ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΑΤΡΩΝ
UNIVERSITY OF PATRAS

ΑΝΟΙΚΤΑ ακαδημαϊκά μαθήματα ΠΠ

Αριθμητικός Έλεγχος Εργαλειομηχανών

Ενότητα 2: Numerical Control Systems

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COMPUTER NUMERICAL CONTROL OF MACHINE TOOLS

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LMS

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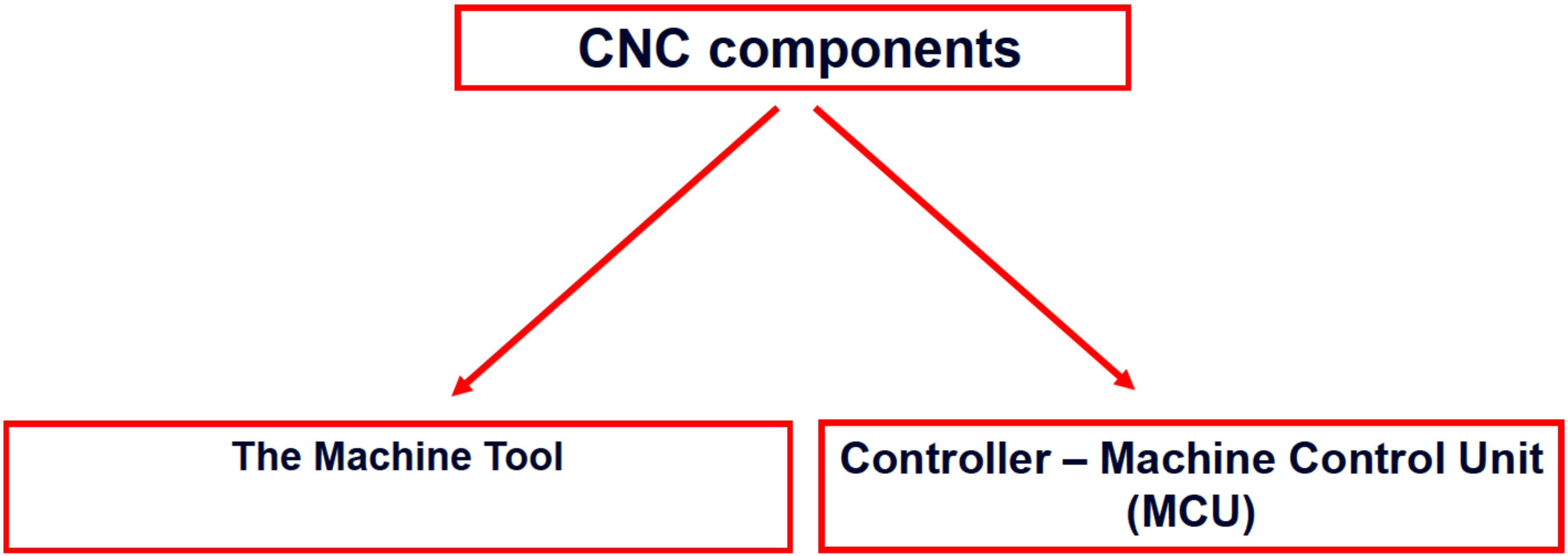
Objectives of Section 2

- Describe the two types of control systems in use on NC equipment
- Name the four types of drive motors used on NC machinery
- Describe the two types of loop systems used
- Describe the Cartesian coordinate system
- Define a machine axis
- Describe the motion directions on a three-axis milling machine
- Describe the difference between absolute and incremental positioning
- Describe the difference between datum and delta dimensioning

CNC Components

- A CNC machine consists of **two major components**



- **MCU** is an **on-board** computer
- **MCU** and **Machine Tool** may be manufactured by the same company

CNC Components

Figure 1: A Typical CNC Controller

CNC controllers manufacturers:

- General Numeric
- Fanuc
- General Electric
- Bendix
- Cincinnati Milacron
- G & L Electronics
- Siemens

CNC Components

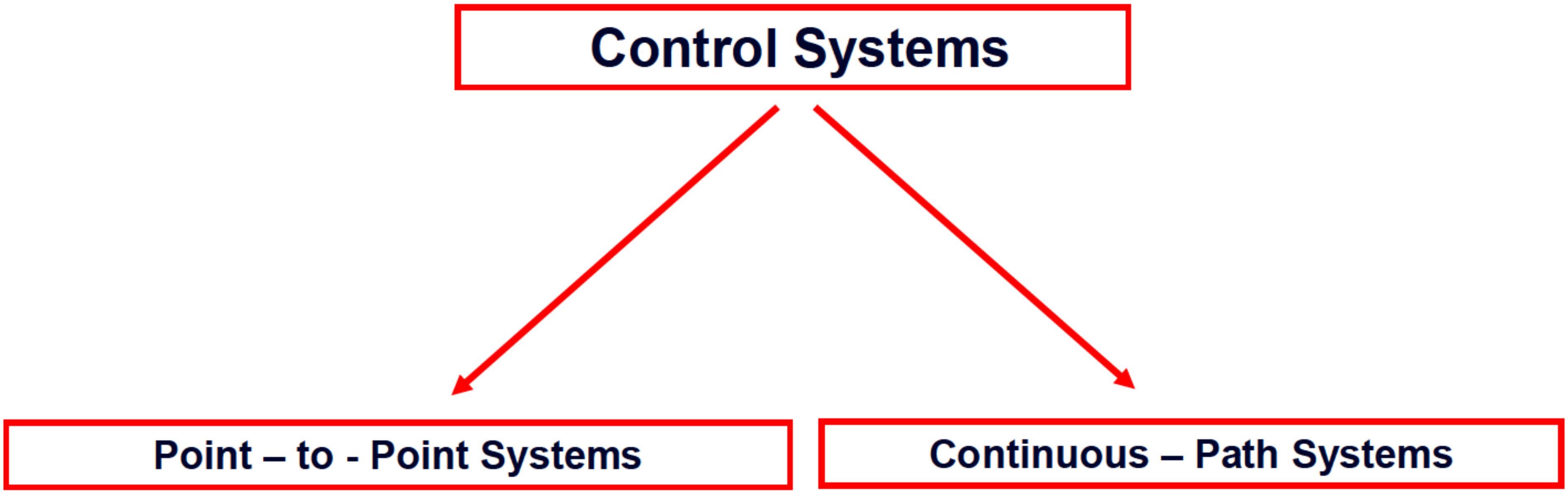
- Each MCU is manufactured with a standard set of **build in codes**
- Other codes are added by the machine tool builders

- **Program codes vary somewhat from machine to machine**

- Every CNC machine is a **collection** of systems **coordinated** by the controller

Types of Control Systems

- There are two types of control systems used on CNC machines



Types of Control Systems

Point – to – Point machines:

- Move in straight lines
- They are limited in practical sense to hole operations:
  - Drilling
  - Reaming
  - Boring etc
- Straight milling cuts parallel to a machine axis
- When making an axis move all affected drive motors run at the same speed

Cutting of 45° angles possible but not angles or arcs other than 45° angles

Types of Control Systems

Continuous - Path machines:

- Have the ability to move the drive motors at **varying rates of speed** while positioning the machine

The cutting of arc segments and any angle can be easily accomplished

Different Types Of System Control

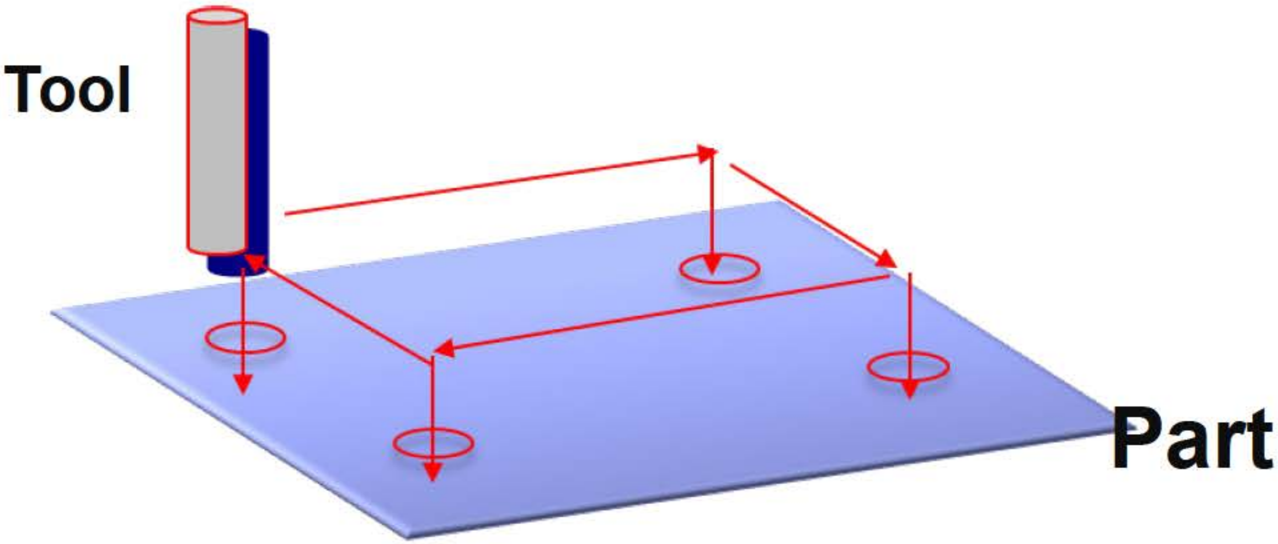


FIGURE 2 Point – to – Point tool movement

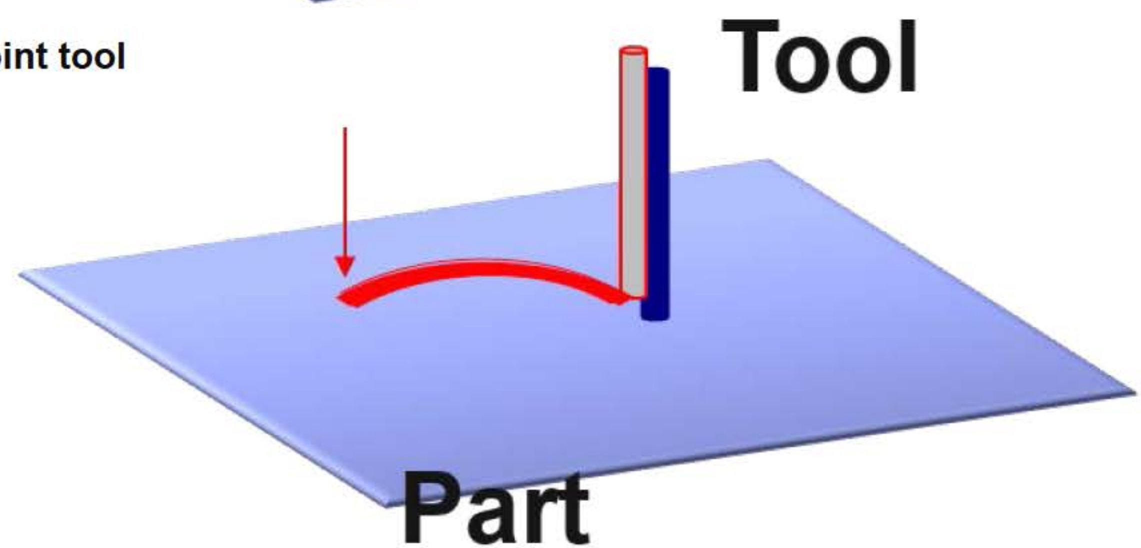


FIGURE 3 Continuous – Path tool movement

Types of Control Systems

- Point – to –Point Machines where common
- Their electronics where **less expensive** to produce
- The machine tools where **less expensive** to acquire
- Technological advancements have **narrowed the cost difference** between point – to point and continuous – path machines

Most CNC machines now manufactured are of <u>continuous – path type</u>

Servomechanisms

The drive systems used on NC machinery:

- **STEPPER motors**
- **DC** (Direct Current) servos
- **AC** (Alternating Current) servos
- **Hydraulic** servos

Servomechanisms

STEPPER motors

- Move **a set amount of rotation** (a step) every time the motor receives an electronic pulse

DC and AC servos

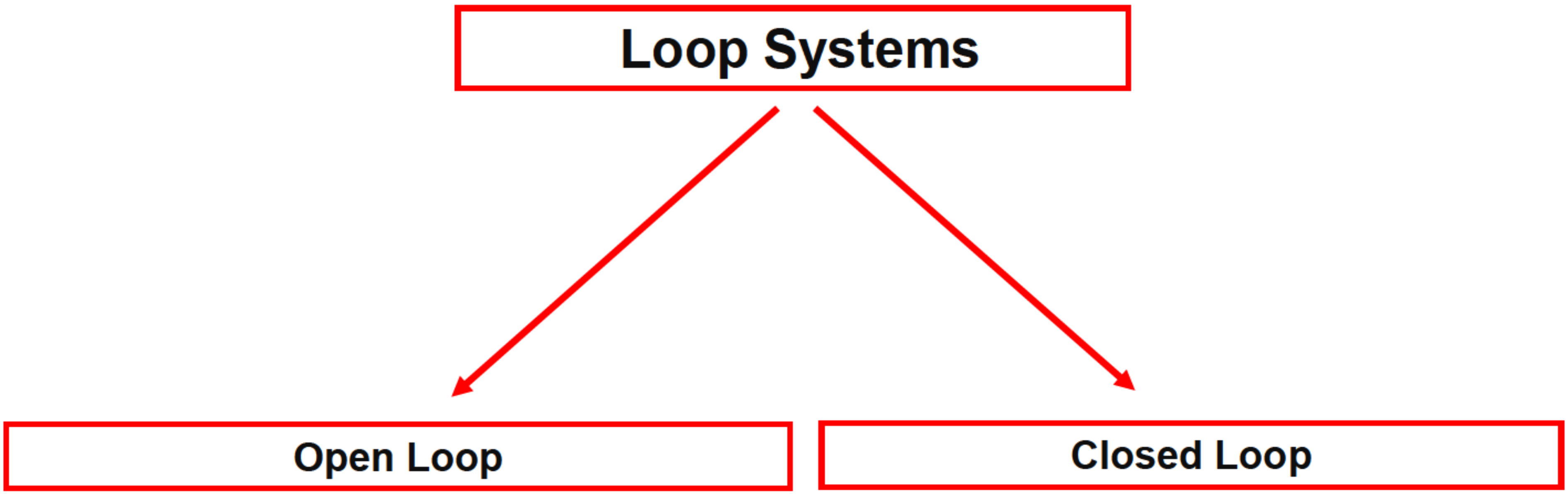
- Widely used variable-speed motors on small & medium continuous path machines
- A servo ***does not move a set distance***
- When **current is applied** the motor **starts** to turn and when the **current is removed** the motor **stops** turning
- The AC motor can create **more power** than a DC motor – used on CNC Machining Centers

HYDRAULIC servos

- Are variable-speed motors
- Produce much more **powe**r than an electric motor
- They are used on large CNC machinery with electronic or pneumatic system attached

Loop Systems

- **Loop systems** are **electronic feedback systems** that send and receive electronic information from the drive motors



- The type of system used **affects the overall accuracy** of the machine
- **Open Loop** use **Stepper Motors**
- **Closed Loop** usually use **Hydraulic, AC and DC Servos**

Loop Systems

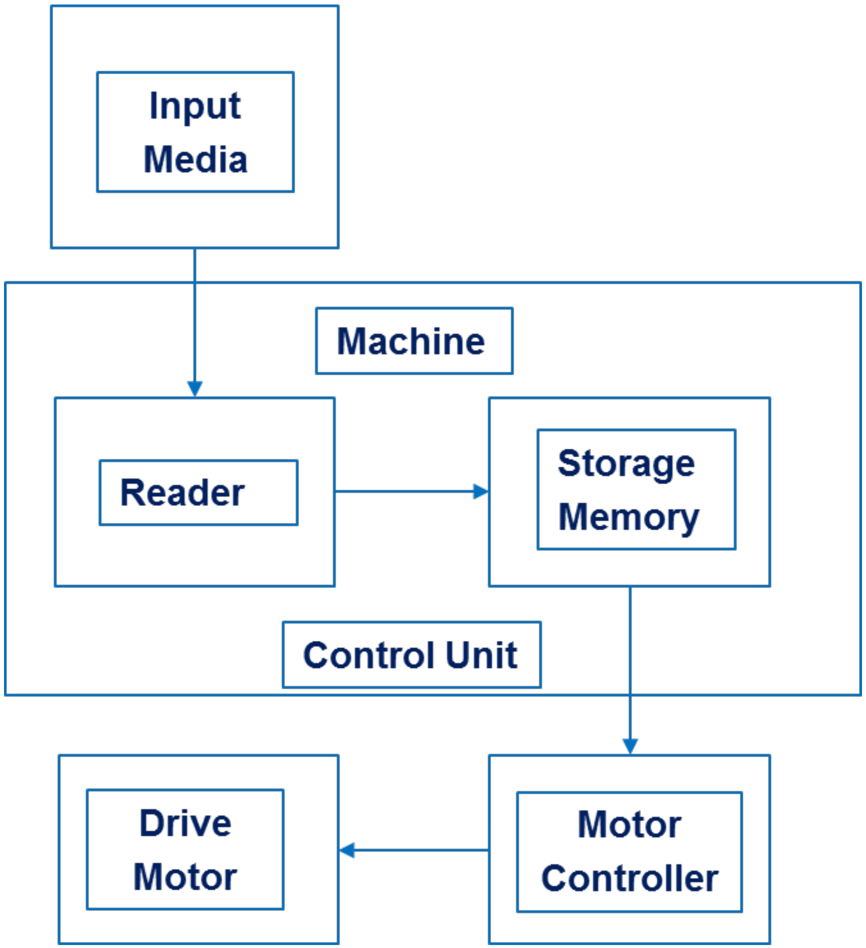


FIGURE 4 An Open – Loop system

Open – Loop System:

- The machine receives its information from the **reader** and stores it in the **storage device**
- When the information is needed it is sent to the **drive motor(s)**
- After the motor has completed its move a signal is sent back to the storage device telling it **that the move has been completed** and the next instruction may be received
- There is ***no process to correct for error*** induced by the drive system

Loop Systems For Controlling Tool Movement

Open Loop Systems

- An open loop system **utilizes stepping motors to create machine movements**. These motors rotate a ***fixed amount, usually 1.8°, for each pulse received***.

- Stepping motors are driven by **electrical signals coming from the MCU**. The motors are connected to the machine table ball-nut lead screw and spindle

- Upon receiving a signal, they move the table and/or spindle a fixed amount. The motor controller sends **signals** back indicating the motors have **completed the motion**

The feedback, however, is not used to check how close the actual machine movement comes to the exact movement programmed

Loop Systems

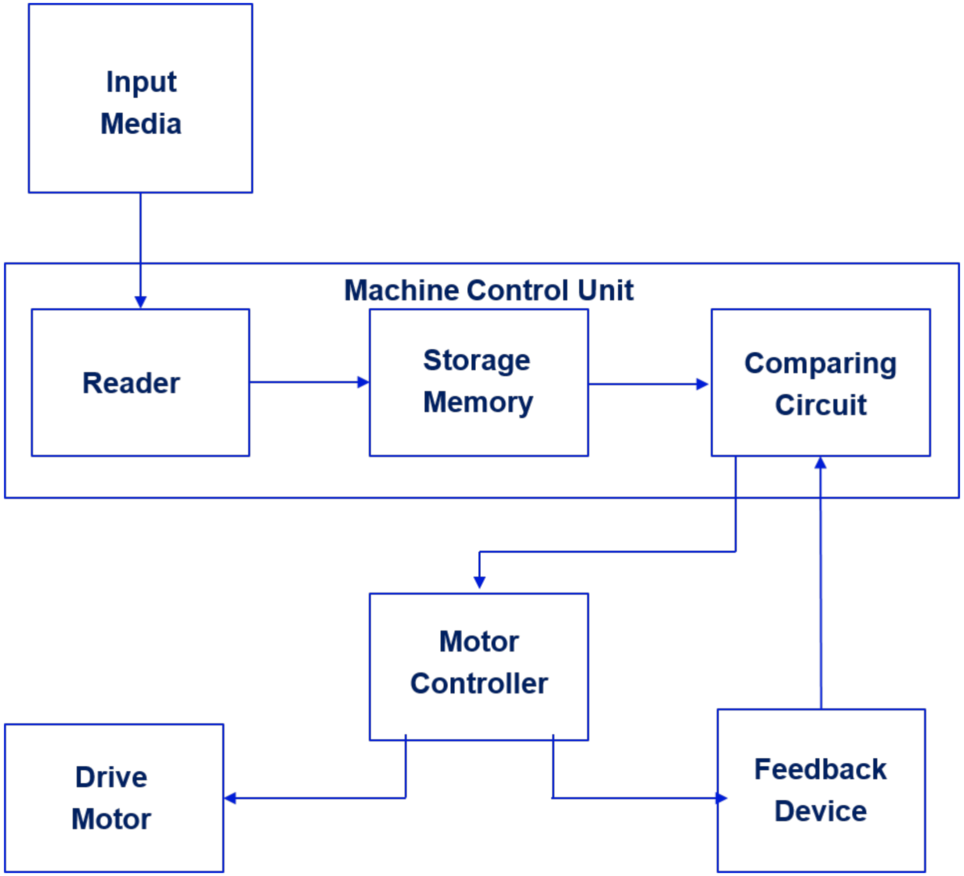


FIGURE 5 An Closed – Loop system

Closed – Loop System:

- The machine receives its information from the reader and stores it in the storage device
- When the information is sent to drive motor the motor's position is **monitored** by the system and compared to what was sent
- If an error is detected the necessary **correction** is sent to the drive system
- If the **error is large** the machine may **stop** executing the program for correcting the inaccuracy
- Most errors produced by the drive motors are eliminated
- **Advanced Stepper Motors make possible extremely accurate Open – Loop Systems and less HW**

Loop Systems For Controlling Tool Movement

Closed Loop Systems

- Special motors called **servos** are used for **executing machine movements** in closed loop systems

- Motor types include **AC servos**, **DC servos**, and **hydraulic servos**. **Hydraulic servos**, being the most powerful, are used on large CNC machines. **AC servos** are next in strength and are found on many machining centers

- A servo does not operate like a pulse counting stepping motor. The speed of an AC or DC servo is variable and depends upon the amount of current passing through it

- The **speed** of a hydraulic servo depends upon the **amount of fluid passing through it**. The strength of current coming from the MCU determines the speed at which a servo rotates

Coordinate Systems

- Geometrical **means of communication** between the operator and digitally driven machine-tool

- Univocal characterization of a point in the plane or in space **relative to a fixed point**

- **Absolute** coordinates

- **Relative** coordinates

The Cartesian Coordinate System

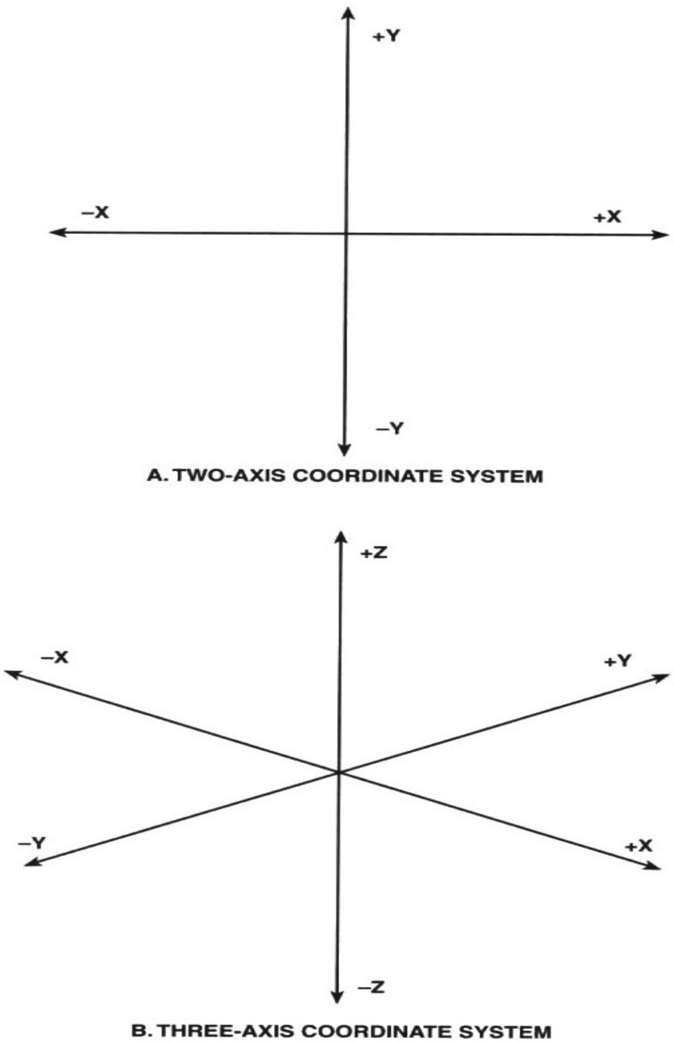


FIGURE 6 Cartesian coordinate system

The Cartesian Coordinate System in machines:

- The **basis** for all machine movement is the Cartesian Coordinate system
- On a machine tool an **axis is a direction of movement**
- In a Two – Axis Milling Machine (Fig. 2-10):
  - X is the direction of the Table travel
  - Y is the direction of the Cross travel

The Cartesian Coordinate System

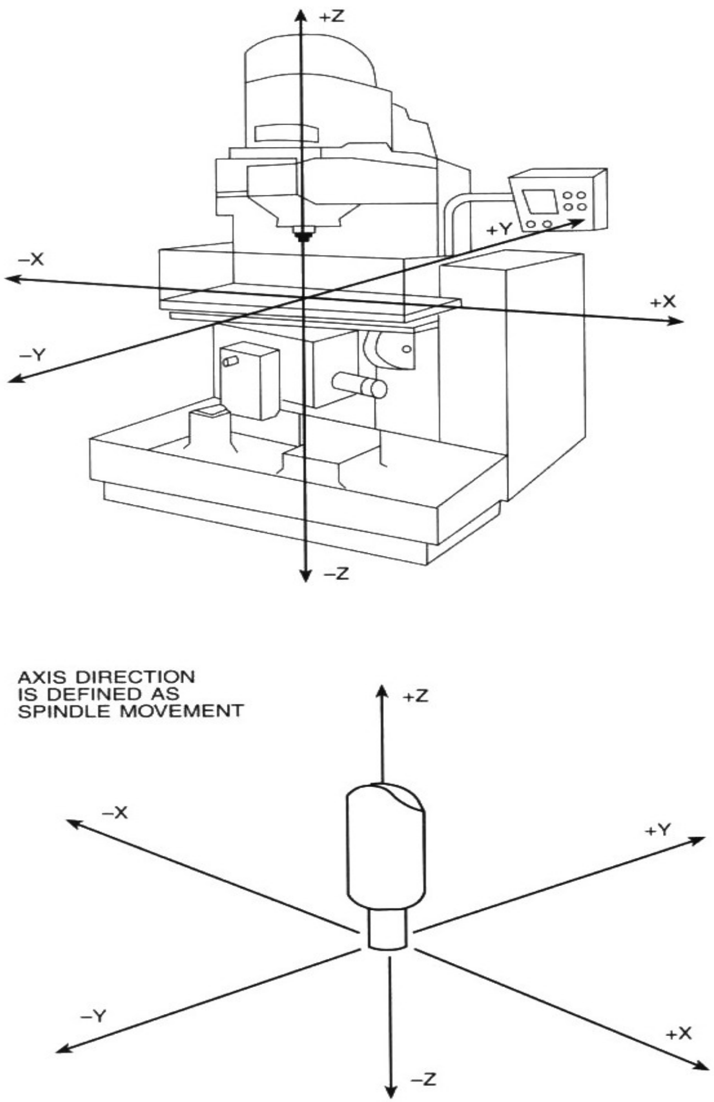
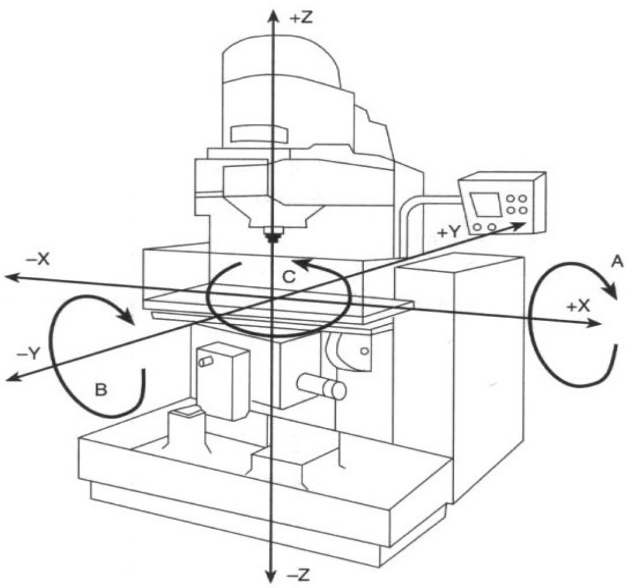


FIGURE 7 Three – Axis vertical mill

Three – Axis Milling machine:

- In a Three – Axis Vertical Milling Machine:
  - X is the direction of the Table travel
  - Y is the direction of the Cross travel
  - Z the Spindle travel up – down

The Cartesian Coordinate System



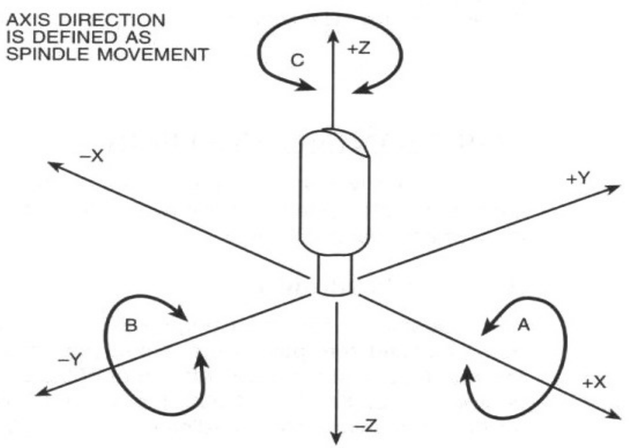


FIGURE 8 Six – Axis machine layout

Six – Axis Milling machine:

- In a **Six – Axis** Vertical Milling Machine:
  - **X** is the direction of the Table travel
  - **Y** is the direction of the Cross travel
  - **Z** the Spindle travel up – down
  - **A** is the rotation around X – axis
  - **B** is the rotation around Y – axis
  - **C** is the rotation Z –axis (spindle)

The Cartesian Coordinate System

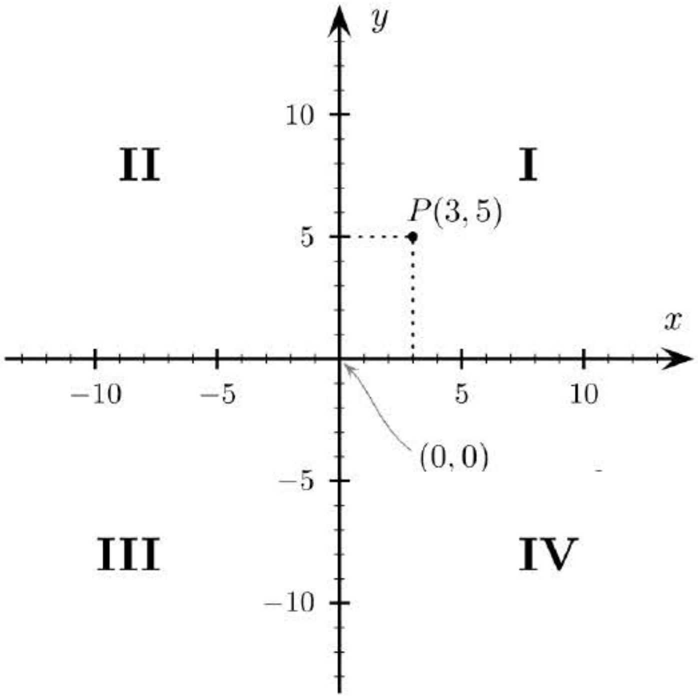


FIGURE 9 Cartesian coordinate quadrants

Cartesian Coordinate Systems:

- Are divided into **quarters (quadrants)**: I, II, III, IV in counter-clockwise direction
- This is the universal way of labelling axis quadrants
- The signs of **X** and **Y** change when moving from quadrant to quadrant

The Cartesian Coordinate System

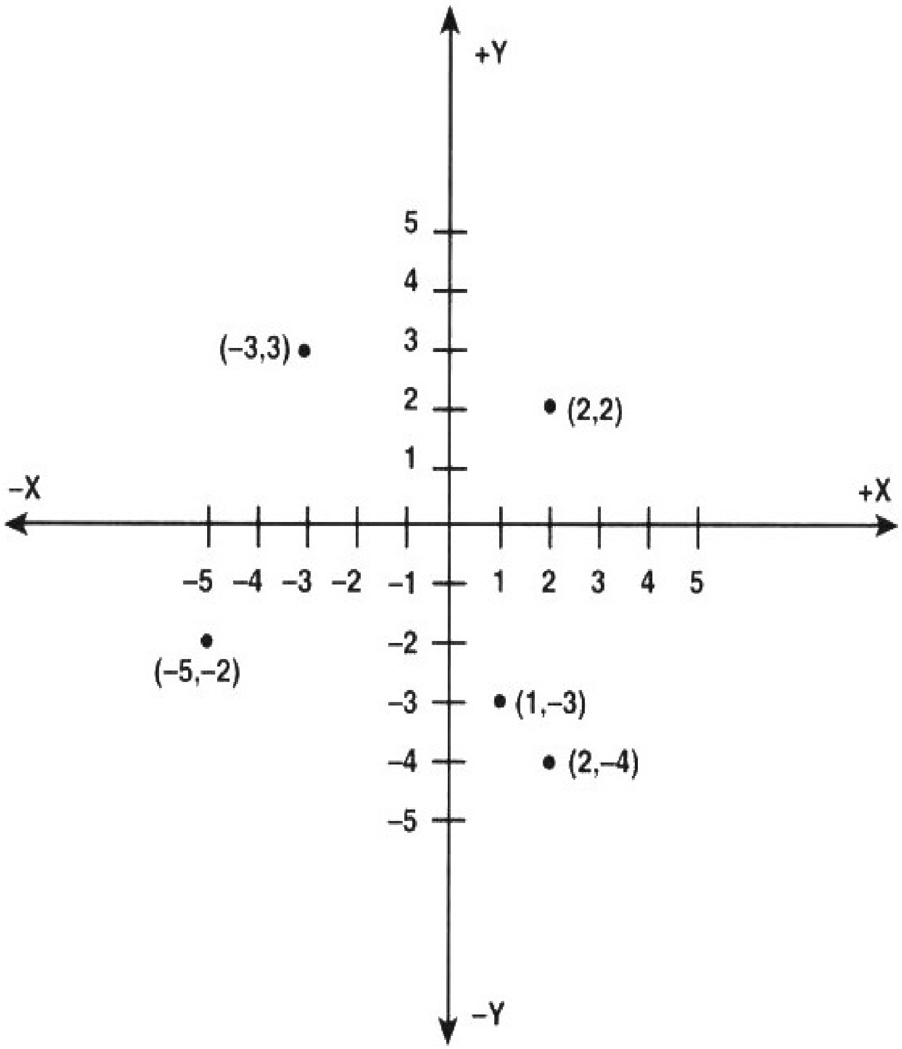
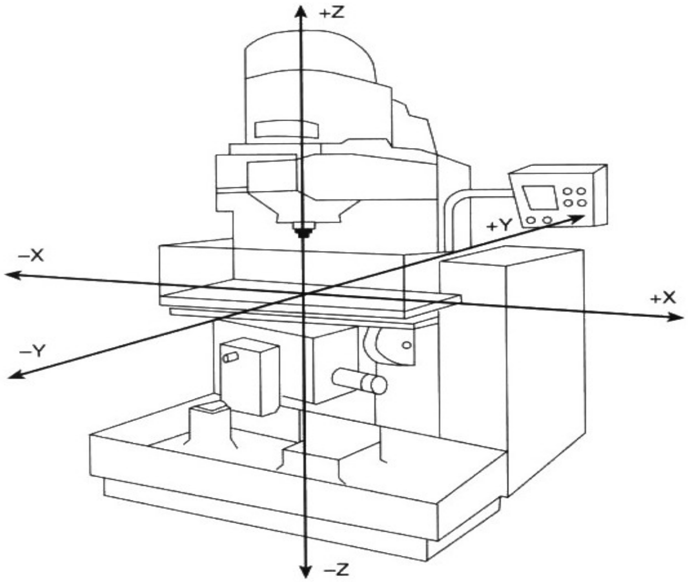


FIGURE 10 Cartesian coordinates

Cartesian Coordinate Systems:

- Points on a two-axis Cartesian system
- Each of the points can be defined as a set of coordinates (X, Y)
- In mathematics this set of points is called an ***ordered pair***
- In NC programming the points are referred as ***coordinates***
- Cartesian coordinates will be used in writing NC programs

Positive and Negative Movement



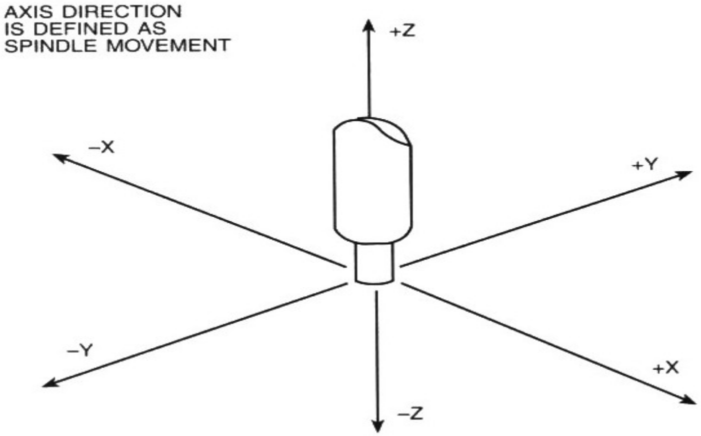


FIGURE 11 Three – Axis vertical mill

- Machine axis direction is defined in terms of *spindle movement*
- On some axes the machine slides actually move on other axes the spindle
- *For standardization the positive and negative direction for each axis is always defined as if the spindle did the travelling*
- The arrows saw the positive and negative direction of spindle movement along axes

<u>Example</u>

- To make a move in the +X direction (spindle right) the table would move to the left
- To make a move in the +Y direction (spindle toward the column) the saddle would move away the column
- The Z-axis movement is always positive (+Z) when the spindle moves towards the machine head and negative (–Z) when it moves toward the workpiece

Positioning Systems

- There are **two ways** that machines **position themselves** with respect to their coordinate systems

Positioning Systems

Absolute Positioning | **Incremental Positioning**

Positioning Systems

Absolute Positioning:

- All machine locations are taken from **one fixed zero point**
- All positions on the part are taken from the (X0, Y0) point at the **lower left corner** of the part

- Example

- **The 1st hole** will have coordinates of (X1.000, Y1.000)
- **The 2nd hole** will have coordinates of (X2.000, Y1.000)
- **The 3rd hole** will have coordinates of (X3.000, Y1.000)
- Every time the machine moves the controller references ***the lower left corner of the part***

Positioning Systems

Incremental Positioning:

- The (X0, Y0) point moves with the machine spindle
- Each position is specified in relation to the previous one
- Example
- **The 1st hole** coordinates are (X1.000, Y1.000)
- **The 2nd hole** coordinates are (X1.000, Y0)
- **The 3rd hole** coordinates are (X1.000, Y0)
- After each machine move ***the current location is reset to (X0, Y0) for the next move***
- The coordinate system moves with the location and the machine controller does not reference any common zero point

Setting the Machine Origin

Machine Coordinate System

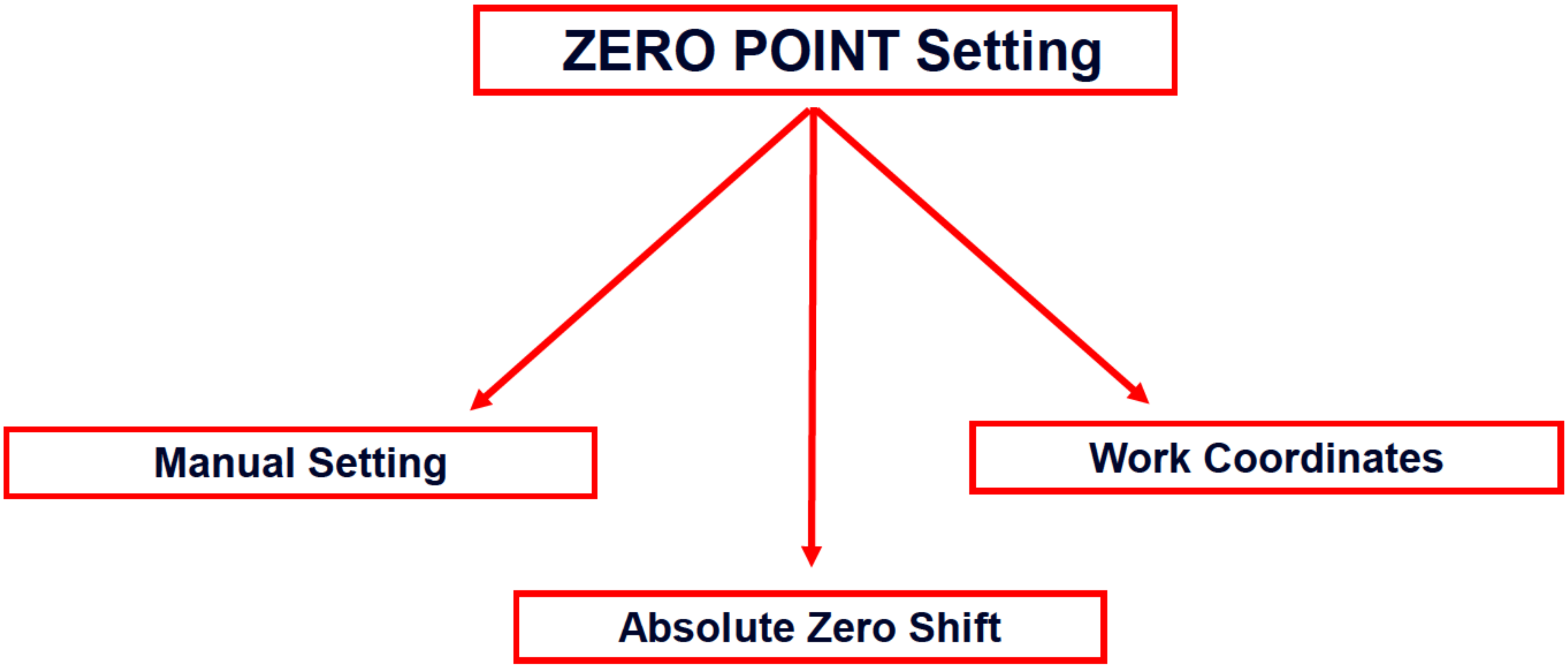
- Most CNC machinery have a default coordinate system assumed during power-up the ***Machine Coordinate System***
- The origin of this system is called the ***Machine Origin*** or ***Home Zero Location***
- ***Home Zero*** is usually located at the ***Tool Change*** position of a Machining Center

Programmer Coordinate System

- A part is programmed independently of the machine ***Coordinate System***
- The programmer can pick a location on the part or fixture becoming the origin of the coordinate system for that part
- The programmer's coordinate system is called the ***Local*** or ***Part Coordinate System***
- The ***Machine*** and ***Part Coordinate System*** will almost **never coincide**
- Prior running the part program the coordinate system must be transferred from the machine system to part system: Setting ***ZERO POINT***

Setting the Machine Origin

- There are **three ways** a **ZERO POINT** can be set on CNC machines



Setting the Machine Origin

Manual Setting

- The set-up person (technician) **positions the spindle over the desires part zero**

- Zero out the coordinate system on the **M**achine **C**ontrol **U**nit (**MCU**) console

- The actual coding for accomplishing zero out **varies** from **MCU** to **MCU**

Setting the Machine Origin

Absolute Zero Shift

- An absolute ***Zero Shift*** is a transfer of the coordinate system inside the NC program
- First: the programmer commands the spindle to the ***Home Zero Location***
- Next: a command is given that tells the MCU how far from the ***Home Zero Location*** the ***Coordinate System Origin*** is to be located

An Absolute Zero Shift is given as follows:

```
(Send the spindle to home zero)
N010 G28 X0 Y0 Z0
(Set the current spindle position)
(To X5.000 Y6.000 Z7.000)
N020 G92 X5.000 Y6.000 Z7.000
```

- Line **0N10**: Spindle moves to Home Zero
- Line **0N20**: The location of the spindle became **X5.0**, **Y6.0**, **Z7.0**, for MCU
- The machine will now reference the Part Coordinate System
- **G28** - Return to reference point
- **G92** – Program absolute zero point

If more than a fixture is to be used on a machine, the programmer will use more than one part coordinate system – send spindle back to home zero **G28 X0**, **Y0**, **Z0** – then **G92** Line

Setting the Machine Origin

Work Coordinates

- A ***work coordinate*** is a modification of the ***absolute zero shift***
- ***Work coordinates*** are **registers** in which the distance from home zero to the part zero can be stored
- The ***part coordinate system*** does not take effect until the ***work coordinate*** is commanded in the NC program
- When using ***G92*** ***zero shifts*** the coordinate system were changed to ***part coordinate system*** when G92 line was issued
- When using ***work coordinates*** a register can be set at one place in the program and called at another
- If more than one fixture is used – a second part zero can be entered in a second work coordinate and called up when needed
- The ***work coordinate registers*** can be set manually by the operator or by the NC programmer without having to send the spindle to the ***home zero location***
- This saves program cycle time by eliminating the moves to ***home zero***

Setting the Machine Origin

Work Coordinates (WC)

- Are set and called in a program by commands called **G-codes**: **G54**, **G55** and **G56**

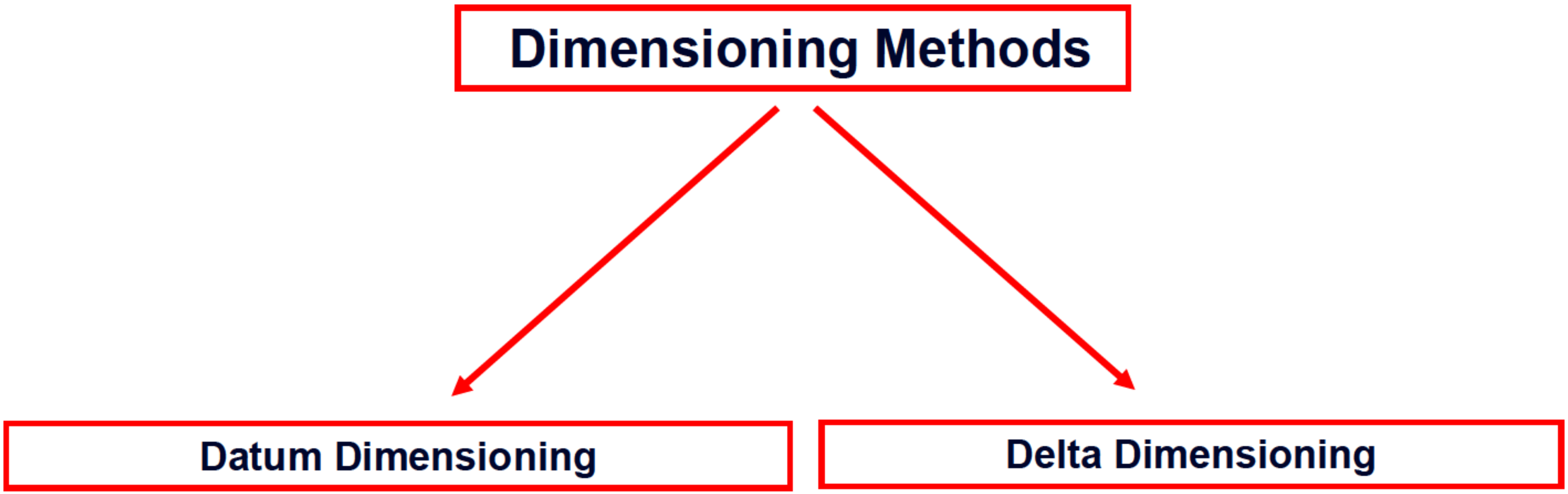
An example of using Work Coordinates:

```
(Set work coordinate P1-which is G54)
(and work coordinate P2-which is G55)
N010 G10 L2 P1 X5.000 Y6.000 Z7.000
N020 G10 L2 P2 X10.000 Y3.000 Z15.000

(Call work coordinate G54 and move)
(To X1.000 Y1.000 Z0.500)
N100 G54 X1.000 Y1.000 Z.500

(Call work coordinate G55 and move)
(To X2.000 Y2.000 Z3.000)
N110 G55 X2.000 Y2.000 Z3.000
```

- **Line N010:** the G54 WC is set to X5.0, Y6.0, Z7.0, from the zero home location
- **Line N20:** the G55 WC is set to X10.0, Y3.0, Z15.0 from home zero
- **Line N100:** the G54 WC is called activating the part coordinate system moving the spindle to X1.0, Y1.0, Z0.5 as referenced from the part activated part coordinate system
- **Line N110:** the G55 WC is called activating the second part coordinate system moving the spindle to X2.0, Y2.0, Z3.0 as referenced from the part activated part coordinate system
- Work coordinates remain active until cancelled by another work coordinate

Dimensioning Methods

- In conjunction with NC machinery there are **two types of dimensioning practices used on blueprints**



- These two dimensioning methods are **related to absolute and incremental positioning**

Dimensioning Methods

Datum Dimensioning:

- All dimensions on a drawing are placed **in reference to one fixed zero point**

- Is ideally suited to ***absolute positioning*** equipment

- All dimensions are taken from the **corner** of the part

Dimensioning Methods

Delta Dimensioning:

- Dimensions placed on a Delta Dimensioned drawing are ***"chain-linked"***

- Each location is **dimensioned from the previous one**

- Delta drawings are suited for programming ***incremental positioning*** machines

- It is not common to find the ***two methods mixed*** on one drawing

Summary 1/2

- The two types of NC control systems are ***point-to-point*** and ***continuous path***
- The four types of drive motors used on NC equipment are ***stepper motors, AC servos, and hydraulic servos***
- ***Loop systems*** are electronic feedback systems used to help control machine positioning. There are two types of loop systems: *open and* ***closed***. Closed-loop systems can correct errors induced by the drive system; open loop system cannot
- The basic of machine movement is the ***Cartesian Coordinate*** system. Any point on the Cartesian coordinate system may be defined by X/Y or X/Y/Z coordinates
- An ***absolute positioning*** system locates machine coordinates relative to a fixed datum reference point
- In an ***incremental positioning*** system, each coordinate location is referenced to the previous one

Summary 2/2

- The machine coordinate system can be transferred to the part coordinate system ***manually***, by an ***absolute zero shift***, or by use of ***work coordinates***

- The ***positive or negative direction*** of an axis movement is always thought of as spindle movement

- Machine movements occur **along axes that correspond to the direction of travel** of the various machine slides.
- On a vertical mill, the **Z axis of a machine is always the spindle axis**. The **X and Y axes of a machine are perpendicular to the Z axis**, with X being the axis of longer travel

- There are two dimensioning systems used on part drawings intended for numerical control: ***datum*** and ***delta***. **Datum** dimensioning references each dimension to a fixed set of reference points; **delta** dimensioning references each dimension to the previous one

Vocabulary Introduced in this Section

- Absolute positioning
- Absolute zero shift
- Cartesian coordinate system
- Closed-loop system
- Continuous-path systems
- Datum dimensioning
- Delta dimensioning
- Incremental positioning
- Machine Control Unit (MCU)
- Point-to-point systems
- Open-loop system
- Work coordinates

End of Section

Funding

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