Chapter 7. Coordinate Metrology

7.1 Introduction

Coordinate metrology is a field of metrology that is becoming increasingly popular in the manufacturing industry. Coordinate metrology enables the three-dimensional measurement to be carried out on complex objects in a single setup. The instrument used for this purpose is known as the coordinate measuring machine or CMM.

In general, the CMM comprises three frames that move along three orthogonal axes, i.e. X-, Y- and Z-axis. Usually, a contact device known as measuring probe is attached to the end of the Z-axis. The displacement along each axis is measured by a linear measurement system and the readings are sent to an electronic controller. The electronic controller is connected to a computer that also enables various types of data processing to be performed.

Repeated measurements on similar objects can be done easily by programming the motion of the axes of the machine. This reduces the time taken for measurement and inspection up to 80% to 90%. These machines are made in various sizes and the methods of operation are based on either manual or computer-aided.

7.2. Types of CMM

The basic CMM consists of three axes, each provided with a guide way that enable precise movement along a straight line. Each guide way has a carrier that moves along. The carrier enables the second carrier to move along a straight line based on the first guide way. Each axis is fitted with a precision scale that records the position of the carrier measured from a reference point. The measuring probe is fitted to the carrier on the third axis. When the measuring probe touches the object being measured, the measurement system records the position of all three axes.

There are several physical configurations of CMMs. All the configurations have a method of moving the probe along three axes relative to the object. Although there are many designs of CMMs but they can be grouped into five basic types as follows:

(a) Cantilever type,
(b) Bridge type,
(c) Horizontal arm type,
(d) Column type and
(e) Gantry type

7.2.1 Cantilever type CMM

The schematic diagram of the cantilever type CMM is shown in Figure 6.1. In the cantilever type CMM the measuring probe it attached to the Z-axis and moves in the vertical direction. The Z-axis carrier is fitted to the cantilever arm and provides movement in the Y-direction. The Z-axis movement is provided by the table. This type of CMM design provides easy access to the work area and has high workspace volume.
7.2.2 Bridge type CMM

In principle, the bridge type CMM has a moving bridge as shown in Figure 7.2. The measuring probe is fitted to the Z-axis arm and the Z-axis carrier is fitted to the X-axis arm. The X-axis carrier in turn is fitted to the Y-axis arm. Both ends of the Y-axis are supported on the table, usually using air bearings.

This type of design provides better rigidity and thus the CMM has higher accuracy compared to the horizontal arm type. The weakness of this design is that it is difficult to place work onto the table because of the obstruction from the vertical parts of the Y-axis frame. However, this design is one of the most popular.

7.2.3 Column type CMM

The design of the column type CMM is similar to the drilling machine or the vertical milling machine (see Figure 7.3). This type of CMM is commonly known as the universal measuring machine. The construction of the column type CMM provides very good rigidity and high accuracy. The movement in the X and Y directions are achieved by moving the table.
7.2.4 Horizontal arm type CMM

The horizontal arm type CMM has a horizontal arm that moves in the horizontal direction (Figure 7.4). The measuring probe is fitted to the Y-axis arm and not the Z-axis arm as in the other designs of CMM. The main advantage of this type of CMM is that the work volume is large and free from obstruction. This type of machine can be used for large work piece such as a car body.

7.2.5 Gantry type CMM

In the gantry type CMM the X and Y-axes are placed overhead and supported by four columns from the base as shown in Figure 7.5. The main advantage of this type of construction is that the operator can move with the probe and measurement on large objects, such as the body of car, can be carried out.
7.3 Types of probes and sensor system

All CMMs have one or more probes and a method of moving them along three orthogonal axes relative to the workpiece. Most the probes used currently are the ‘soft’ or touch sensitive types. These types of probes use electronic mechanism to break the circuit when contact between the probe and workpiece occurs.

Several types of touch probes are available and the type selected depends on the workpiece material and dimension to be measured. All of these can be grouped into three types as follows:

(a) Ball type probe
   These are standard type probes used in CMMs and have various applications (Figure 7.6(a)).

(b) Tapered probe
   These are used for determining the location and diameter of holes (Figure 7.6(b)).

(c) Cylindrical probe
   The cylindrical probes are used to measure thin plates (Figure 7.6(c)).

The sensor system commonly used in the touch sensitive probes is the circuit breaker type shown in Figure 7.7.
In this type of sensor system an arrangement of spheres and rods are used to keep the flow of current in the sensor circuit. When the probe end touches the surface of the workpiece, deflection of the probe will occur and this will cause one of the spheres to be lifted and thus break the sensor circuit. The position of all three axes is frozen momentarily when this occurs and the value of the readings of the linear measurement system is transferred to the controller or computer.

7.4. Linear measurement System

The movement of each frame of the CMM is measured accurately using an optical system. The optical system is made up of a light source, photo detector and a pair of gratings. The schematic arrangement is shown in Figure 7.8.
The gratings are placed so that there is small angle between them. Under this condition, interference fringes known as moiré fringes will be formed. One of the gratings is fitted to the movable part of the machine while the other is fixed. When there is relative motion between the gratings the moiré fringes will move. The distance between the moiré fringes are much larger compared to the distance between the lines on the grating. In this way, the displacement of the grating can be amplified.

If one of the gratings moves in direction A as shown in Figure 7.9, the moiré fringes will move in direction B. If the grating moves a distance of one pitch, the moiré fringes will move a distance of one fringe spacing. If the distance traveled by the grating is a fraction of the pitch then the distance the fringes moves is also a fraction of the fringe spacing. Thus, the movement of the moiré fringes can be used as a measurement for linear motion of the grating. In addition, if the grating moves over a long distance, the distance traveled by the arm or frame to which the grating is attached can be determined by counting the number of moiré fringes the crosses a fixed point.

If a beam of light is passed through the gratings the output light can be focused onto a photo detector, such as a photosensitive diode or photocell. The electrical output from the photo detector can be converted to voltage pulses that are inputted to a digital display. In practical conditions modern electronics enables the input signal to be divided in fractions of

Figure 7.8. Linear measurement system in a CMM.

Figure 6.9. Moiré fringes formed by two gratings.
fringe movement. If the pitch of the grating is 0.04 mm and this is divided into four then each pulse represents a distance of 0.01 mm. Based on this principle the system can give digital reading up to 0.001 mm.

7.5 Computer Functions

A CMM that is not equipped with a computer is a machine that only enables measurement at only a few selected points. Meaningful readings can only be obtained from detailed calculation. However, the objective of metrology is to analyze individual points that were recorded on the workpiece and obtain information concerning dimensions, shape and position of certain characteristics. This is the main task of a computer in a CMM. Other functions that must be fulfilled by the computer are as follows:

(a) Correction
Correction is done to overcome errors caused by deviation in the guide way, deviation in squareness, deflection of the machine frames, thermal effects, radius of the measuring probe and deflection of the probe. The objective of the correction is to eliminate or reduce systematic effects that may give false readings and results.

(b) Transformation
All measurements done on the CMM are based on the coordinate system of the machine and must be converted to the coordinate system of the workpiece. Moreover, if a rotary table is used the coordinate system of the rotary table must be converted to the coordinate system of the workpiece.

(c) Calculation
The actual geometry on a workpiece can only be determined when there are a large number of measurement points. If the shape of the component being measured differs only slightly from the standard geometry such as a cylinder, sphere or cone, the number of measurement points can be reduced to a minimum. Yet, a disadvantage of this method is that error of measurement will increase.

Review Questions

Question 7.1
Explain the benefits of CMMs for dimensional measurement compared to other traditional instruments such as vernier calipers, comparators, micrometers and so on.

Question 7.2
Which is the most popular type of CMM? Give reasons.

Question 7.3
Explain the features found in the following types of CMMs:
   i) Bridge type CMM
   ii) Gantry type CMM

Which of these is suitable form measuring the dimensions on the body of a car? Why?

Question 7.4
Explain the operating principle of the linear measurement system commonly used in a CMM.