



Experiment no. 04
Coordinate Measuring Machine (CMM)

Conventional measuring devices



Micrometer



Dial indicator



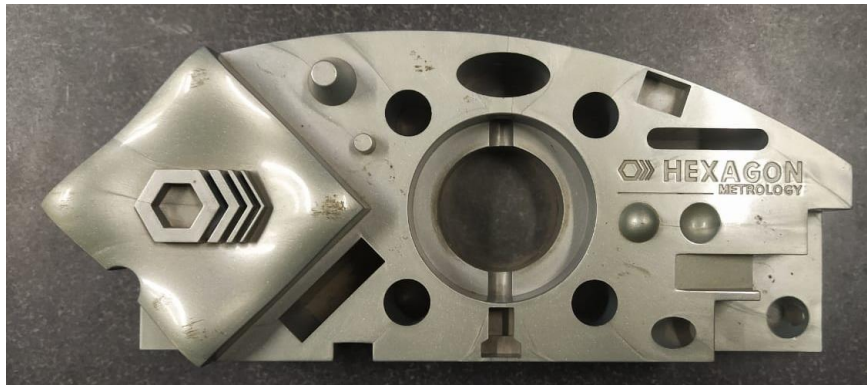
Ring Gauge



Sine bar



Plug Gauge



Object

Drawbacks

1. Can measure a single feature
2. Time consuming
3. Limited range
4. Error in measurement
 - Human Error
 - Corrosion in instrument
 - Manufacturing Error
 - Environmental Error

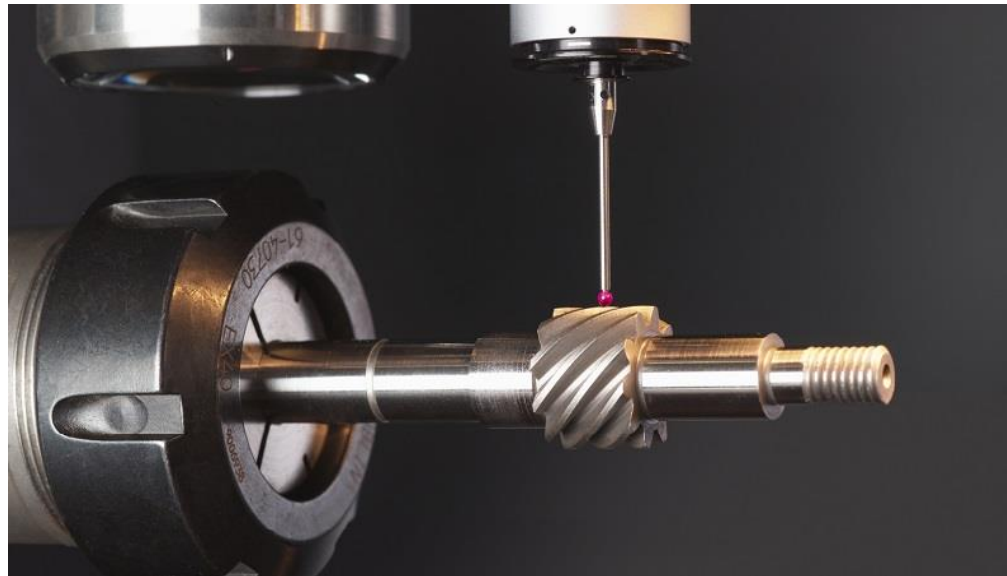
Coordinate Measuring Machine (CMM)

- A 3D device to measure the *physical geometrical characteristics* of an object.
- It finds the *coordinates* of points on a work surface and then calculates the dimension in mathematical forms.
- CMM has 3 axes which are orthogonal to each other.
- Measurements are made by probe (a sensing device) attached to the Z-axis of machine.

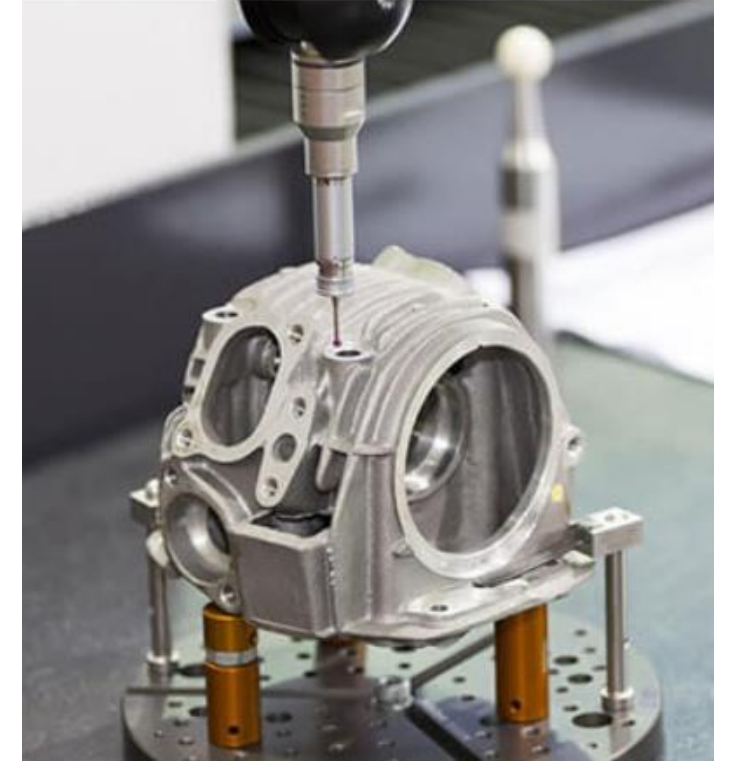


Advantage of CMM over conventional devices

- It can measure complex and large components.
- Many geometrical features can be measure through the same probe in CMM.
- Faster than conventional devices.
- Very accurate.



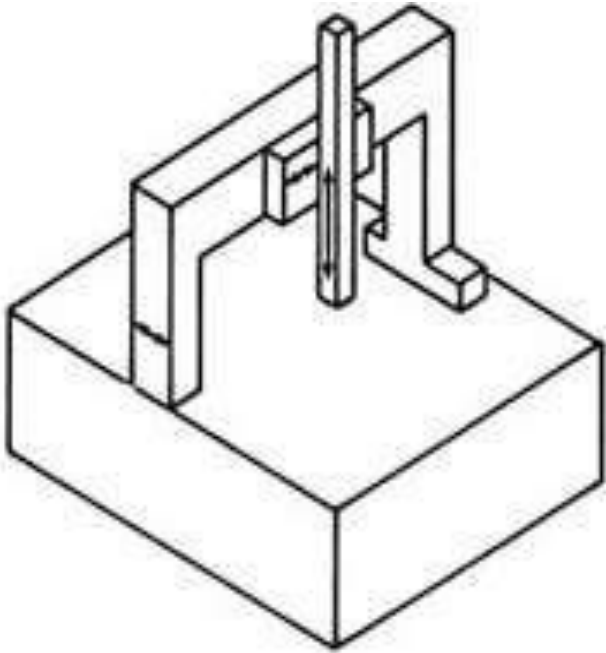
<https://metrology.news/multi-sensor-cmm-gear-measurement-software/>



<https://www.3erp.com/blog/everything-about-coordinate-measuring-machine/>

Types of CMM

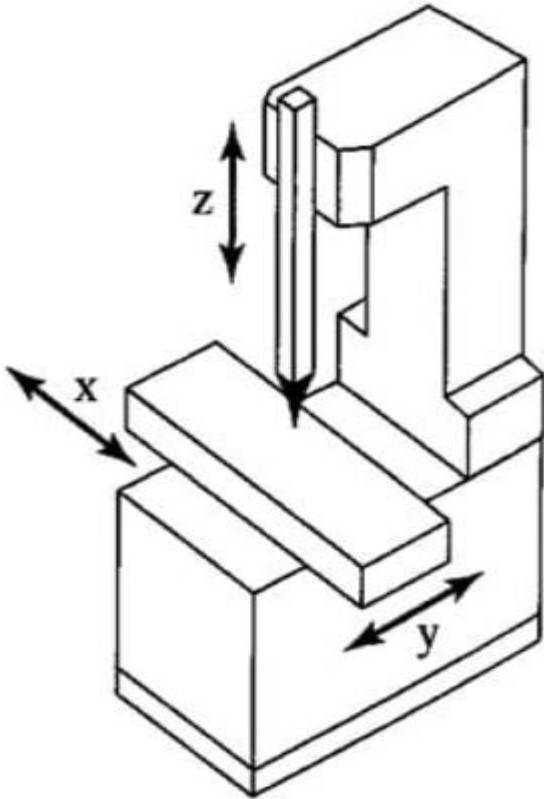
1. Moving bridge type



- Most widely used CMM.
- Has stationary table to support work piece to be measured and a moving bridge.
- Good rigidity owing to compact bridge design, thus small measuring deviations.
- *More accuracy.*
- *Medium to large measuring range.*
- *Limited accessibility due to the bridge.*

Types of CMM Contd...

2. Cantilever type

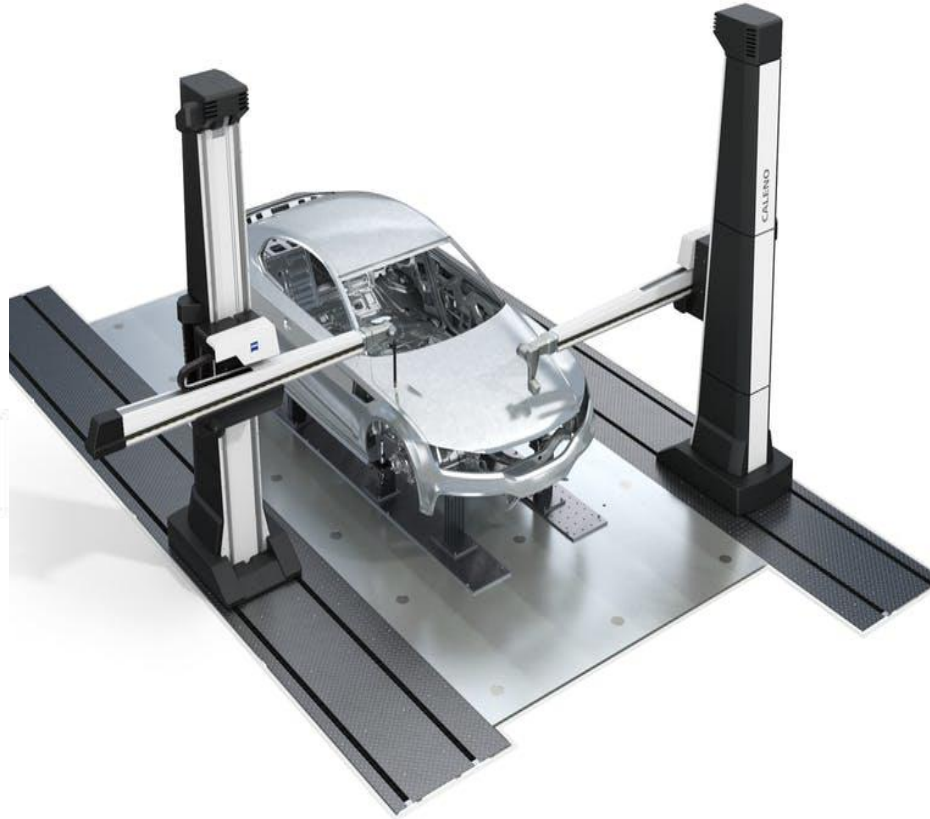
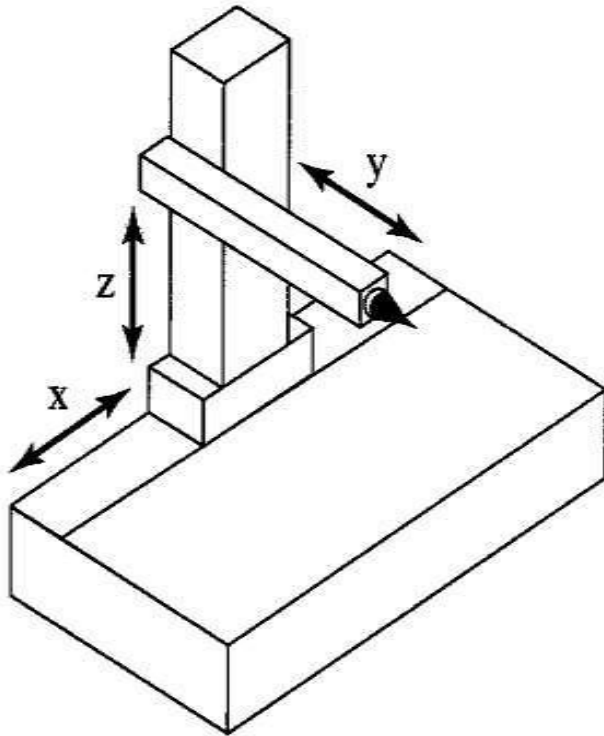


Courtesy: <https://www.hexagonmi.com/en-gb/products/coordinate-measuring-machines/shop-floor-cmms/tigo-sf>

- Easy access and *precision measurement*.
- Small space requirement.
- Limited to small and medium sized machines.
- Parts larger than the machine table can be inserted into the open side without inhabiting full machine travel.

Types of CMM Contd...

3. Horizontal arm

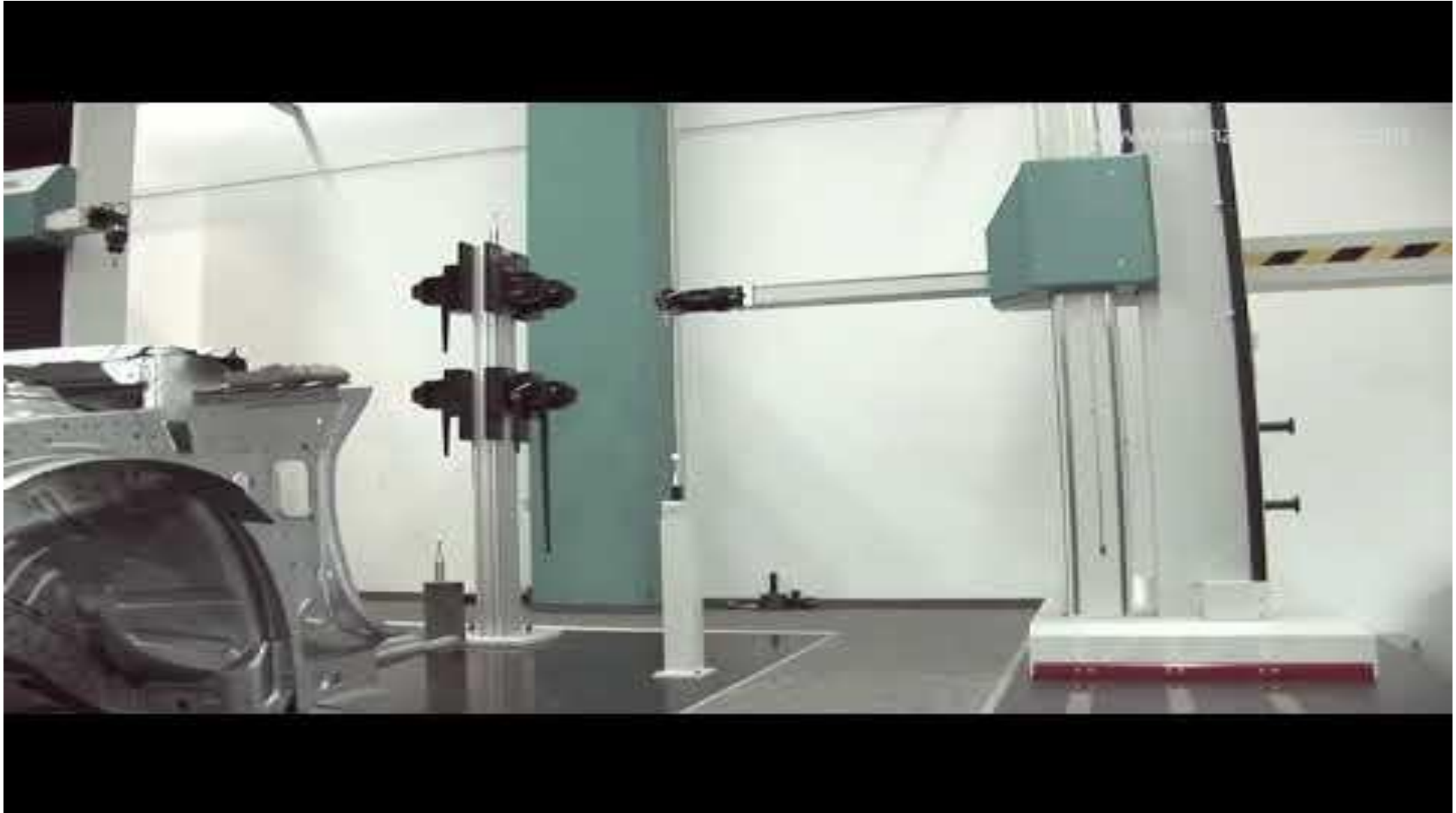


Courtesy:

<https://www.zeiss.com/metrology/products/systems/coordinate-measuring-machines/horizontal-arm-cmms/caleno.html>

- It has an overhanging arm which supports the probe head.
- Designed for large work piece.
- Suitable for measuring large objects such as dies, car bodies, etc.
- *Maximum accessibility.*
- *Low accuracy.*

Horizontal arm CMM



Courtesy: <https://www.youtube.com/watch?v=uxkmgVJmci0>

Types of CMM Contd...

4. Gantry type



Courtesy:
<https://accurategauging.com/products/gantry-type-cmm/>



Courtesy:
<http://www.leadssailmetrology.com/cmm/navigator-series-gantry-type-coordinate.html>

- Suitable for measurement of very large components.
- Probe head is held by fixed supports.
- This setup allows to walk along the work piece with the probe, which is helpful for extremely large pieces.

Gantry type CMM

The image shows the letters 'CMM' in a large, bold, blue, sans-serif font. The letters are centered horizontally and vertically against a solid black background. The 'C' is a simple open circle, while the 'M's are composed of thick vertical and diagonal strokes.

Types of CMM Contd...

5. Portable CMM



- Manually operated: Easy to operate.
- Compute the coordinate from the rotary position of each joint and the known length between joints.
- The accuracy of this CMM is low, but it can be used where the portability is the biggest criteria.

*Traditional CMMs are strictly used for quality inspection, whereas portable CMMs can be used for other applications including **reverse engineering** and **rapid prototyping**.*

Courtesy: <https://gomeasure3d.com/blog/common-questions-portable-cmms/>

Reverse engineering through Portable CMM

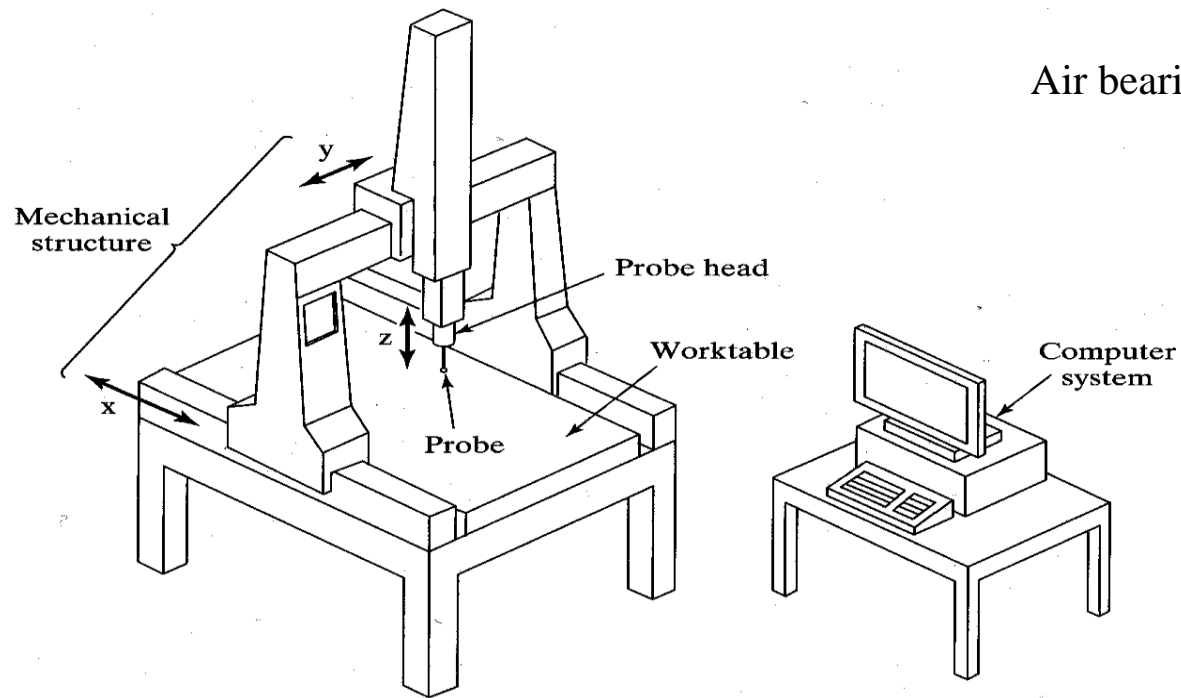


Different CMM and their characteristic

CMM Type	Accuracy	Best used for measuring	Application areas
Bridge	High	Medium to large component requiring high accuracy	Alloy wheel of automobile, combustion-chamber
Cantilever	Highest	Smaller components requiring very high accuracy	Precision instruments, Gauges and master parts
Horizontal arm	Low	Large components requiring low accuracy	Automotive body parts, Sheet metal, shipbuilding construction
Gantry	High	Very large components requiring high accuracy	Car body, turbine, very large machine construction
Portable arm type	Lowest	When portability is absolutely the biggest criteria	Reverse engineering, Rapid prototyping

Parts of CMM

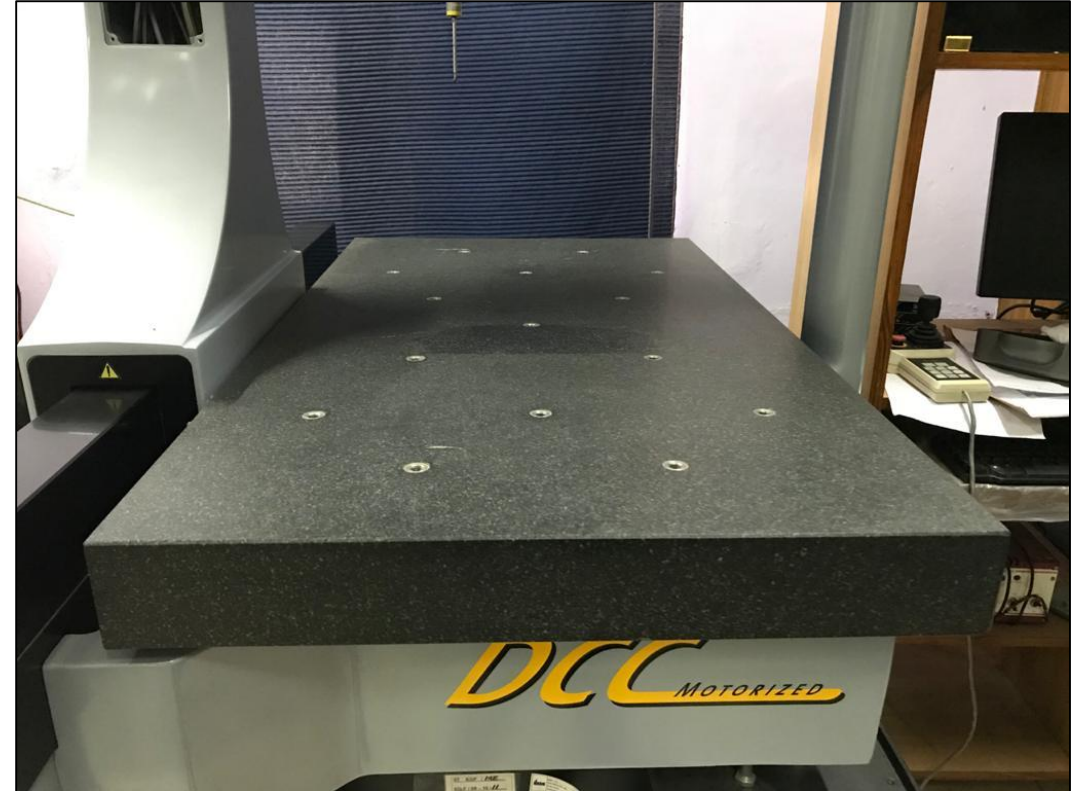
1. Main structure
2. Probing System
3. Data collection system



Main Structure

1. Machine Bed - Granite Table (Structurally and thermally stable material)

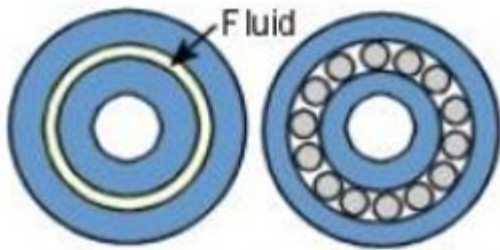
- Low Porosity
- Low moisture absorption
- Low coefficient of thermal expansion
- Superior strength
- Uniformity of texture



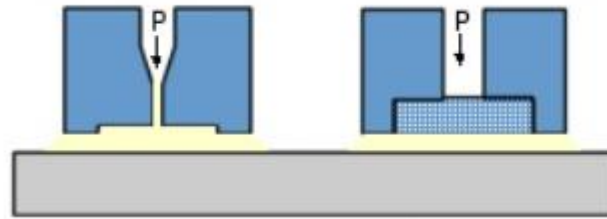
Main Structure Contd...

2. Air Bearings

- Provided for ensuring friction free travel.
- Compressed air is forced through a series of small holes in a flat bearing surface to provide a smooth and controlled *air cushion* on which the CMM can move in a frictionless manner.

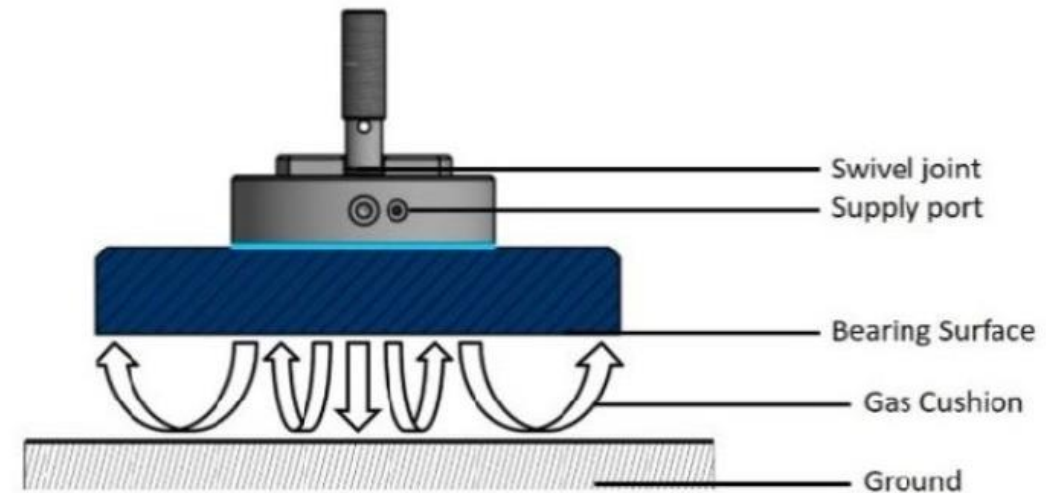


Fluid bearing & ball bearing



Orifice feeding and porous media feeding

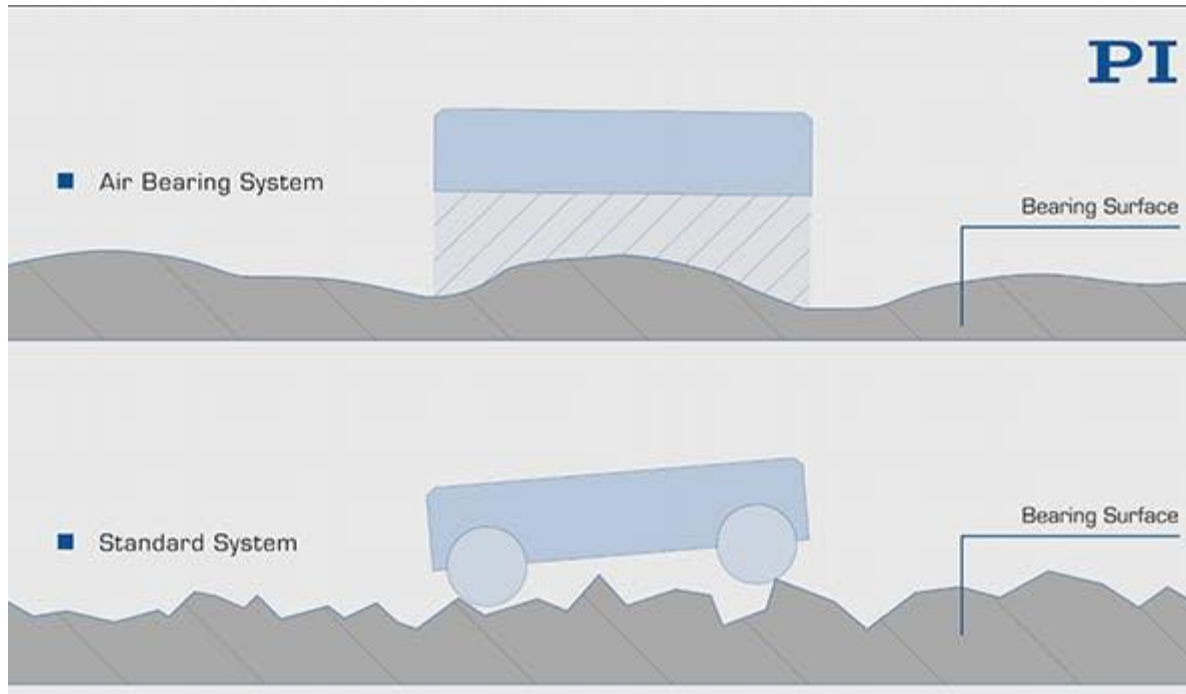
Courtesy: http://www.nelsonair.com/NA_primer.htm



Plane air bearing

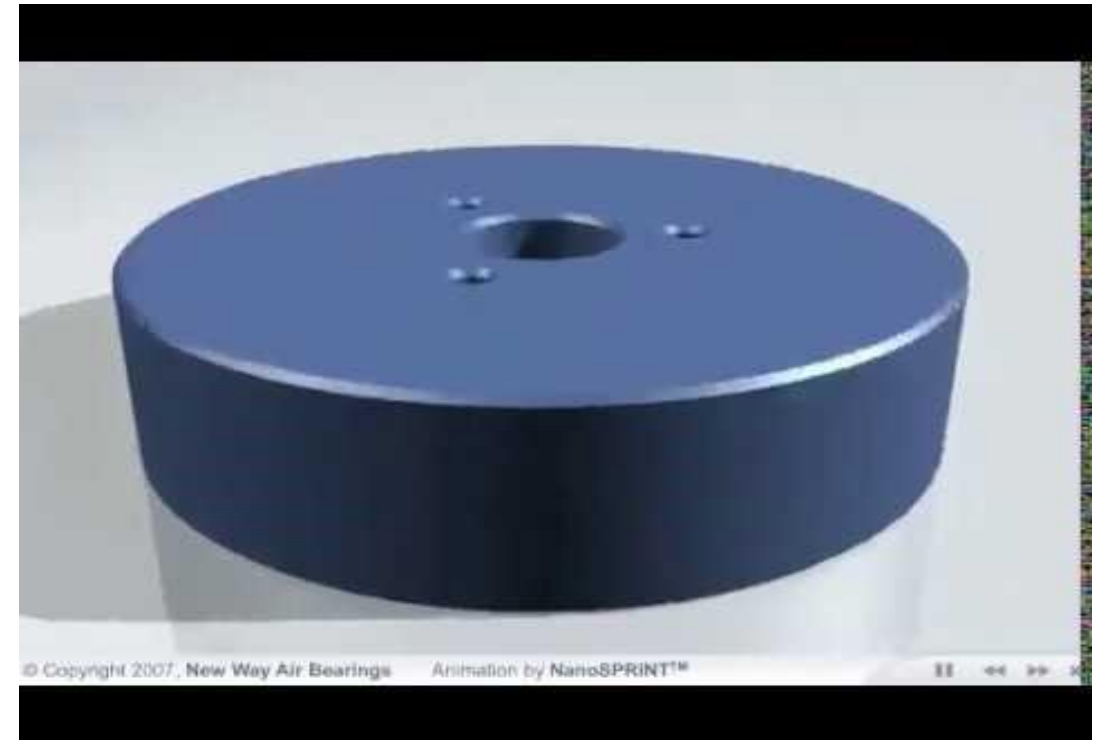
Courtesy:
https://www.researchgate.net/publication/318216975_An_Experimental_Platform_for_Multi-spacecraft_Phase-Array_Communications/figures?lo=1

Air bearing Contd...



Air bearing and ball bearing

Courtesy: <https://www.machinedesign.com/mechanical-motion-systems/bearings/article/21831998/advantages-of-air-bearings>



Plane air bearing

Courtesy: <https://youtu.be/znUEXvVTM-I?>

Probing System

Two general categories:

- **Contact Type**

- Touch trigger Probe
- Analog scanning Probe

- **Non Contact Type**

(For inspection of printed circuit board, measuring a clay or wax model, it reduces the risk of damaging probe's stylus or the work piece itself)

- Laser Probe
- Video Probe

1. *Co-ordinate measuring machine ram (or spindle).*

2. *Probe extension.*

3. *Probe changing system.*

4. *Probe.*

5. *Stylus changing system*

6. *Stylus extension*

7. *Stylus shaft.*

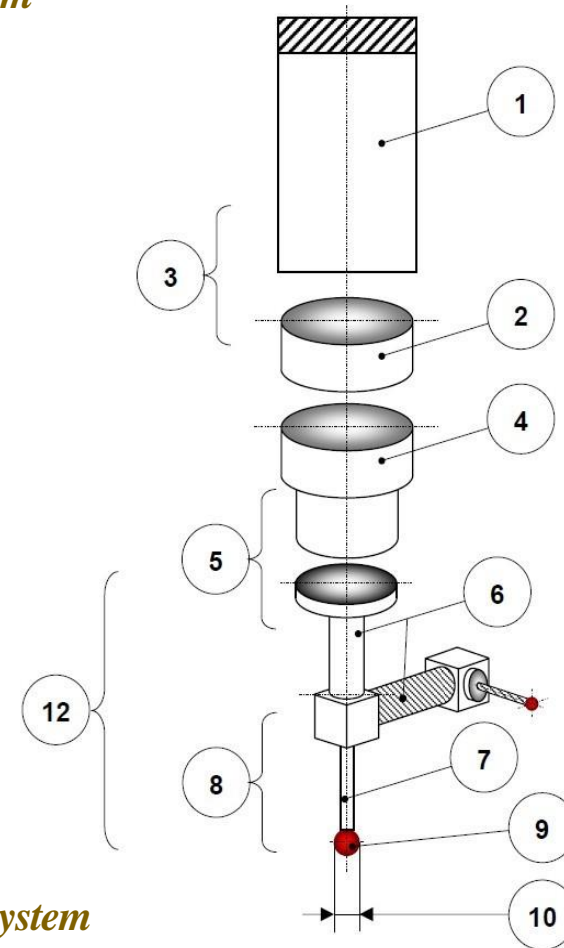
8. *Stylus.*

9. *Stylus tip.*

10. *Tip diameter.*

11. *Generic, fixed probing system.*

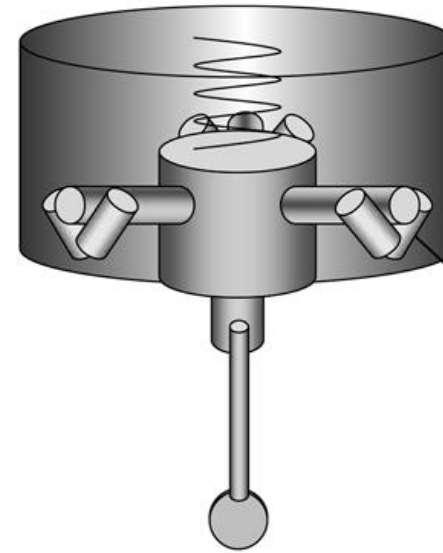
12. *Stylus system (composed of stylus system components).*



Contact Type Probes

Touch trigger probe

- As the sensor makes contact with the part, the difference in contact resistance indicates that the probe has been deflected.
- The computer records this contact point coordinate space.
- An LED light and an audible signal usually indicate contact.
- Touch probe assemblies consist of three components; probe head, probe and stylus.
- **Used where superior accuracy is top priority.**



https://www.researchgate.net/publication/220410845_Factors_influencing_probing_accuracy_of_a_coordinate_measuring_machine/figures?lo=1

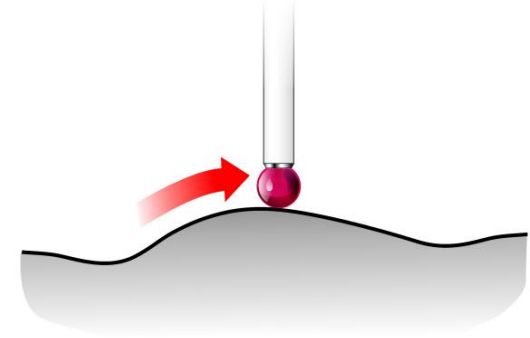


Courtesy: <https://youtu.be/vJdcbhGa7Jk>

Contact Type Probes Contd...

Analog scanning probe

- Remains in contact with the surface of the part as it moves.
- Continuously records the points by moving the ball over the surface.
- Improve the speed and accuracy.
- Use to measure tight fit tolerance parts, complex parts, contour and irregular surfaces.



Scanning of irregular surface



Courtesy: <https://youtu.be/ve0vsm-CvUA>

Non - Contact Type Probes

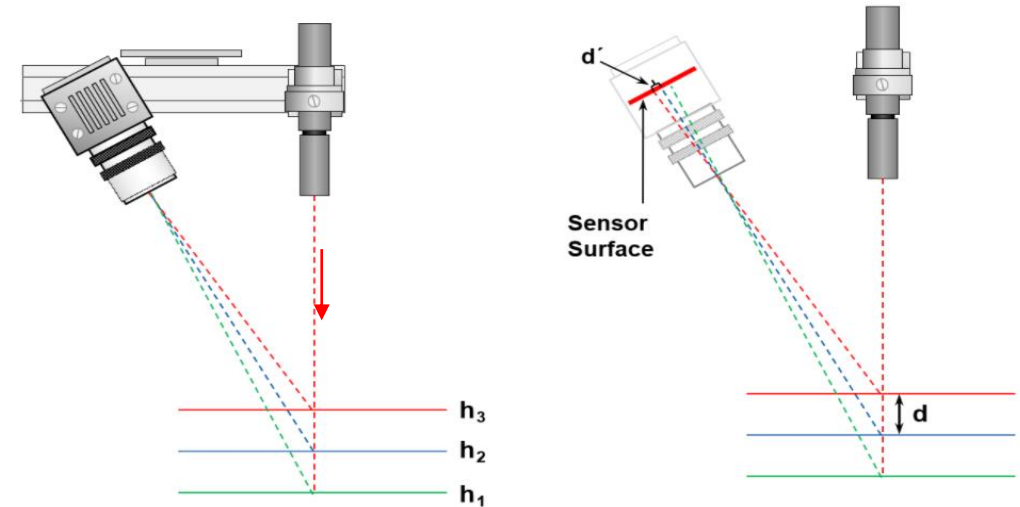
Laser scanning probe

- Laser probes project a concentrated light beam onto the surface of a part.
- When the light beam is triggered, the position is read by *triangulation* through a lens in the probe receptor.
- Laser tool have a high degree of speed and accuracy.



Laser scanner probe

Courtesy: <https://www.sariki.es/en/measuring-equipment/3d-measurement/multisensor-probes/laser-scanner-probe/>



laser-triangulation

Courtesy :<https://www.movimed.com/knowledgebase/what-is-laser-triangulation/>

Laser scanning probe



Courtesy: https://youtu.be/Da5Nb09e_Zg

Non - Contact Type Probes Contd...

Video probe

- The probe is equipped with high resolution camera and a built in illumination system.
- The probe use laser locator or enhanced lighting for creating contrast for better edge definition.
- The feature are measured by computer by counting of the pixels of the electronic image.
- These probe are ideal for electronic and medical devices; precision components with micro holes.



Courtesy: <https://www.renishaw.com/en/revo-2-rvp-vision-probe--35452>



Courtesy: <https://www.hexagonmi.com/en-US/products/coordinate-measuring-machines/cmm-sensors/non-contact-sensors/hp-c-vision-sensor>



REVO fringe probe (RFP)

REVO® 5-axis multi-sensor measurement system

RENISHAW 

Different Types of Stylus

Straight Styli

- Used for Simple features.
- Short styli are preferred to avoid bending.

Star Shaped Styli

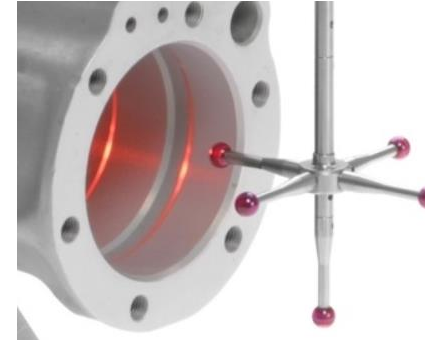
- Used for surfaces and holes that can be approached directly.
- Enhanced flexibility by featuring different probe without changing the stylus.

Disc Shaped Styli

- Disc of various diameter and thicknesses.
- Used for grooves in the bores, which are not accessible through other stylus.



Straight styli



Star styli



Disc styli

Courtesy: <https://www.thome-precision.com/Renishaw-styli.html#Kugeln>



Courtesy: <https://www.indiamart.com/proddetail/cmm-stylus-and-accessories-22330174691.html>

Different Types of Stylus Contd...

Cylindrical Styli

- Used for measuring thin sheet, pressed parts, where good contact with the spherical styli is not guaranteed.
- Used for the measurement of threaded holes.



Cylindrical Styli

Hemispherical Styli

- Large, effective ball diameter with minimal mass.
- For measuring deep features and bores.
- For probes on rough surfaces, as the roughness is mechanically filtered out by the large diameter area.



Hemispherical Styli

Shaft material of Stylus

Tungsten Carbide

- Exceptional stiffness.
- Used for small shaft.

Ceramic

- Used for long styli because ceramic have low weight.
- Thermally stable.

Steel

- Used where mass is not an important issue.
- Cost-effective.

Carbon fiber

- Used where thermal stability is an issue.
- Due to light weight it can be used for long shaft.
- It can be even used in the production environment (harsh environment).

Titanium

- Good flexural rigidity and very light weight.
- Suitable for long extensions.



Stylus shaft

Courtesy: <https://www.thome-precision.com/Renishaw-styli.html#Kugeln>

Stylus Ball Material

Ruby

- After diamond ruby is one of the hardest material.
- Ideal ball material due to exceptional wear resistance and high compressive strength.
- Not suitable for the heavy duty scanning application of *aluminum and cast iron*, due to **adhesive wear** and **abrasive wear** respectively.



Ruby

Silicon Nitride

- Ceramic material similar to ruby in terms of technical properties.
- Very good wear resistance.
- Best suited for the scanning aluminum surfaces, because it does not have attraction to the *aluminum*.



Silicon Nitride

Zirconium Oxide

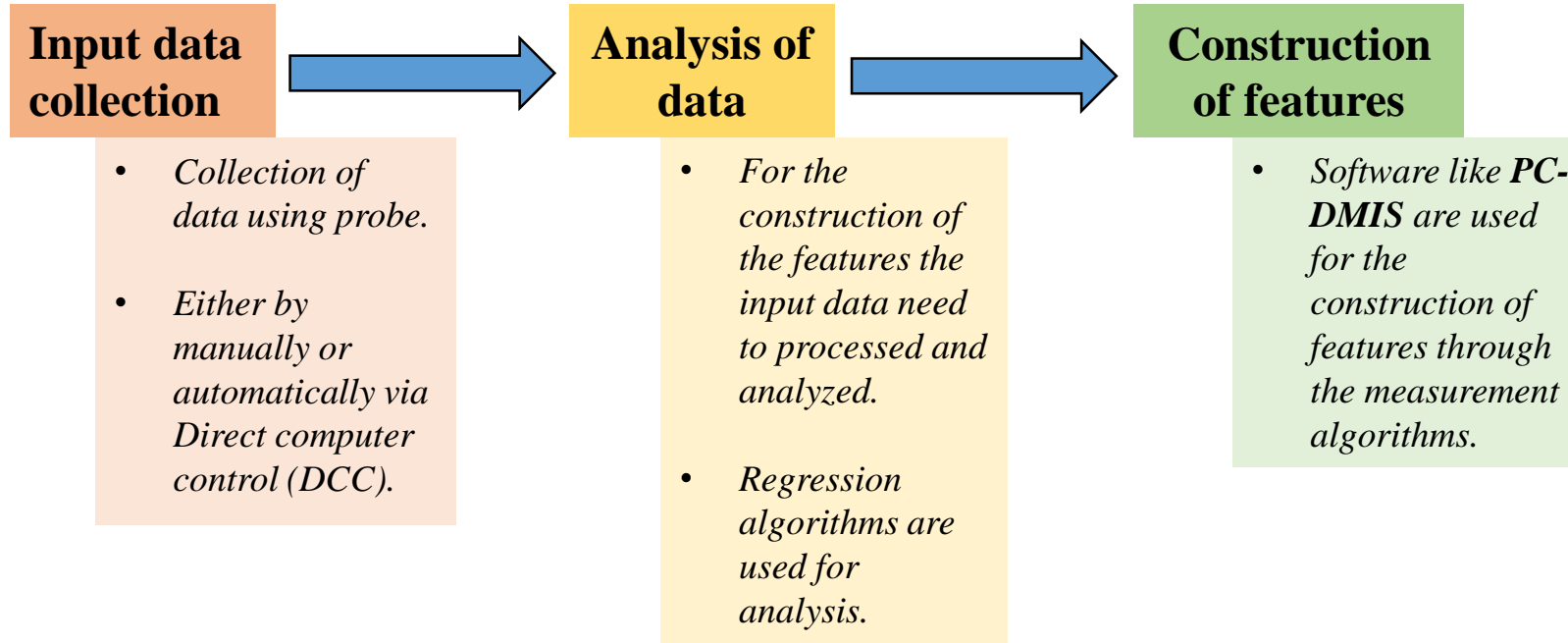
- Tough ceramic material with hardness and wear characteristics approaching those of ruby.
- Best suited for scanning abrasive surfaces like *cast iron*.



Zirconium Oxide

Courtesy: <https://www.renishaw.com/en/styli-materials--6423>

Data Collection System



Modes of Operation

1. Manual mode

- Free floating probe.
- Digital display to show data points.
- Software does the calculation.

2. Motorized computer assisted mode

- Joystick is used to drive machine axes.
- Digital display to show data points.
- Software does the calculation.

3. Direct computer controlled (DCC) mode

- Fully programmable.
- Uses taught locations of CAD data to decide where probe contacts the job and then collects measurement of data.
- Software does the calculation.



Application of CMM



Inspection of Aircraft Ribs, Hinges and Machined Parts

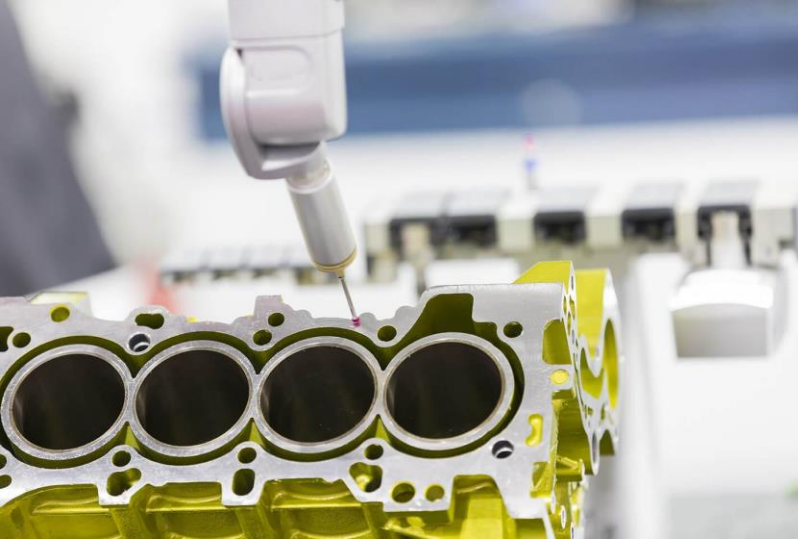
Courtesy: <https://www.hexagonmi.com/en-IN/solutions/industries/aerospace/aircraft-structure/inspection-of-aircraft-ribs-hinges-and-machined-parts>



Inspection of Aero Engine Gears and Transmission Components

<https://www.hexagonmi.com/en-IN/solutions/industries/aerospace/aero-engine/aero-engine-gear-and-transmission-component-inspection>

Application of CMM Contd...



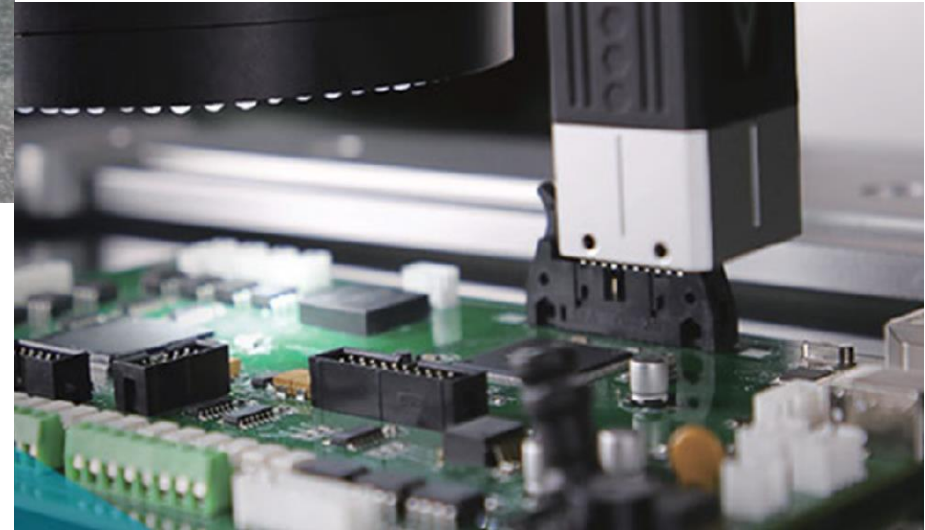
Automobile

<https://www.deva.co.uk/products/categories/automatic-cmm-solutions>



Precision Gear manufacturing

<https://develop3d.com/manufacture/BP-Riduttori-Hexagon-Metrology-measuring-machine-shifting-gears/>



Electronics

<https://metrology.news/hexagon-launches-new-entry-level-optical-cmm/>

Errors in CMM

- Error caused due to *thermal expansion*.
To avoid this error, the CMM needs to operate in a *controlled temperature environment*.
- Error caused due to *deflection during measurement*.
To avoid this error, the shaft must have *maximum stiffness*.
- Error caused due to *wearing of stylus ball*.
To avoid this error, *proper selection of the stylus ball material* as per the scanning material is required.

Calibration

To avoid any error, calibration through the master sphere is required before starting the measurements.



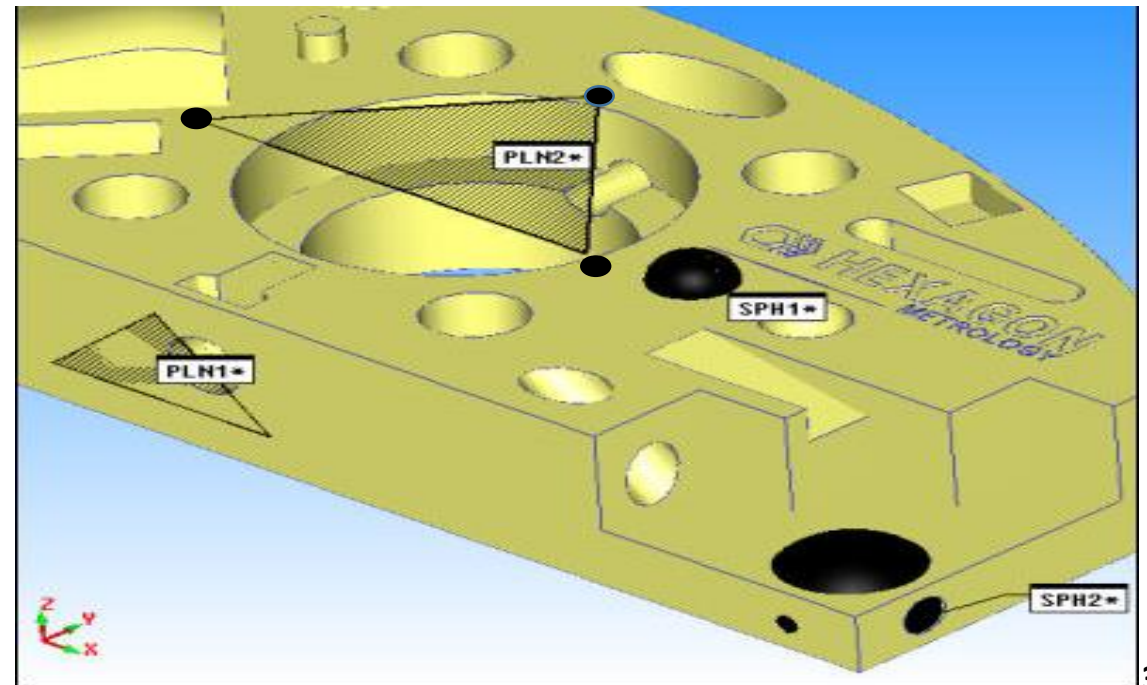
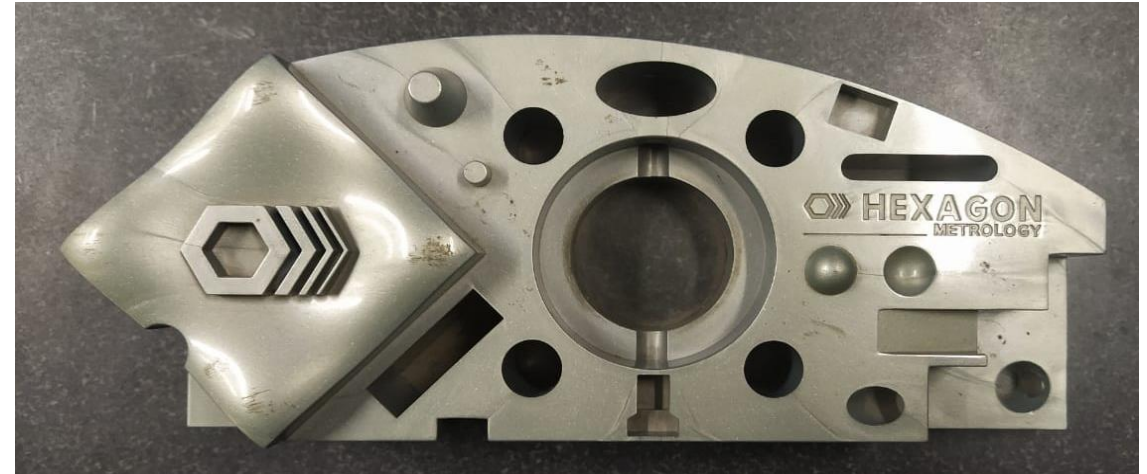
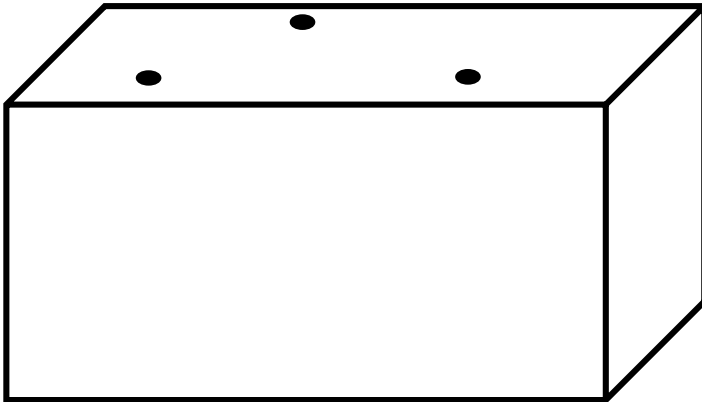
Calibration of CMM

Measurements

Plane, Circle, Sphere, Round Slot

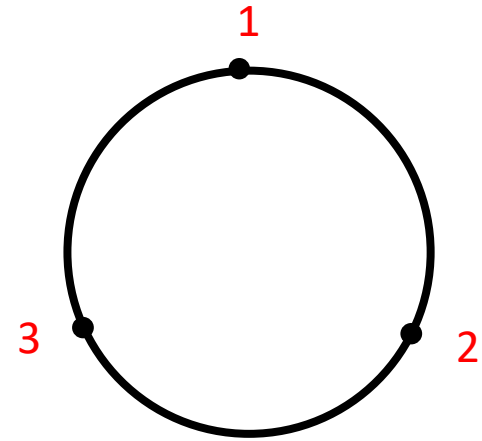
1. Plane

- Move the probe near the surface.
- Take 3 points on the surface for creating a plane.



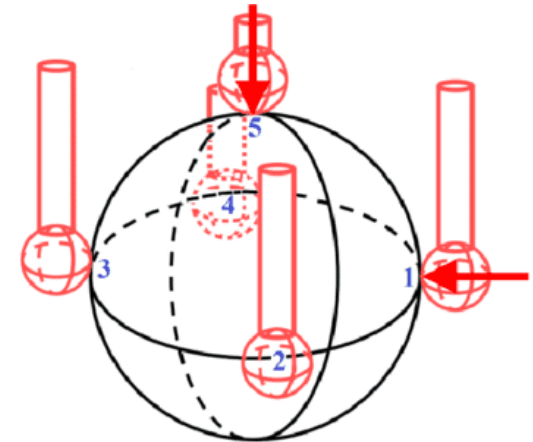
2. Circle

- Move the probe towards the circle.
- Touch 3 points on the periphery of the circle.



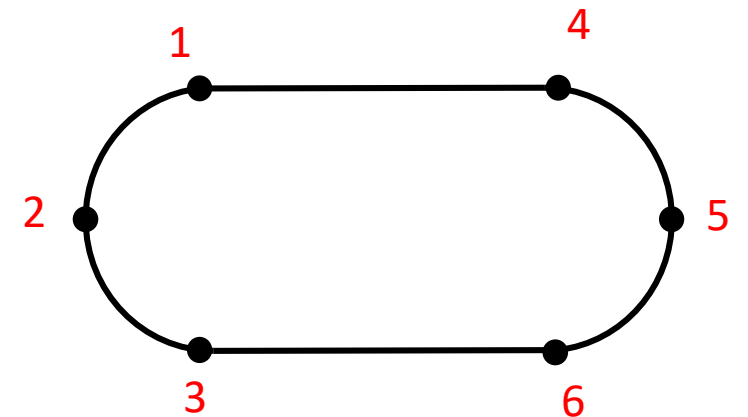
3. Sphere

- Move the probe towards the spherical object.
- The first point should be taken on the pole of sphere
- The other 3 points are taken on circumference



4. Round Slot

- Move the probe towards the first half circle.
- Touch 3 points on the periphery of the circle.
- Repeat the same on the other circle.



Demonstration of CMM



Courtesy: <https://www.youtube.com/watch?v=IaWx8-oetQ&t=124s>

References

- <https://www.slideshare.net/DhruvPatel742/cmm-probe>
- <https://www.foxvalleymetrology.com/blog/posts/2020/january/analog-scanning-vs-touch-probing/>
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THANK YOU