Coordinate Measuring Machine

Introduction

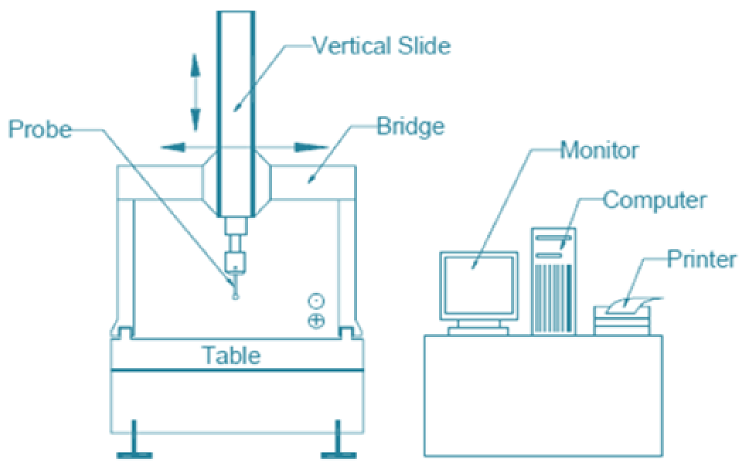
With the advent of numerically controlled machine tools, the demand has grown for some means to support these equipment. There has been growing need to have an apparatus that can do faster first piece inspection and many times, 100% dimensional inspection. The Coordinate Measuring Machine (CMM) plays a vital role in the mechanisation of the inspection process. Some of the CMMs can even be used as layout machines before machining and for checking feature locations after machining.

Coordinate measuring machines are relatively recent developments in measurement technology. Basically, they consist of a platform on which the workpiece being measured is placed and moved linearly or rotated. A probe attached to a head capable of lateral and vertical movements records all measurements. Coordinate measuring machines are also called measuring machines. They are versatile in their capability to record measurement of complex profiles with high sensitivity (0.25 μm) and speed.

Definition of CMM

A coordinate measuring machine (CMM) is a device that measures the geometry of physical objects by sensing discrete points on the surface of the object with a probe.

Parts of CMM



A CMM consists of four main elements:

1. Main Structure – The machine incorporates the basic concept of three coordinate axes so that precise movement in *x*, *y*, and *z* directions is possible. Each axis is fitted with a linear measurement transducer. The transducers sense the direction of movement and gives digital display.

2. Probing System – It is the part of a CMM that sense the different parameters required for the calculation. Appropriate probes have to be selected and placed in the spindle of the CMM.

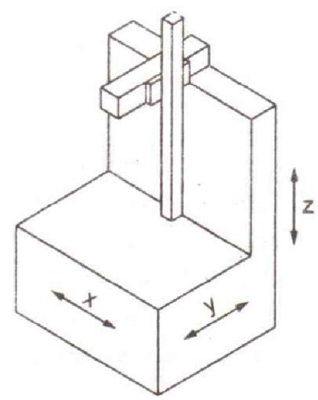
3. Machine Control and Computer Hardware – The control unit allows manual measurement and self teach programming in addition to CNC operation. The control unit is microprocessor controlled. Usually a joystick is provided to activate the drive for manual measurement.

4. Software for Three-dimensional Geometry Analysis – In a CMM, the computer and the software are an inseparable part. They together represent one system. The efficiency and cost effectiveness of a CMM depend to a large extent on the software. The features that the CMM software should include:

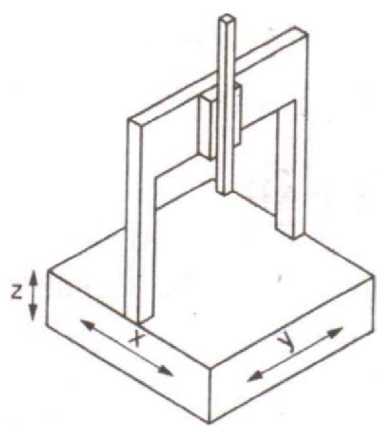
- Measurement of diameter, center distances, lengths, geometrical and form errors in prismatic components, etc.
- Online statistics for statistical information in a batch.
- Parameter programming to minimize CNC programming time of similar parts.
- Measurement of plane and spatial curves.
- Data communications.
- Digital input and output commands for process integration.
- Program for the measurement of spur, helical, bevel and hypoid gears.
- Interface to CAD software.

Types of CMM

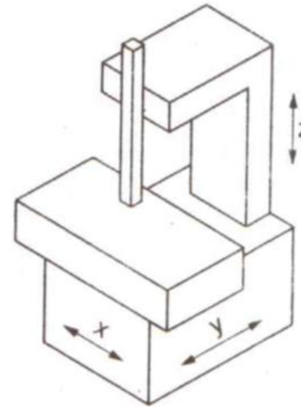
1. Cantilever type – The cantilever construction combines easy access and relatively small floor space requirements. It is typically limited to small and medium sized machines. Parts larger than the machine table can be inserted into the open side without inhibiting full machine travel.



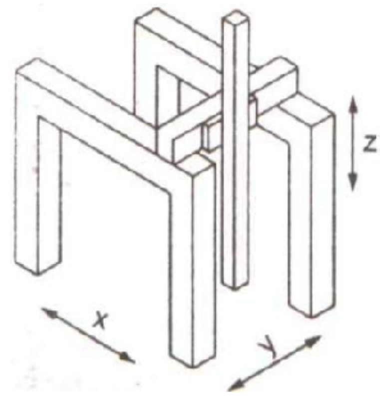
2. Bridge type – The bridge arrangement over the table carries the quill (z-axis) along the x-axis and is sometimes referred to as a travelling bridge.



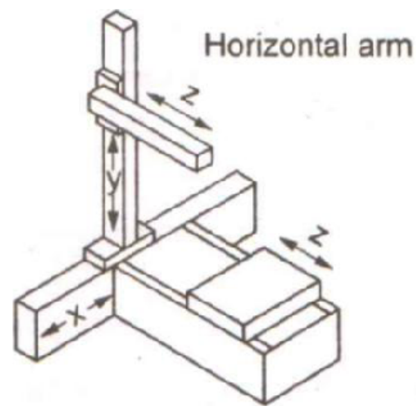
3. Column type – The column type machine is commonly referred to as a universal measuring machine rather than a CMM. These machines are usually considered gage room instruments rather than production floor machine. The constructional difference in column type with the cantilever type is with *x* and *y*-axes movements.



4. Gantry type – In a gantry type arrangement, arms are held by two fixed supports as shown in figure. Other two arms are capable of sliding over the supports. The gantry type construction is particularly suited for very large components and allows the operator to remain close to the area of inspection.



5. Horizontal Arm type – The open structure of this arrangement provides optimum accessibility for large objects such as dies, models, and car bodies. Some horizontal arm machines are referred to as layout machines. There are some horizontal machines where the probe arm can rotate like a spindle to perform tramming operations. Tramming refers to accurate mechanical adjustment of instrument or machine with the help of tram.



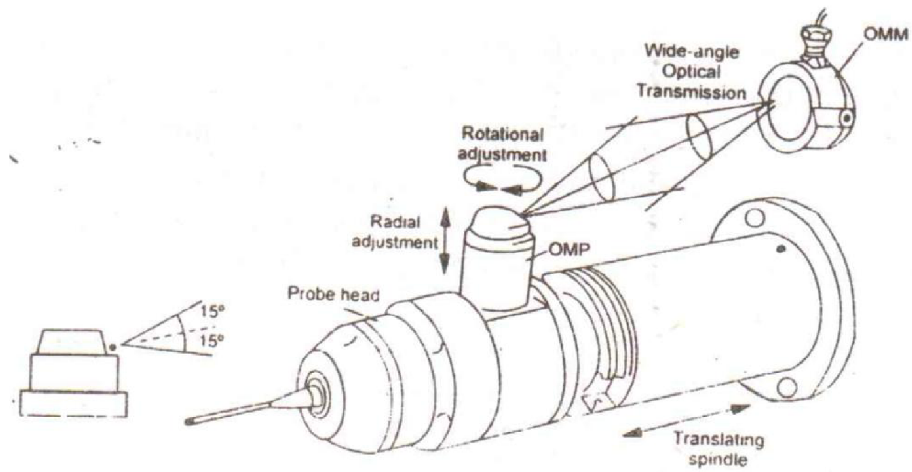
Probing System

It is the part of a CMM that sense the different parameters required for the calculation. Appropriate probes have to be selected and placed in the spindle of the CMM.

1. Inductive Transmission Probe –

Power is transmitted using inductive linking between modules fitted to the machine structure and attached to the probe. Figure shows a schematic of the inductive transmission probe. The hard-wired transmission probe shown is primarily for tool setting and is mounted in a fixed position on the machine structure.

2. Optical Transmission Probes –



The optical transmission probe shown in figure allows probe rotation between gauging moves, making it particularly useful for datuming the probe. The wide-angle system allows greater axial movement of the probe and is suitable for the majority of installation.

3. Motorized Probe –

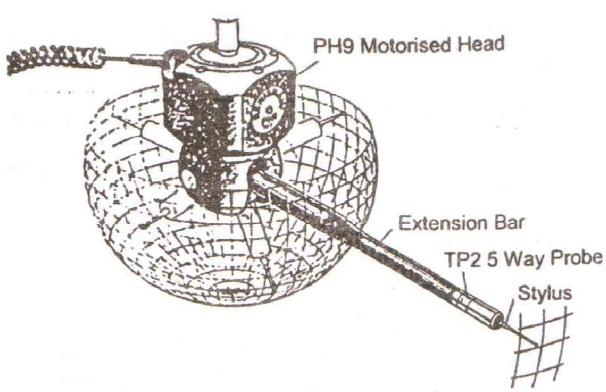
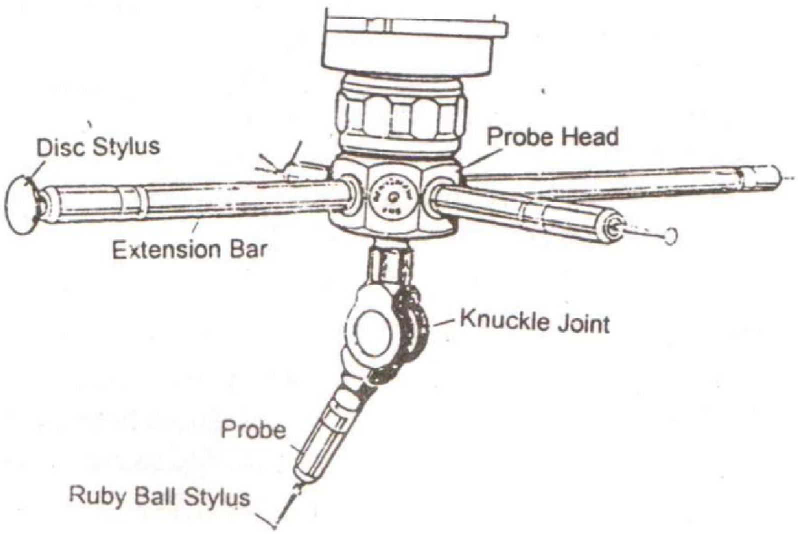


Fig. (a) Motorized Probe

Fig. (b) Typical Applications of Motorized Probe

With the motorized probe, 48 positions in the horizontal axis, 15 in the vertical axis can be programmed for a total of 720 distinct probe orientations. Figure (b) shows some typical applications for motorized probe. It shows that with a range of light weight extensions, the head can reach into deep holes and recesses. The second diagram shows that head of the probe is sufficiently compact to be regarded as an extension of the machine quill. This enables the inspection of complex components that would otherwise be impossible or involve complex setups.

4. <u>Multiple Styluses Probe Heads</u> –



Wide ranges of styli have been developed to suit many different gauging applications. Some of the different styli available are shown mounted on a multiple gauging head in figure. The selection of stylus is done based on the application for which the probe is to be used.

Advantages of CMM

CMM has got a number of advantages. The precision and accuracy given by a CMM is very high. It is because of the inherent characteristics of the measuring techniques used in CMM. Following are the main advantages that CMM can offer:

1. Flexibility – CMMs are essentially universal measuring machines and need not be dedicated to any particular task. They can measure almost any dimensional characteristic of a part configuration, including cams, gears and warped surfaces. No special fixtures or gages are required. Because probe contact is light, most parts can be inspected without being clamped to the table.
2. Reduced Setup Time – Part alignment and establishing appropriate reference points are very time consuming with conventional surface plate inspection techniques. Software allows the operator to define the orientation of the part on the CMM, and all subsequent data are corrected for misalignment between the parts-reference system and the machine coordinates.
3. Single Setup – Most parts can be inspected in a single setup, thus eliminating the need to reorient the parts for access to all features.
4. Improved Accuracy – All measurements in a CMM are taken from a common geometrically fixed measuring system, eliminating the introduction and the accumulation of errors that can result with hand-gage inspection methods and transfer techniques.
5. Reduced Operator Influence – The use of digital readouts eliminate the subjective interpretation of readings common with dial or vernier type measuring devices. Operator “feel” is virtually eliminated with modern touch-trigger probe systems, and most CMMs have routine measuring procedures for typical part features, such as bores or centre distances. In computer assisted systems; the operator is under the control of a program that eliminates operator choice. In addition, automatic data recording, available on most machines, prevents errors in transcribing readings to the inspection report. This adds upto the fact that less skilled operators can be easily instructed to perform relatively complex inspection procedures.
6. Improved Productivity – The above-mentioned advantages help make CMMs more productive than conventional inspection techniques. Furthermore, productivity is realized through the computational and analytical capabilities of associated data-handling systems, including calculators and all levels of computers.

Factors for selection of CMM

1. Size consideration – Before taking any other factors into consideration, the first criteria to identify is the exact sizing that will be needed for the CMM. When purchasing the right CMM size, one need to consider the part sizes and number of parts being measured as well as the manufacturing footprint or room limitations. One needs to think about where the CMM will be located, how much room is available there, and the size of the largest part, or if one is measuring groups of parts at the

same time. It is also a good exercise to examine whether the part size will increase in the next 5-10 years.

2. Measuring Requirements – If you require highly-accurate measurements, it is important to select a CMM that meets your requirements using a 4 to 1 or 10 to 1 rule. Industry practice is to select a measurement device 4 to 10 times more precise than the most challenging part tolerance. There are other factors to consider, including type of geometric features, manufacturing process creating the feature, design phase, etc. where a qualified OEM CMM application engineer can help to refine your choice.
   Some elements of the CMM to consider include:
   a) Machine structure: Moving bridge, fixed bridge, gantry, cantilever – CMM structures can impact CMM precision; typically, higher stiffness gives better performance.
   b) Fixed probe head versus indexing: A fixed probe head is typically more precise, however today's indexing wrist and probe combinations often provide acceptable precision and added flexibility.
   c) Scanning versus touch-trigger probing: Scanning probes collect large amounts of data faster. With more data, measurement uncertainty is decreased and the repeatability of the measuring process is increased.
3. Parts with Multiple Feature Characteristics or Material Types – For parts that have multiple feature characteristics, it is important to have an all-in-one solution that can adapt to specific feature requirements. When searching for a CMM, one should look for a system that can change from tactile to non-contact probing to adjust for a wide range of features and material types.
   To increase measurement throughput, a probe or styli rack saves time between inspection of a part with different feature types. Probe changer racks perform fast and repeatable exchanges of probes, extensions and probe modules on CMM probe heads or touch-trigger probes.
4. Environment – Will the CMM be placed on the production floor? In these environments, dust, dirt, and oils can impact measurement results. If one needs to place a CMM on the shop floor, it is a good idea to opt for a more rugged system that is highly reliable.
5. Evaluate the Performance of the Machine – Overall CMM measurement performance is critical to manufacturing productivity. In the case of CMM performance, one size does not fit all. Assessing performance is truly a combination of the right technologies to best suit one's specific application requirements. Selecting the right measurement capacity, system throughput, precision and sensor combination will ensure the best outcome.

Measurement Capabilities

CMMs can be designed to perform different types of measurement. These include:

- **Dimensional** measurements are sizing measurements made in the x, y, and z directions.
- **Profile** measurements are made to capture information about the form or profile of an object. These measurements may be 2D or 3D, depending on the machine capabilities.
- **Angularity** or orientation measurements are made to capture angle information between points on an object.
- **Depth mapping** is constructed by measuring the difference between two stereo images. Stereo images are successive images of the same scene taken at slightly different angles. The objects farther away will move relatively little from one image to the next, whereas objects closer to the viewer will move by a greater degree. A depth map is then created, resulting in a single image using different intensities to represent the different depths.
- **Digitizing or imaging** provides a digital format or image to visually capture the geometry of the workpiece from the measurements made by the CMM.
- **Shaft** measurements are application-specific designations for measurements made by CMMs designed specifically for inspecting shafts.

CMM Design Factors

Equipment design includes a CMM system's control mechanism, method of operation, mounting style, and probe type.

1. Control: CMM probes are designed to be controlled either manually or via CNC. Selection is largely a function of part quantity, complexity, and cost.

- **CNC** (Computer Numerical Control), or DCC (Direct Computer Control), is a control system built in the CMM to control probe movement. CNC CMMs are best-suited for production environments requiring a higher volume of measurements, and also in applications requiring complex and small measurements with fine features. They tend to be more expensive than manually controlled machines.
- **Manual** or operator-controlled devices require an operator that physically moves the probe along the axis to make contact and record measurements. Manual CMMs generally cost less than CNC CMMs of the same size, and are better suited for prototype shops with smaller quantities of measurements.

2. Operation: Operation describes a CMM's method or style of measuring, which is usually dependent on the design or orientation of the probe arm(s).

- **Bridge-style** machines incorporate an arm suspended vertically from a horizontal beam that is supported by two vertical posts in a bridge arrangement. The machine *x*-

axis carries the bridge, which spans the object to be measured. The bridge supports the guide rail (the machine *y*-axis), the bearings, and the machine's z-axis bar. These are considered the most popular type of machine style.

- **Gantry-style** machines have a frame structure raised on side supports so as to span over the object to be measured or scanned. Gantry machines are similar in construction to bridge-style designs.
- **Horizontal arm** machines incorporate an arm that supports the probe, horizontally cantilevered from a movable vertical support. They are known for robust construction and low power consumption. They are capable of measuring large envelopes at acceptable accuracy and are mainly used for large workpieces such as auto body parts and weldments.
- **Articulated arm** machines incorporate an articulated or multi-axis arm. This allows the probe to be placed in many different directions. This design is very common for portable machines.
- **Cantilever**-style machines incorporate a vertical arm that is supported by a cantilevered support structure.

3. Mounting: Sometimes a CMM requires a specific mounting style when incorporated into a system or method of operation. These mounting options include:

- **Benchtop** machines mount on a benchtop or desk. This is typical of most CMMs.
- **Freestanding** machines can support themselves and do not require mounting.
- **Portable** machines are devices that may be moved freely and are not designed to be bolted or hardwired in place. Handheld machines are a subset of portable devices describing those designed to be operated by hand.

4. Probes and Sensors: CMMs can incorporate different types of probes and sensors that detect and record position differently.

- **Touch or discrete** point probes are the most common probe type and also the least expensive. Discrete point probes actually touch the surface of the workpiece. Upon contact, a signal containing the coordinates of that point is sent to the CMM. The probe is then backed off and moved to the next location where the process is repeated. Types of touch probes include kinematic (switching), strain-sensing, and piezoelectric.
- **Laser triangulation** probes are generally referred to as scanning probes. This method generally involves passing the probe over a target surface at its working range. As the probe scans the surface, it transmits a continuous flow of data to the measurement system.
- **Line lasers** provide the fastest way to inspect non-linear surfaces and contours. The accuracy ranges from +0.001 in. to 0.00025 in. These devices are popular for reverse engineering.
- **Camera** probes have a still camera installed as the probe head, which takes pictures in order to find and measure points.
- **Video camera** probes have a moving camera installed as the probe head, which inspects workpieces through video imaging. These are best-suited for flat parts such as sheet metal stampings.