ENGINEERING METROLOGY

ACADEMIC YEAR 92-93, SEMESTER ONE

COORDINATE MEASURING MACHINES
OPTICAL MEASUREMENT SYSTEMS;

DEPARTMENT OF MECHANICAL ENGINEERING
ISFAHAN UNIVERSITY OF TECHNOLOGY

Dep. of Mech. Eng.

Coordinate Measuring Machines

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Coordinate Measuring Machines (CMM)

- ✓ A *coordinate measuring machine* used to measure geometric features of workpieces such as size, diameter, angle, angularity, and parallelism
- ✓ Relatively complex shape, size and position measurements are reduced to the determination and mathematical evaluation of the spatial coordinates of discrete points
- ✓ CMMs are capable of recording measurements of complex profiles with high resolution (0.25 μm) and high speed

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CMM Construction

- ✓ A CMM basically consists of a platform on which the workpiece being measured is placed and then is moved linearly or rotated
- ✓ The measuring carriages are moved in the coordinate axes either manually or by motorized drives
- ✓ An important aspect in CMM is the probing sensor for detecting the measured points
- ✓ The probe could be tactile or optical
- ✓ The structure of CMM must be rigid to minimize deflections that contribute to measurement errors

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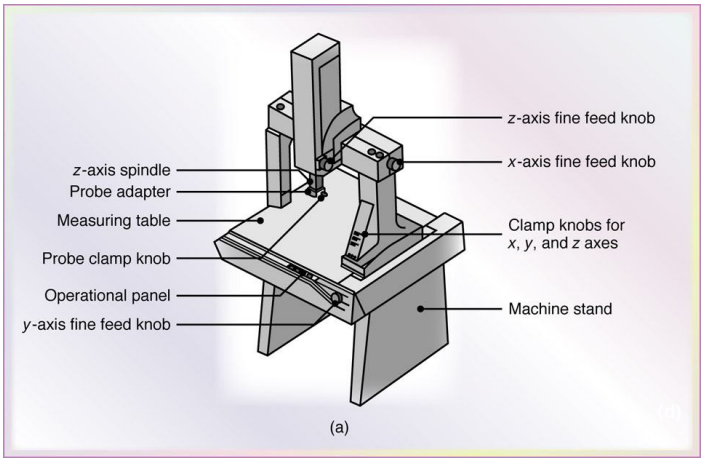
Coordinate-Measuring Machine



(a) Schematic illustration of a coordinate-measuring machine

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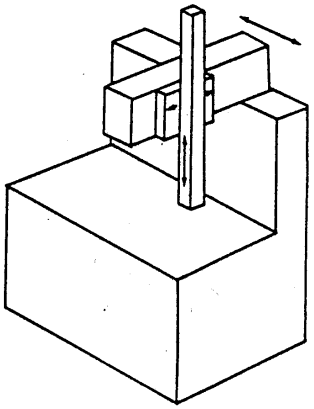
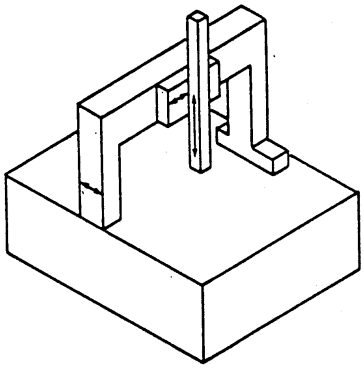
Types of CMM



Fixed Table Cantilever Coordinate Measuring Machine



Moving Bridge Coordinate Measuring Machine

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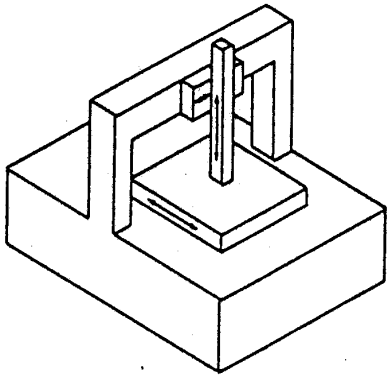
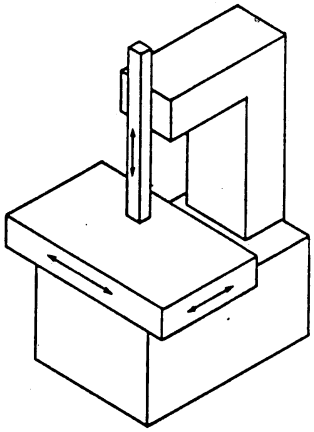
Types of CMM



Fixed Bridge Coordinate Measuring Machine



Column Coordinate Measuring Machine

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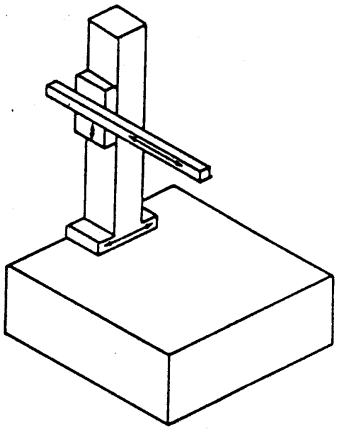
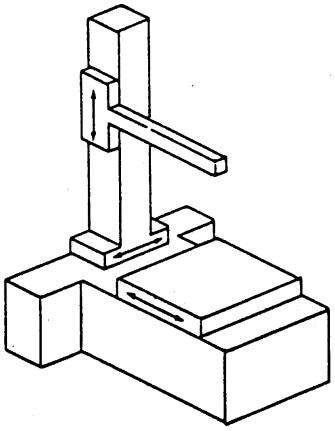
Types of CMM



Moving Ram Horizontal Arm Coordinate Measuring Machine



Moving Table Horizontal Arm Coordinate Measuring Machine

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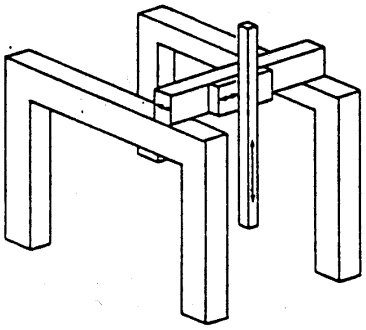
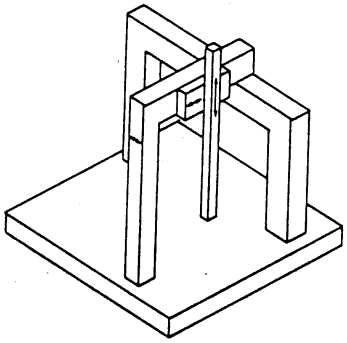
Types of CMM



Gantry Coordinate Measuring Machine



L-shaped Bridge Coordinate Measuring Machine

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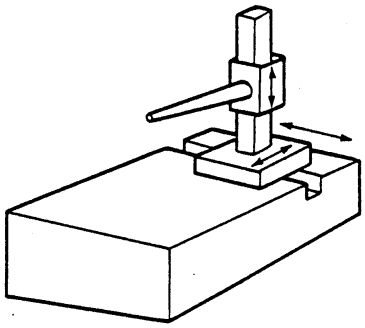
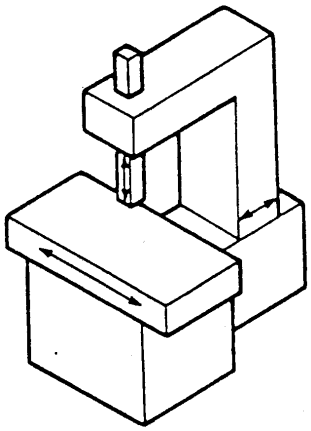
Types of CMM



Fixed Table Horizontal Arm Coordinate Measuring Machine



Moving Table Cantilever Arm Coordinate Measuring Machine

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Coordinate-Measuring Machine for Car Bodies

A large coordinate-measuring machine with two heads measuring various dimensions on a car body. *Source*: Courtesy of Mitutoyo Corp.

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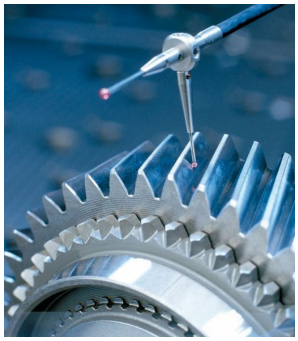
Coordinate-Measuring Machine



(a)

(b)

(a) A touch signal probe. (b) Examples of laser probes.

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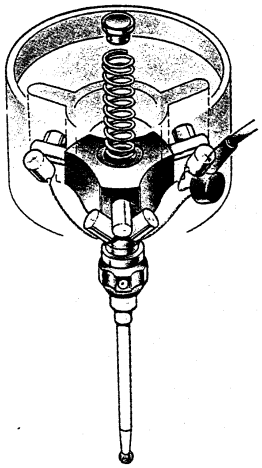
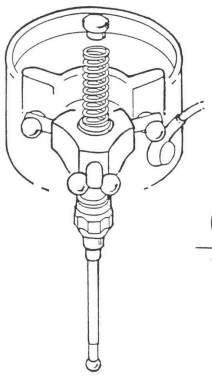
Probe Systems

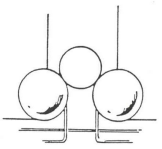


Switching probe system

Continuous measuring probe system



Kinematic touch trigger probe



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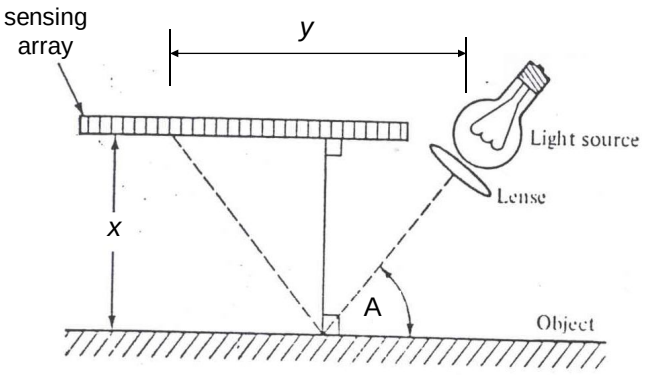
Proximity Sensor



$x = 0.5\, y \tan(A)$

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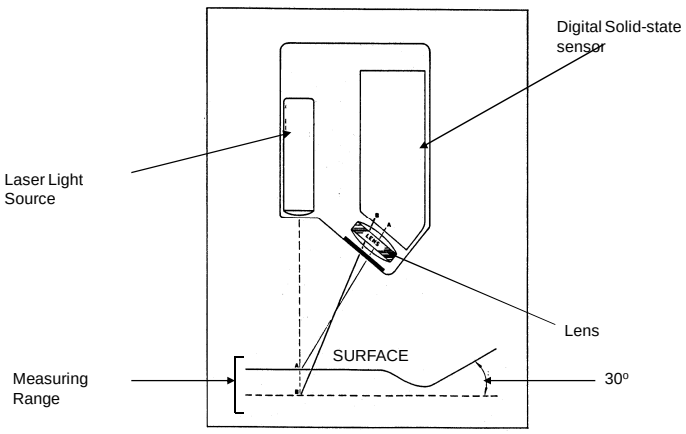
Diffracto Non-contact Laser Probe



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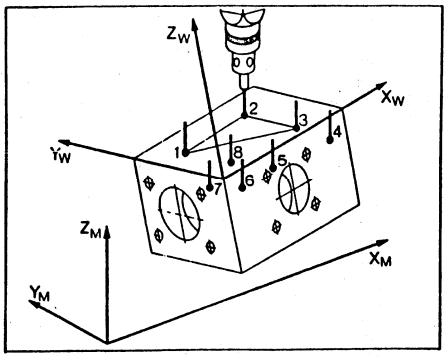
Automatic Axis Alignment



X_w, Y_w, Z_w – Work piece related coordinate system

X_M, Y_M, Z_M – Machine related coordinate system

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Measurement with a CMM

- Step 1: Calibration of the stylus or probe tip with respect to the probe head reference point using a calibrated ball.
- Step 2: Metrological determination of the work piece position in the measuring machine-related coordinated system.
- Step 3: Measurement of the surface points on the work piece in the measuring machine-related coordinate system.
- Step 4: Evaluation of the geometric parameters of the work piece
- Step 5: Representation of the measurement results after coordinate transformation into the work piece related coordinate system.

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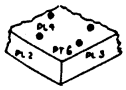
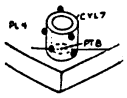
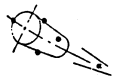
Basic Geometric elements

	**Circle:** Requires 3 points for measurement: By measuring 4 (up to 50) or more points form deviation is determined
	**Plane:** Planar measurements require 4 or more points for form. The intersection of Planes 2 and 3 generate Line 5; Point 6 is the intersection of Plane 4 and Line 5
	**Cylinder:** To define a cylinder, 5 points are necessary. Calculations provide its axis and diameter. The intersection of the Cylinder 7 and Plane 4 is Line 8.
	**Cone:** The cone (or taper) requires at least 6 points for definition. Calculations determine the cone's included angle and its axis in space.
	**Sphere:** The location of a sphere is found by measuring 4 points is also calculated.

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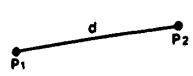
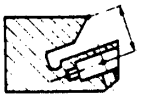
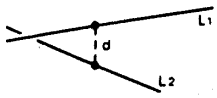
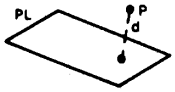
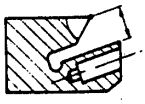
Calculated Solution - Distance

SYMBOL	RELATION	EXAMPLE
	Distance between two points	
	Shortest distance point to line	
	Shortest distance between two lines	
	Shortest distance point to plane	

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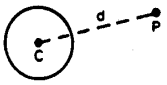
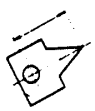
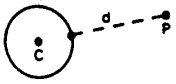
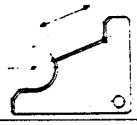
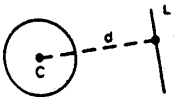
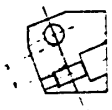
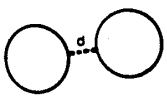
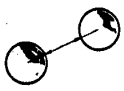
Calculated Solution - Distance

	Distance between point and circular feature	
	Distance between point and nearest point on circular feature	
	Shortest distance between line and circular feature	
	Shortest distance between two circular features	

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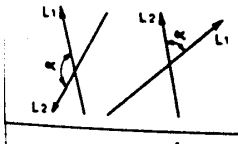
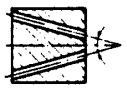
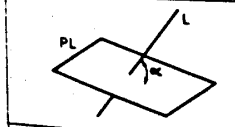
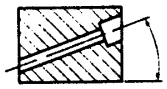
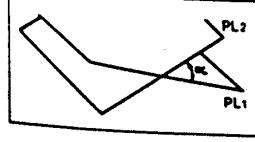
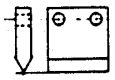
Calculated Solutions - Angle

SYMBOL	RELATION	EXAMPLE
	Angle between two lines	
	Angle between line and plane	
	Acute angles between two planes	

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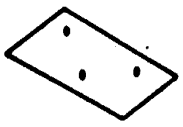
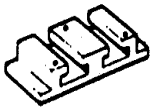
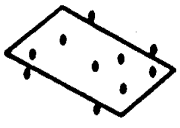
Calculated Solutions - Plane

SYMBOL	RELATION	EXAMPLE
	Plane by three points	
	Average plane defined by 4 to 20 points	

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Calculated Solutions - Circle

SYMBOL	RELATION	EXAMPLE
	Circle by three points	
	Average circle defined by 4 to 20 points	

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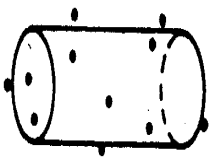
Calculated Solutions - Cylinder

SYMBOL	RELATION	EXAMPLE
	Average cylinder defined by 6 to 20 points	

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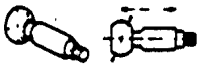
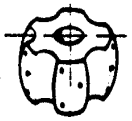
Calculated Solutions - Sphere

SYMBOL	RELATION	EXAMPLE
	Sphere by 4 points	
	Average sphere defined by 5 to 20 points	

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Calculated Solutions - Cone

SYMBOL	RELATION	EXAMPLE
	Construction of a cone by 6 to 20 points	

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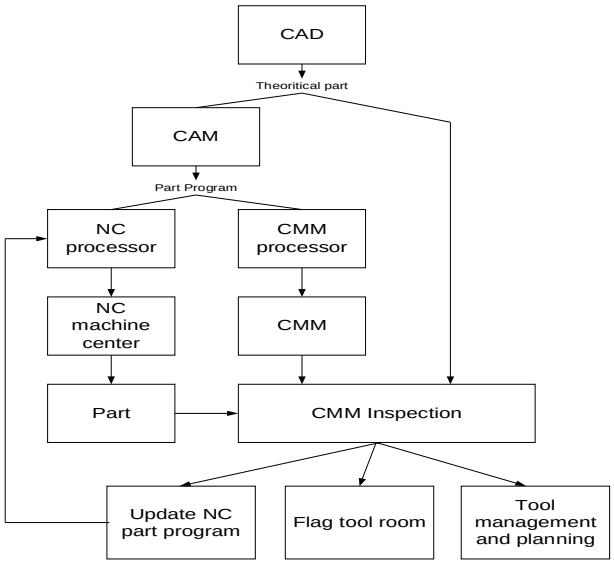
Data flow between CAD/CAM system and CMM



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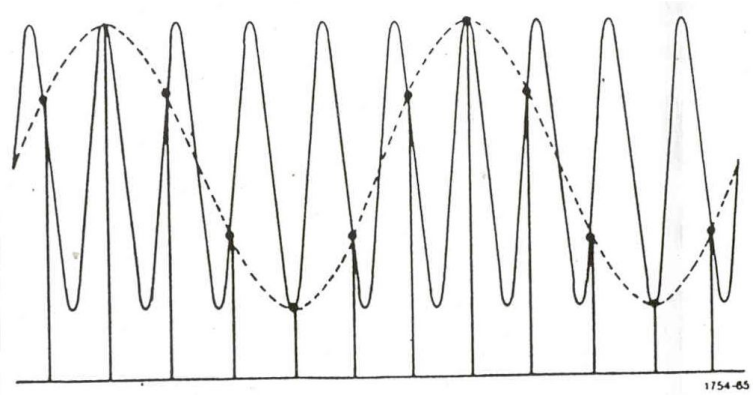
Example of insufficient sampling



Insufficient sampling of a high-frequency component results in a low-frequency alias

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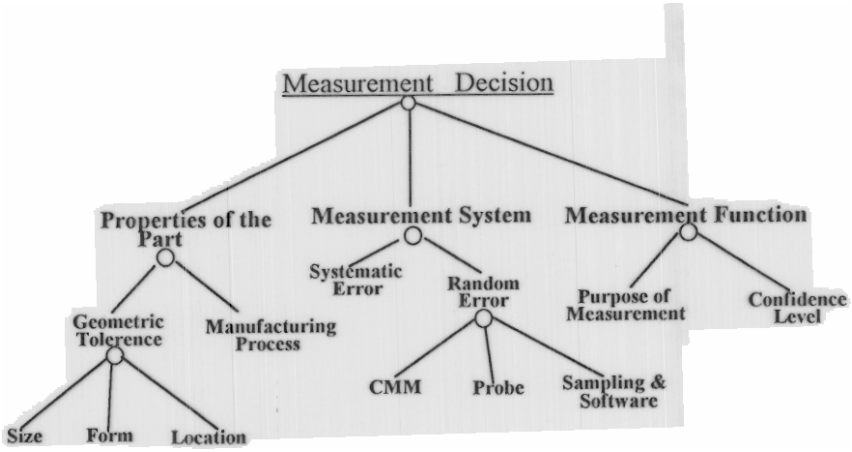

Element	Minimum Number of Points Mathematical	Recommended	Comments Regarding Minimum Number of Points
Line	2	5	
Plane	3	9	Approximately three lines of three points.
Circle	3	7	To detect upto six lobes.
Sphere	4	9	Aproximately three circles of three in parallel planes.
Cylinder	5	12	Circles in four planes for information on straightness.
		15	Five points on each circle for information on roundness.
Cone	6	12	Circles in four planes for information on straightness.
		15	Five points on each circle for information on roundness.

Optical principles

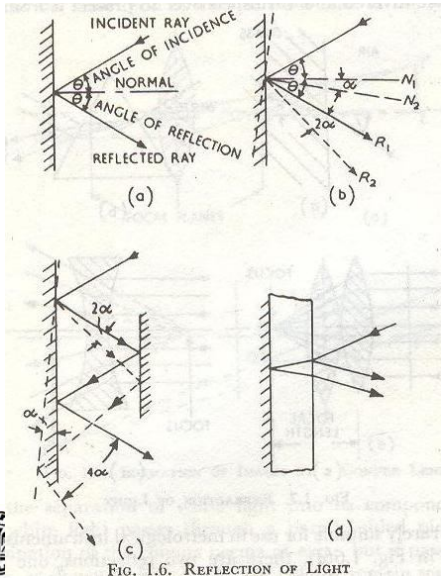

FIG. 1.6. REFLECTION OF LIGHT

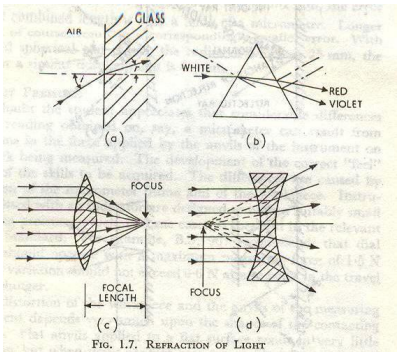

FIG. 1.7. REFRACTION OF LIGHT

Optical principles

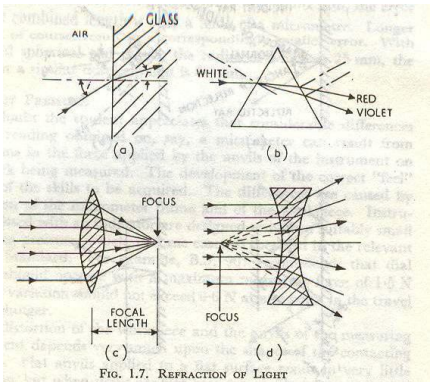

FIG. 1.7. REFRACTION OF LIGHT

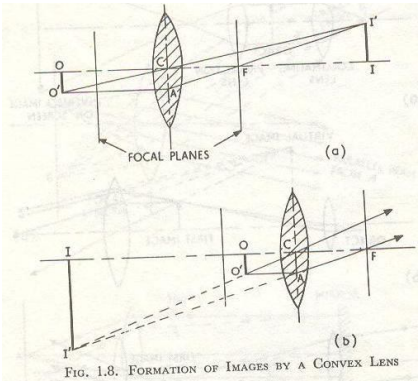

FIG. 1.8. FORMATION OF IMAGES BY A CONVEX LENS

Optical principles

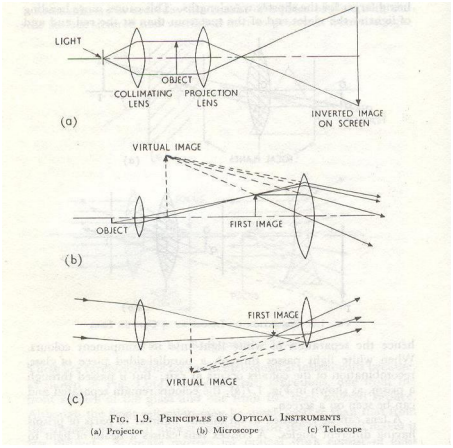

FIG. 1.9. PRINCIPLES OF OPTICAL INSTRUMENTS
(a) Projector (b) Microscope (c) Telescope

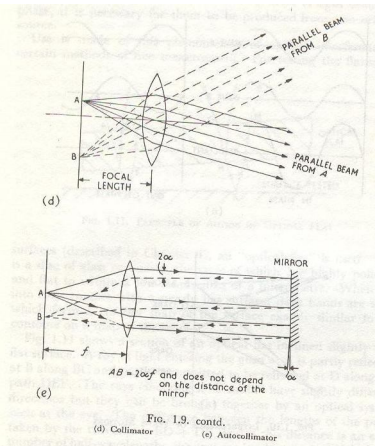

FIG. 1.9. contd.
(d) Collimator (e) Autocollimator

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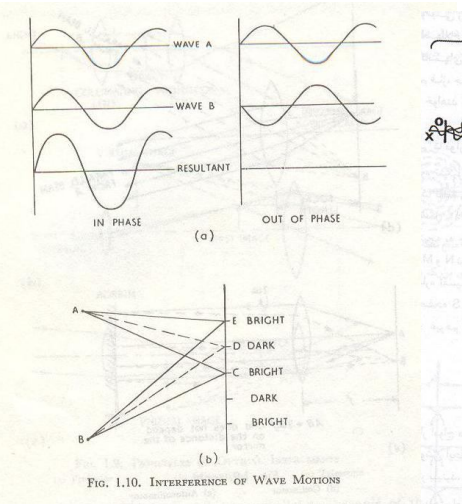
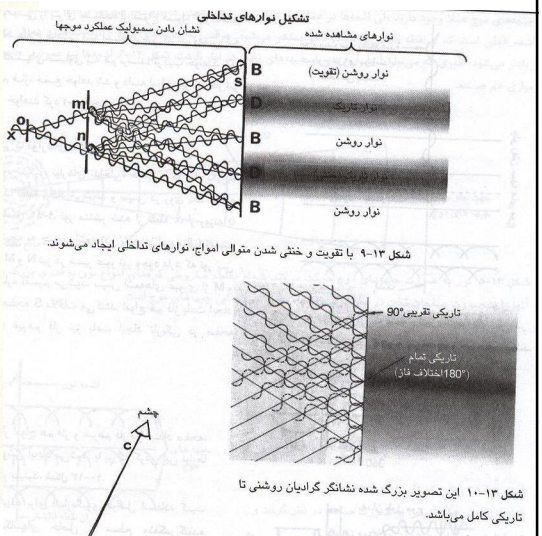


FIG. 1.10. INTERFERENCE OF WAVE MOTIONS



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Objectives

- Check pieces for size, flatness, and parallelism using optical flats
- Describe the operation of a laser interferometer
- Explain the application of lasers to measurement

Measuring with Light Waves

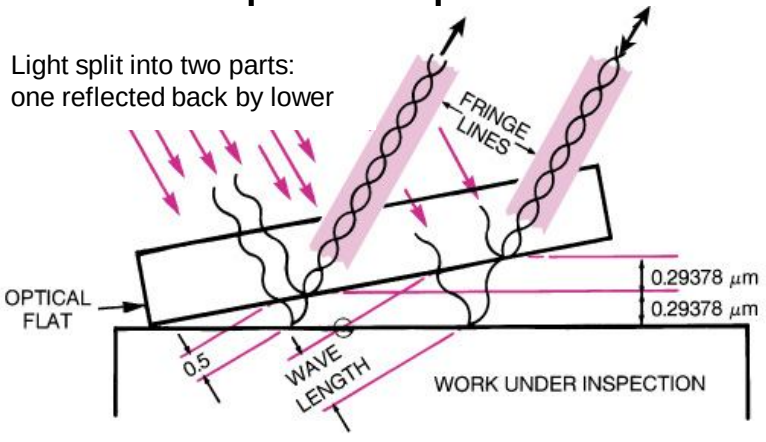
- Two most precise measuring methods
  - Optical flats
  - Laser
- Both use source of monochromatic light to produce highly accurate measurements

Optical flat and helium light source

Optical Flats

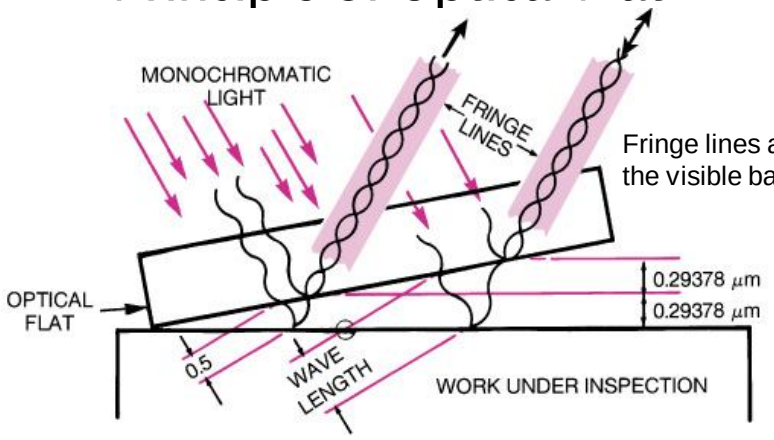
- Used with monochromatic light to check work for flatness, parallelism and size
- Disks of clear fused quartz, lapped to within few millionths of an inch of flatness
- Used with helium light source
  - Produces greenish-yellow light 23.1323 μin.

Principle of Optical Flat



Optical flat, perfectly flat, transparent disk, placed on surface of work. Surface adjacent ot workpiece is transparent and capable of reflecting light.

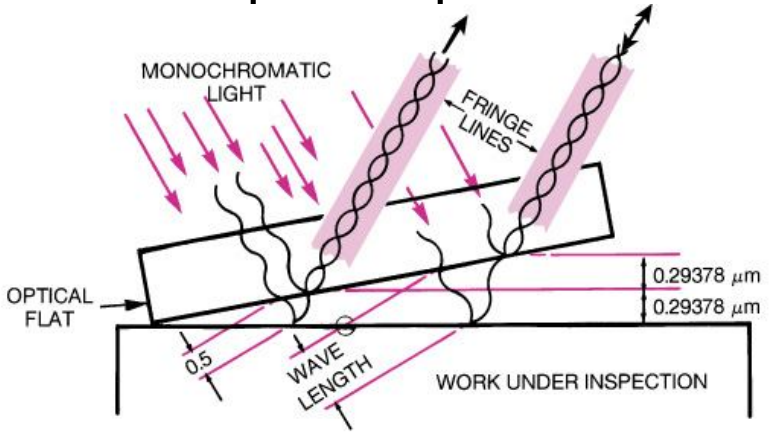
Principle of Optical Flat



Fringe lines are the visible bands.

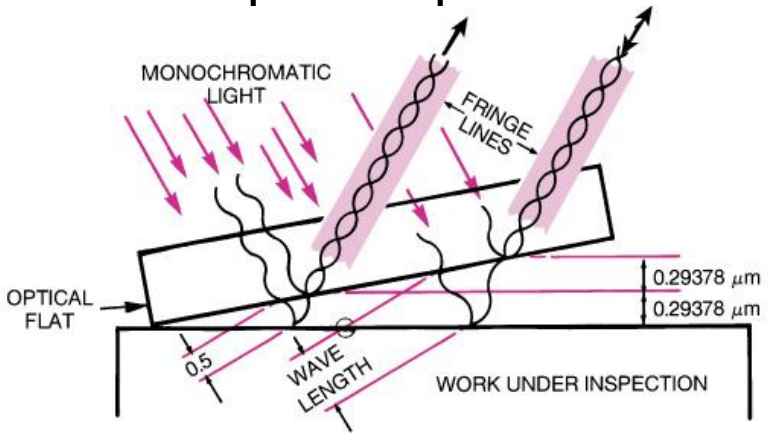
Light split into two parts:one reflected back by lower surface of flat and other reflected by upper surface of work. When two light waves cross each other (interfere) they become visible.

Principle of Optical Flat



The fringe lines occurs whenever distance between lower surface of flat and upper surface of workpiece is only ½ of a wavelength or multiples thereof.

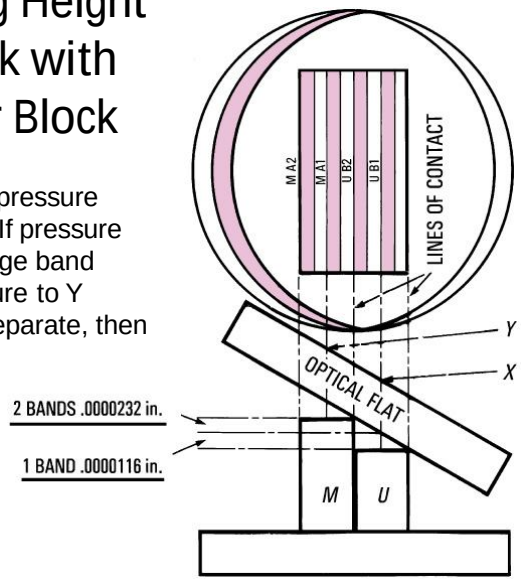
Principle of Optical Flat



Wavelength of helium light is 23.1323 μin, therefore ½ = 11.6 μin
Each dark band represents a progression of 11.6 μin.

Checking Height of Block with Master Block

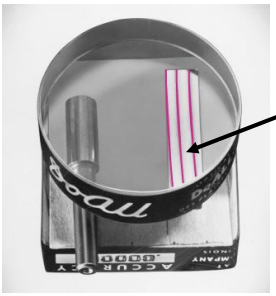
By applying finger pressure to points X and Y. If pressure at X does not change band pattern, and pressure to Y causes bands to separate, then master block larger.



How to Interpret the Bands

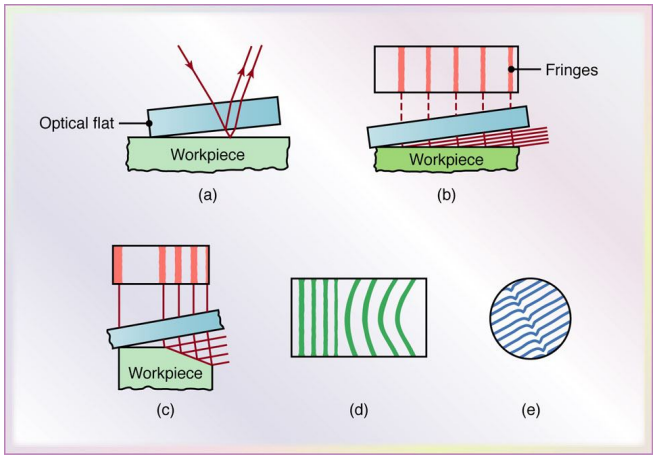
Two bands appear on master, so workpiece is 2 x 11.6 µin. out of flat

Three bands on master and six bands on unknown block. More bands = smaller. Lines slope down so left side of block lower by one-half band



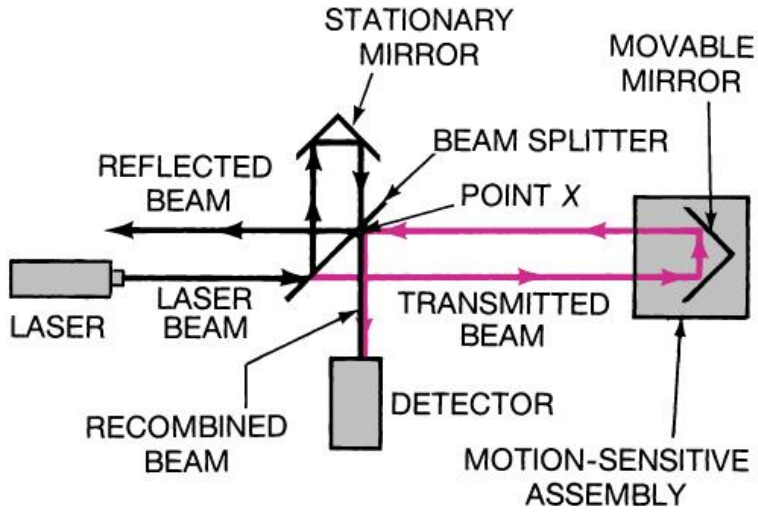
Curve on band shows workpiece not exactly parallel

Measuring Flatness



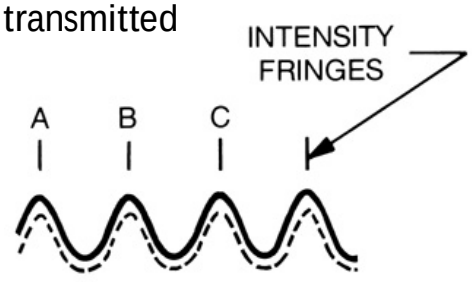
(a) Interferometry method for measuring flatness using an optical flat. (b) Fringes on a flat, inclined surface. An optical flat resting on a perfectly flat workpiece surface will not split the light beam, and no fringes will be present. (c) Fringes on a surface with two inclinations. *Note*: the greater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

Interferometer



Interferometer Principle

- Laser beam split into two parts by beam splitter
- One beam transmitted to motion-sensitive mirror then back so beams rejoin
- Recombined beams transmitted to detector
- Both portions in same phase then accurate



Interferometer Principle

- Any movement at sensitive mirror, beam reflected will be altered and fluctuate out of phase with other beam
- Number of fluctuations computed relative to laser wavelength
- Used widely
  - Precise linear measurement and alignment
  - Calibrate precision machines and measuring devices
  - Construction and surveying
  - Space and military: Distance, missile guidance, etc.

Lasermike (Optical micrometer)

- Heart of instrument is helium-neon laser beam projected in straight line with no diffusion
- Beam directed to mirrors, mirrors "scan" laser beam through lens which aligns beams in parallel and project them toward receiving lens
- Object placed in center of laser beam, creates shadow segment in scan path, detected by photocell
- High-frequency crystal clock times interval between edges and converts time to linear dimensions

Optical Comparator

Optical comparator is a non contact inspection instrument that applies the principle of optics to magnify and project the image of an inspected part. Optical inspection instruments allow the inspection of a part while the part is actually moving and being machined on the machine tool. Light source emits light beam that travels through prism and projects the shadow of an object onto a screen a few feet away so it can be compared with a chart showing tolerance levels for the part

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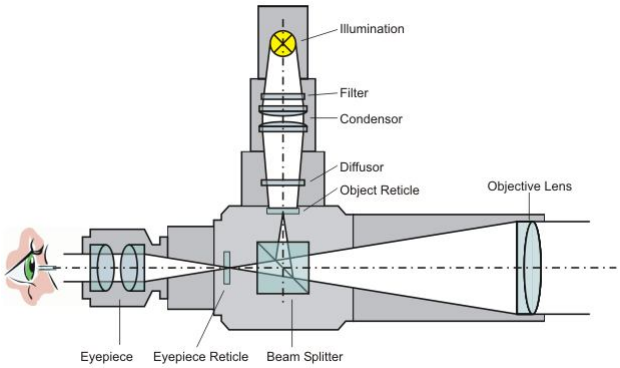
The autocollimator



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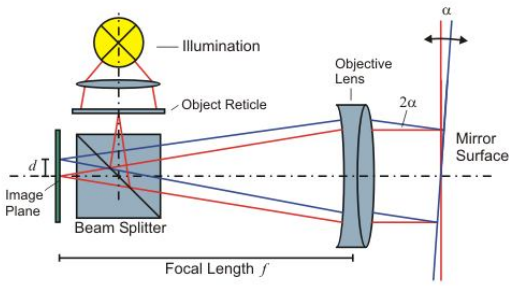
The autocollimator



Autocollimator combines both optical tools, the collimator and the telescope into one instrument using a single objective lens. Both beam paths are separated by using a beam splitter. The autocollimator is a very sensitive angle measuring device and is thus used for the precise angular adjustment of optical or machine components. Due to the collimated beam (infinity adjustment) the measurement results are independent from the distance to the object under test.

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