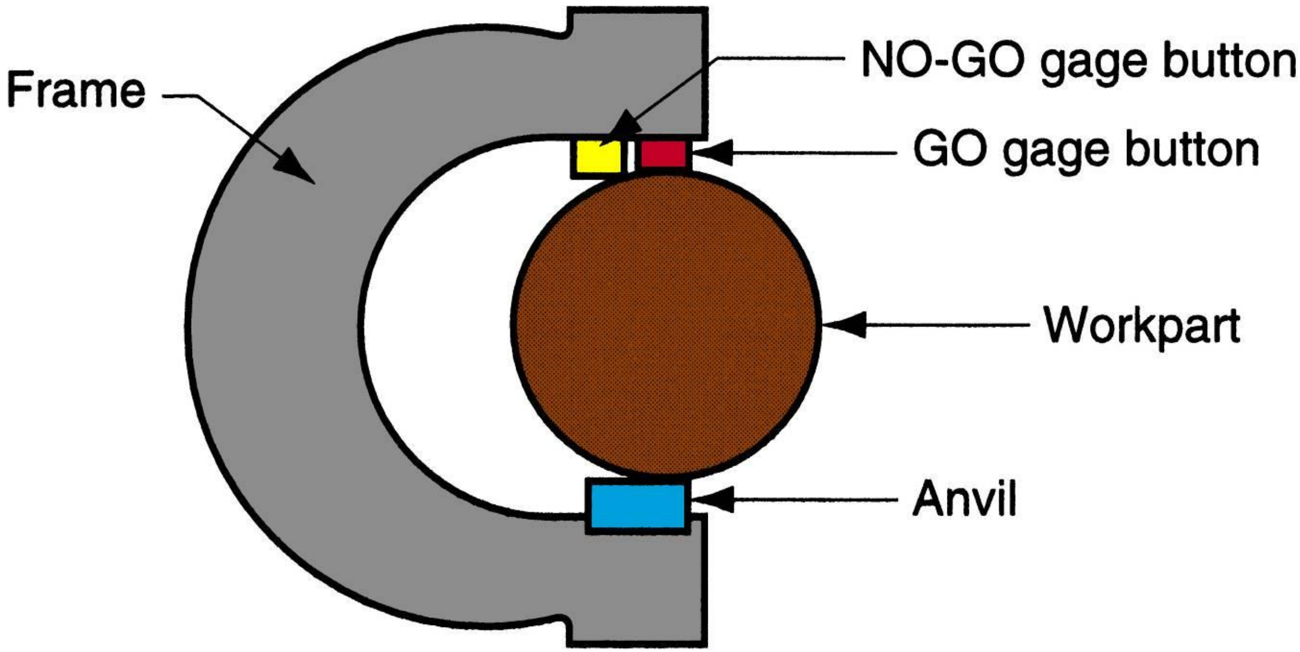


Figure 45.8 Snap gage for measuring diameter of a part; difference in height of GO and NO-GO gage buttons is exaggerated.

Measurement of Surfaces

Two parameters of interest:

- *Surface texture* - geometry of the surface, commonly measured as surface roughness
  - Surface roughness - small, finely-spaced deviations from the nominal surface determined by material and process that formed the surface
- *Surface integrity* - deals with the material characteristics immediately beneath the surface and the changes to this subsurface that resulted from the processes that created it

Advanced Technologies in Inspection

- Substitutes for manual measuring and gaging techniques in modern manufacturing
- Usually faster and more reliable than manual inspection
- Include contact and non-contact sensing methods:
  1. Coordinate measuring machines
  2. Lasers
  3. Machine vision
  4. Other non-contact techniques

Coordinate Measuring Machine (CMM)

Measuring machine consisting of a contact probe and a mechanism to position the probe in three-dimensions relative to surfaces and features of a workpart

- The probe is fastened to a structure that allows movement relative to the part
- Part is fixtured on worktable connected to structure
- The location coordinates of the probe can be accurately recorded as it contacts the part surface to obtain part geometry data

Coordinate measuring machine (photo courtesy of Brown and Sharpe Mfg Co.).

CMM Probes

- Modern "touch-trigger" probes with sensitive electrical contact that signals when the probe is deflected from neutral position in the slightest amount
  - On contact, the coordinate positions are recorded by the CMM controller, adjusting for overtravel and probe size

CMM Advantages

- Higher productivity - a CMM can perform complex inspection procedures in much less time than traditional manual methods
- Greater inherent accuracy and precision than conventional methods
- Reduced human error
- Versatility - a CMM is a general purpose machine that can be used to inspect a variety of part configurations

Measurements with Lasers

- *Laser* stands for light amplification by stimulated emission of radiation
- Lasers for measurement are low-power gas lasers that emit light in the visible range
- Laser light beam is:
  - Highly monochromatic - the light has a single wave length
  - Highly collimated - the light rays are parallel
- These properties have motivated many applications in measurement and inspection

Scanning Laser Systems

Laser beam deflected by a rotating mirror to sweeps a beam of light past an object

- Photodetector on far side of the object senses the light beam during its sweep except for the short time while it is interrupted by the object
- This time period can be measured quickly with great accuracy
- A microprocessor system measures the time interruption related to the size of the object in the path of the laser, and converts it to a linear dimension

Scanning Laser Measurement

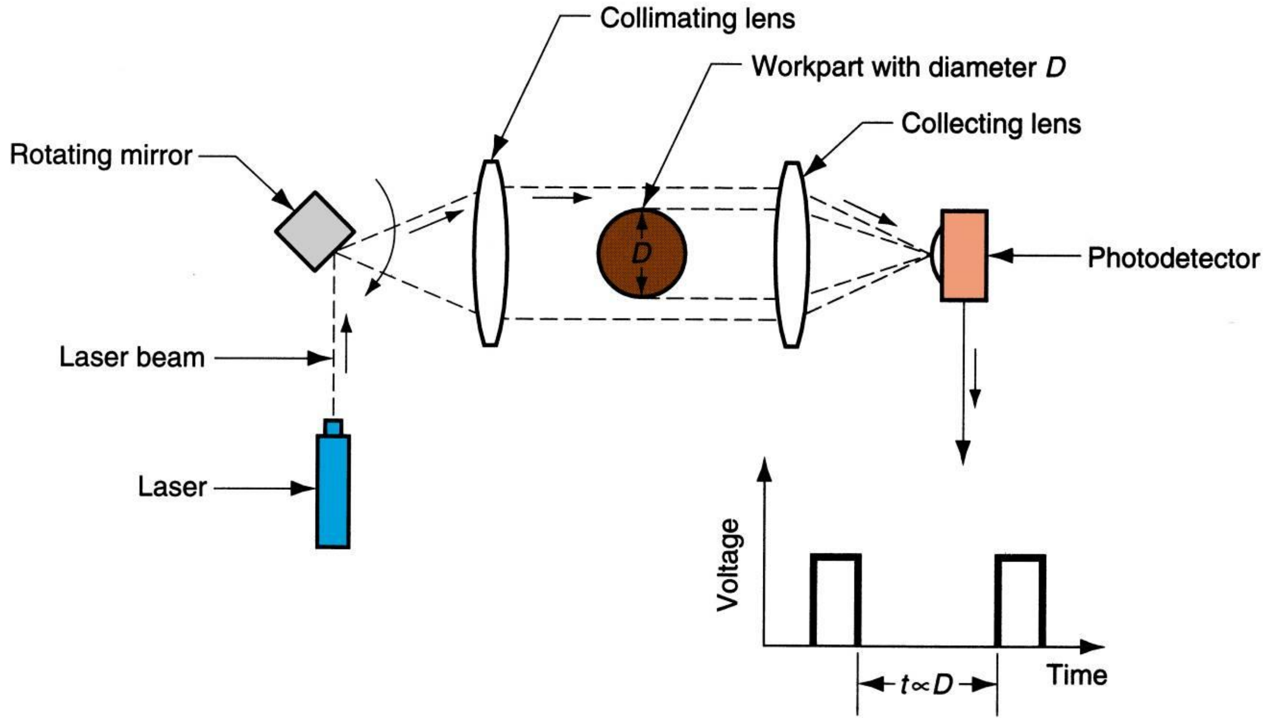


Figure 45.15 Scanning laser system for measuring diameter of cylindrical workpart; time of interruption of light beam is proportional to diameter *D.*