Coordinate Measuring Machines
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

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
Coordinate-Measuring Machine

(a) Schematic illustration of a coordinate-measuring machine

Types of CMM

Fixed Table Cantilever Coordinate Measuring Machine  Moving Bridge Coordinate Measuring Machine
Types of CMM

Fixed Bridge Coordinate Measuring Machine

Column Coordinate Measuring Machine

Moving Ram Horizontal Arm Coordinate Measuring Machine

Moving Table Horizontal Arm Coordinate Measuring Machine
Types of CMM

Gantry Coordinate Measuring Machine

L-shaped Bridge Coordinate Measuring Machine

Types of CMM

Fixed Table Horizontal Arm Coordinate Measuring Machine

Moving Table Cantilever Arm Coordinate Measuring Machine
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.

Coordinate-Measuring Machine

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

- Switching probe system
- Continuous measuring probe system
- Kinematic touch trigger probe

Proximity Sensor

\[ x = 0.5 \, y \, \tan(A) \]
**Diffracto Non-contact Laser Probe**

- **Laser Light Source**
- **Digital Solid-state sensor**
- **Lens**
- **Measuring Range**
- **SURFACE**
- **30°**

**Automatic Axis Alignment**

- $X_w, Y_w, Z_w$ – Work piece related coordinate system
- $X_M, Y_M, Z_M$ – Machine related coordinate system
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.

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.
## Calculated Solution - Distance

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>RELATION</th>
<th>EXAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>$d_{p_1}$</td>
<td>Distance between two points</td>
<td><img src="image1" alt="Distance between two points" /></td>
</tr>
<tr>
<td>$d_{p_1}$</td>
<td>Shortest distance point to line</td>
<td><img src="image2" alt="Shortest distance point to line" /></td>
</tr>
<tr>
<td>$d_{L_1}$</td>
<td>Shortest distance between two lines</td>
<td><img src="image3" alt="Shortest distance between two lines" /></td>
</tr>
<tr>
<td>$d_{p_1}$</td>
<td>Shortest distance point to plane</td>
<td><img src="image4" alt="Shortest distance point to plane" /></td>
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</table>

### Calculated Solution - Distance

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</thead>
<tbody>
<tr>
<td>$d_{c}$</td>
<td>Distance between point and circular feature</td>
<td><img src="image5" alt="Distance between point and circular feature" /></td>
</tr>
<tr>
<td>$d_{c}$</td>
<td>Distance between point and nearest point on circular feature</td>
<td><img src="image6" alt="Distance between point and nearest point on circular feature" /></td>
</tr>
<tr>
<td>$d_{c}$</td>
<td>Shortest distance between line and circular feature</td>
<td><img src="image7" alt="Shortest distance between line and circular feature" /></td>
</tr>
<tr>
<td>$d_{c}$</td>
<td>Shortest distance between two circular features</td>
<td><img src="image8" alt="Shortest distance between two circular features" /></td>
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</tbody>
</table>
### Calculated Solutions - Angle

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>RELATION</th>
<th>EXAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>L₁₂</td>
<td>Angle between two lines</td>
<td><img src="angle_example.png" alt="Example" /></td>
</tr>
<tr>
<td>L₁₂</td>
<td>Angle between line and plane</td>
<td><img src="line_angle_example.png" alt="Example" /></td>
</tr>
<tr>
<td>PL₁₂</td>
<td>Acute angles between two planes</td>
<td><img src="plane_angle_example.png" alt="Example" /></td>
</tr>
</tbody>
</table>

### Calculated Solutions - Plane

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>RELATION</th>
<th>EXAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PL</td>
<td>Plane by three points</td>
<td><img src="plane_three_points.png" alt="Example" /></td>
</tr>
<tr>
<td>PL</td>
<td>Average plane defined by 4 to 20 points</td>
<td><img src="plane_average_points.png" alt="Example" /></td>
</tr>
</tbody>
</table>
### Calculated Solutions - Circle

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>RELATION</th>
<th>EXAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="symbol1.png" alt="Circle" /></td>
<td>Circle by three points</td>
<td><img src="example1.png" alt="Example1" /></td>
</tr>
<tr>
<td><img src="symbol2.png" alt="Circle" /></td>
<td>Average circle defined by 4 to 20 points</td>
<td><img src="example2.png" alt="Example2" /></td>
</tr>
</tbody>
</table>

### Calculated Solutions - Cylinder

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>RELATION</th>
<th>EXAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="symbol1.png" alt="Average Cylinder" /></td>
<td>Average cylinder defined by 6 to 20 points</td>
<td><img src="example1.png" alt="Example1" /></td>
</tr>
</tbody>
</table>
### Calculated Solutions - Sphere

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>RELATION</th>
<th>EXAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sphere by 4 points</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average sphere defined by 5 to 20 points</td>
<td></td>
</tr>
</tbody>
</table>

### Calculated Solutions - Cone

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>RELATION</th>
<th>EXAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Construction of a cone by 6 to 20 points</td>
<td></td>
</tr>
</tbody>
</table>
Data flow between CAD/CAM system and CMM

- CAD
  - Theoretical part
  - CAM
    - Part Program
    - NC processor
      - NC machine center
      - Part
        - CMM
          - CMM processor
          - CMM
            - CMM Inspection
              - Update NC part program
            - CMM
              - Flag tool room
              - Tool management and planning

Example of insufficient sampling

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

**Dep. of Mech. Eng.**

**Property of the Part**
- Geometric Tolerance
- Manufacturing Process

**Measurement System**
- Systematic Error
- Random Error
- CMM
- Probe
- Sampling & Software

**Measurement Function**
- Purpose of Measurement
- Confidence Level

**Decision**

### Table: Minimum Number of Points

<table>
<thead>
<tr>
<th>Element</th>
<th>Mathematical</th>
<th>Recommended</th>
<th>Comments Regarding Minimum Number of Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line</td>
<td>2</td>
<td>5</td>
<td>Approximately three lines of three points.</td>
</tr>
<tr>
<td>Plane</td>
<td>3</td>
<td>9</td>
<td>To detect up to six lobes.</td>
</tr>
<tr>
<td>Circle</td>
<td>3</td>
<td>7</td>
<td>Approximately three circles of three in parallel planes.</td>
</tr>
<tr>
<td>Sphere</td>
<td>4</td>
<td>9</td>
<td>Circles in four planes for information on straightness.</td>
</tr>
<tr>
<td>Cylinder</td>
<td>5</td>
<td>12</td>
<td>Five points on each circle for information on roundness.</td>
</tr>
<tr>
<td>Cone</td>
<td>6</td>
<td>12</td>
<td>Circles in four planes for information on straightness.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15</td>
<td>Five points on each circle for information on roundness.</td>
</tr>
</tbody>
</table>
Optical principles

Optical principles
Optical principles

Mohsen Badrossamay


Dimensional Metrology

اصول تداخل سنجی

Mohsen Badrossamay

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 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

Light split into two parts: one reflected back by lower 

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

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

Fringe lines are the visible bands.

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 is 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 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.

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.