NUMERICAL CONTROL AND INDUSTRIAL ROBOTICS

- Numerical Control
- Industrial Robotics
- Programmable Logic Controllers

Numerical Control

A form of programmable automation in which the mechanical actions of a piece of equipment are controlled by a program containing coded alphanumeric data

- The data represent relative positions between a workhead and a workpart
  - Workhead = tool or other processing element
  - Workpart = object being processed
- NC operating principle is to control the motion of the workhead relative to the workpart and to control the sequence in which the motions are carried out

Components of a Numerical Control System

- *Part program* - the detailed set of commands to be followed by the processing equipment
- *Machine control unit* (MCU) - microcomputer that stores and executes the program by converting each command into actions by the processing equipment, one command at a time
- *Processing equipment* - accomplishes the sequence of processing steps to transform starting workpart into completed part

NC Coordinate System

- Consists of three linear axes (*x*, *y*, *z*) of Cartesian coordinate system, plus three rotational axes (*a*, *b*, *c*)
  - Rotational axes are used to orient workpart or workhead to access different surfaces for machining
  - Most NC systems do not require all six axes

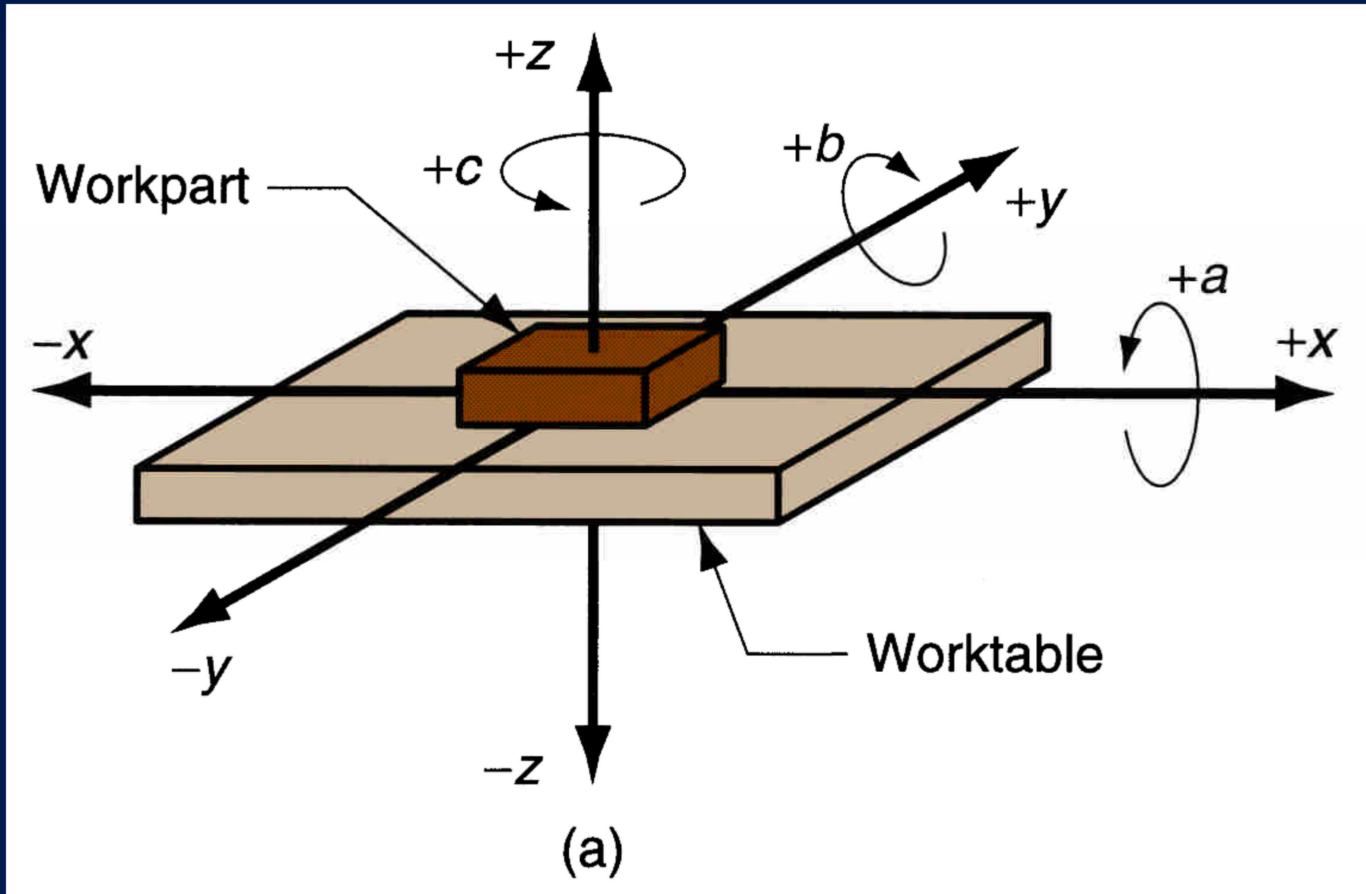


Figure 38.2 - Coordinate systems used in numerical control: (a) for flat and prismatic work

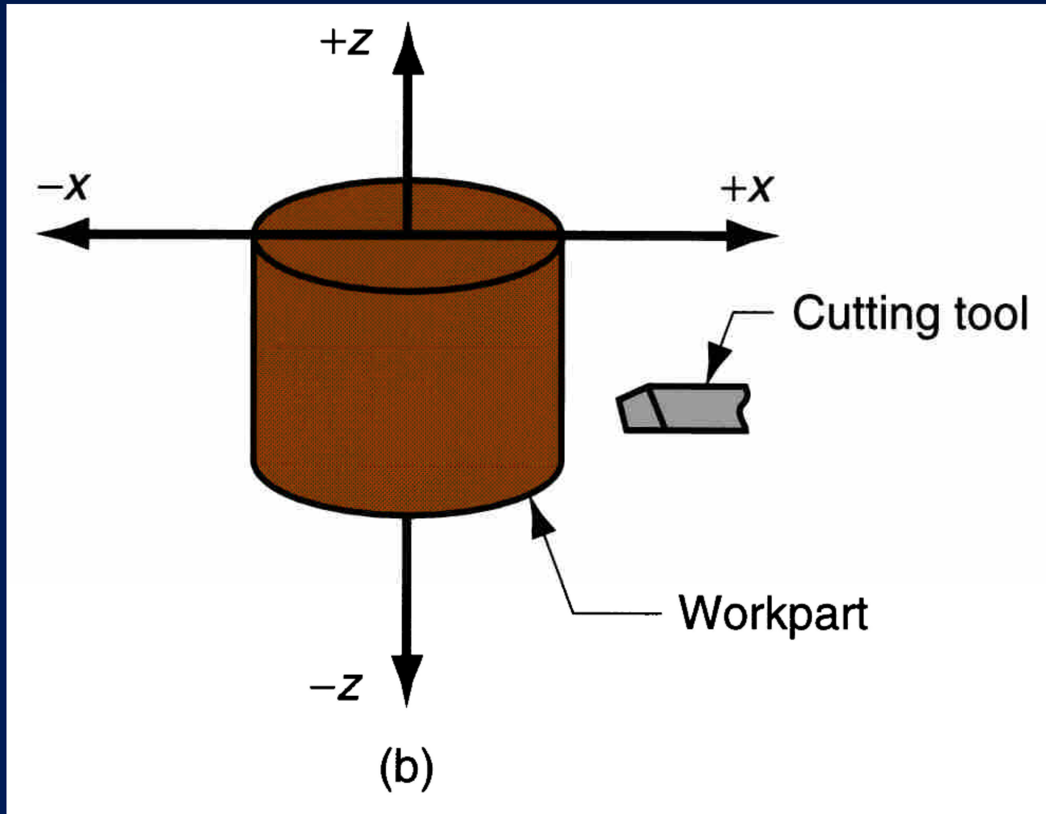


Figure 38.2 - Coordinate systems used in numerical control: (b) for rotational work

NC Motion Control Systems

- Two types:
  1. Point-to-point
  2. Continuous path

Point-to-Point (PTP) System

Workhead (or workpiece) is moved to a programmed location with no regard for path taken to get to that location

- Once the move is completed, some processing action is accomplished by the workhead
  - Examples: drilling or punching a hole
- Thus, the part program consists of a series of point locations at which operations are performed
- Also called *positioning systems*

Continuous Path (CP) System

Continuous simultaneous control of more than one axis, thus controlling path followed by tool relative to part

- Permits tool to perform a process while axes are moving, enabling the system to generate angular surfaces, two-dimensional curves, or 3-D contours in the workpart
  - Examples: many milling and turning operations, flame cutting
- Also called *contouring* in machining operations

Two Types of Positioning

- *Absolute positioning*
  - Locations are always defined with respect to origin of axis system
- *Incremental positioning*
  - Next location is defined relative to present location

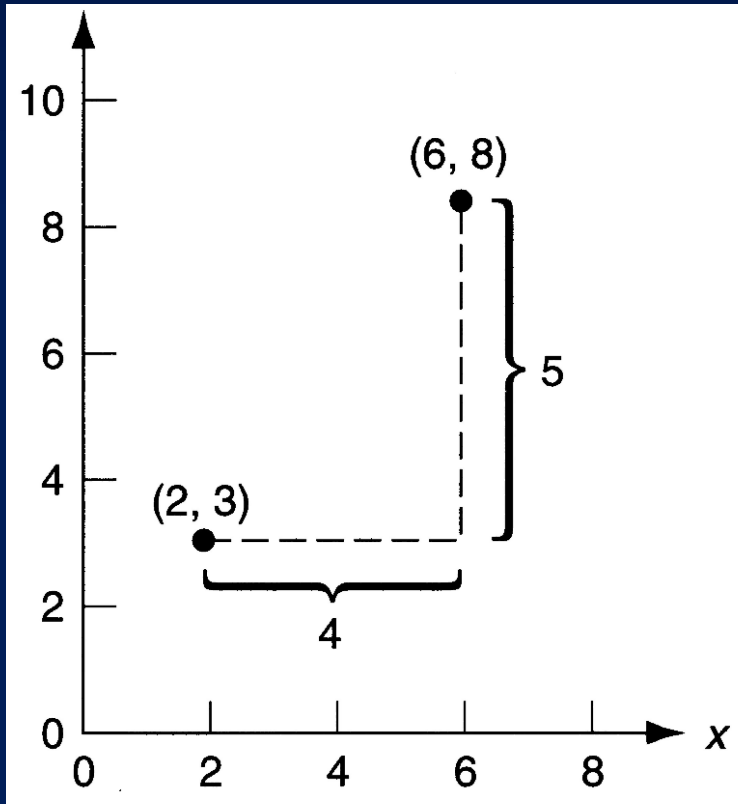


Figure 38.3 - Absolute vs. incremental positioning. The workhead is presently at point (2,3) and is to be moved to point (6,8). In absolute positioning, the move is specified by x = 6, y = 8; while in incremental positioning, the move is specified by x = 4, y = 5

NC Positioning System

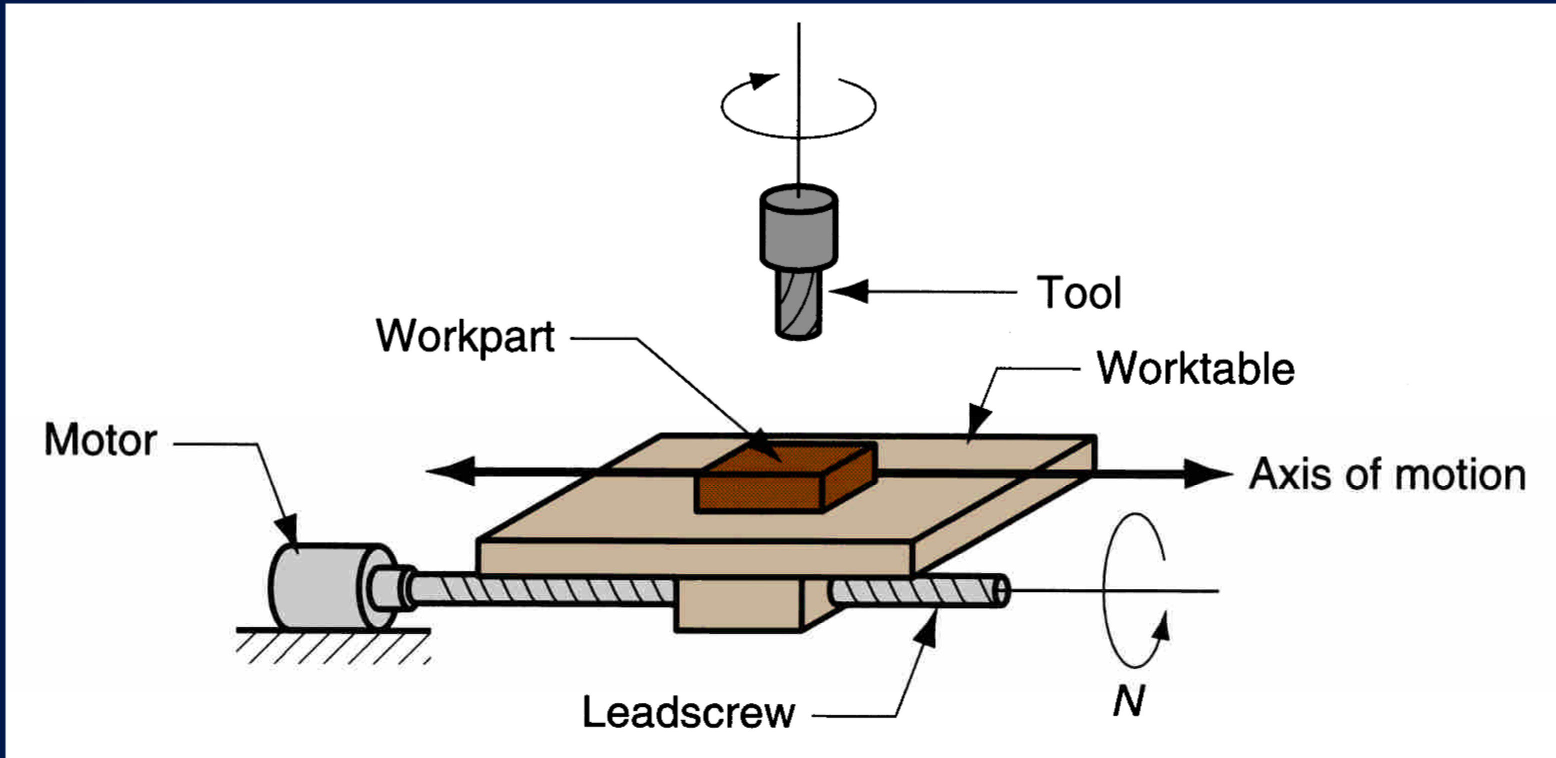


Figure 38.4 - Motor and leadscrew arrangement in a NC positioning system

NC Positioning System

Converts the coordinates specified in the NC part program into relative positions and velocities between tool and workpart during processing

- Leadscrew pitch *p* - table is moved a distance equal to the pitch for each revolution
- Table velocity (e.g., feed rate in machining) is set by the RPM of leadscrew

- To provide *x*-*y* capability, a single-axis system is piggybacked on top of a second perpendicular axis

Two Basic Types of Control in NC

- *Open loop system*
  - Operates without verifying that the actual position is equal to the specified position
- *Closed loop control system*
  - Uses feedback measurement to verify that the actual position is equal to the specified location

Precision in Positioning

- Three critical measures of precision in positioning:
    1. Control resolution
    2. Accuracy
    3. Repeatability

Control Resolution (CR)

Defined as the distance separating two adjacent control points in the axis movement

- Control points are sometimes called *addressable points* because they are locations along the axis to which the worktable can be directed to go
- CR depends on:
  - Electromechanical components of positioning system
  - Number of bits used by controller to define axis coordinate location

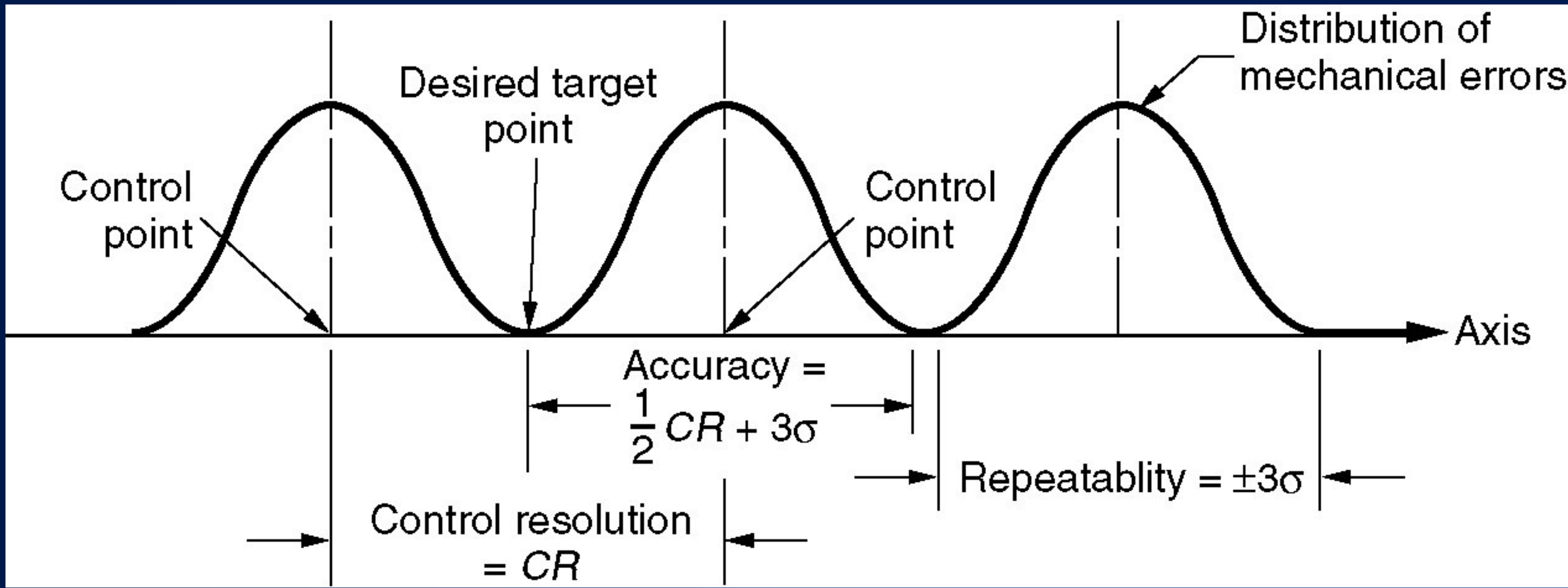


Figure 38.7 - A portion of a linear positioning system axis, with showing control resolution, accuracy, and repeatability

Statistical Distribution of Mechanical Errors

- When a positioning system is directed to move to a given control point, the capability to move to that point is limited by mechanical errors
  - Errors are due to a variety of inaccuracies and imperfections, such as play between leadscrew and worktable, gear backlash, and deflection of machine components
- It is assumed that the errors form an unbiased normal distribution with mean = 0 and that the standard deviation σ is constant over axis range

Accuracy in a Positioning System

Maximum possible error that can occur between desired target point and actual position taken by system

- For one axis:

$$\text{Accuracy} = 0.5\,CR + 3\sigma$$

where CR = control resolution; and σ = standard deviation of the error distribution

Repeatability

Capability of a positioning system to return to a given control point that has been previously programmed

- Repeatability of any given axis of a positioning system can be defined as the range of mechanical errors associated with the axis

$$\text{Repeatability} = \pm 3\sigma$$

NC Part Programming Techniques

1. Manual part programming
2. Computer-assisted part programming
3. CAD/CAM- assisted part programming
4. Manual data input

- Common features:
  - Points, lines, and surfaces of the workpart must be defined relative to NC axis system
  - Movement of the cutting tool must be defined relative to these part features

Manual Part Programming

Uses basic numerical data and special alphanumeric codes to define the steps in the process

- Suited to simple point-to-point machining jobs, such as drilling operations

Manual Part Programming: Example

- Example command for drilling operation:

  n010 x70.0 y85.5 f175 s500

  where *n*-word (n010) = a sequence number; *x*- and *y*-words = *x* and *y* coordinate positions (*x* = 70.0 mm and *y* = 85.5 mm), and *f*-word and *s*-word = feed rate and spindle speed (feed rate = 175 mm/min, spindle speed = 500 rev/min)
- Complete part program consists of a sequence of commands

Computer-Assisted Part Programming

- Uses a high-level programming language
  - Suited to programming of more complex jobs
  - First NC part programming language was *APT* = Automatically Programmed Tooling
  - In APT, part programming is divided into two basic steps:
    1. Definition of part geometry
    2. Specification of tool path and operation sequence

APT Geometry Statements

- Part programmer defines geometry of workpart by constructing it of basic geometric elements such as points, lines, planes, circles, and cylinders
  - Examples:

    P1 = POINT/25.0, 150.0

    L1 = LINE/P1, P2

  where P1 is a point located at x = 25 and y = 150, and L1 is a line through points P1 and P2
- Similar statements are used to define circles, cylinders, and other geometry elements

APT Motion Statements: Point-to-Point (PTP)

- Specification of tool path accomplished with APT motion statements
  - Example statement for point-to-point operation:

    GOTO/P1

- Directs tool to move from current location to P1
  - P1 has been defined by a previous APT geometry statement

APT Motion Statements (CP)

- Use previously defined geometry elements such as lines, circles, and planes.
  - Example command:

    GORGT/L3, PAST, L4

- Directs tool to go right (GORGT) along line L3 until it is positioned just past line L4
  - L4 must be a line that intersects L3

CAD/CAM-Assisted Part Programming

Takes computer-assisted part programming further by using a CAD/CAM system to interact with programmer as part program is being prepared

- In conventional use of APT, program is written and then entered into the computer for processing
  - Programming errors may not be detected until computer processing
- With CAD/CAM, programmer receives immediate visual verification as each statement is entered
  - Errors can be corrected immediately rather than after entire program has been written

Manual Data Input (MDI)

Machine operator enters part program at the machine

- Involves use of a CRT display with graphics capability at machine tool controls
  - NC part programming statements are entered using a menu-driven procedure that requires minimum training of machine tool operator
- Because MDI does not require a staff of NC part programmers, MDI is a way for small machine shops to economically implement NC

Applications of Numerical Control

- Operating principle of NC applies to many operations
  - There are many industrial operations in which the position of a workhead must be controlled relative to the part or product being processed
- Two categories of NC applications:
  1. Machine tool applications
  2. Non- machine tool applications

Machine Tool Applications

- NC is widely used for machining operations such as turning, drilling, and milling
- NC has motivated the development of *machining centers*, which change their own cutting tools to perform a variety of machining operations under NC
- Other NC machine tools:
  - Grinding machines
  - Sheet metal pressworking machines
  - Tube bending machines
  - Thermal cutting processes

Non-Machine Tool Applications

- *Tape laying* machines and *filament winding* machines for composites
- *Welding* machines, both arc welding and resistance welding
- *Component insertion* machines in electronics assembly
- *Drafting* machines
- *Coordinate measuring machines* for inspection

Benefits of NC Relative to Manually Operated Equipment

- Reduced non-productive time which results in shorter cycle times
- Lower manufacturing lead times
- Simpler fixtures
- Greater manufacturing flexibility
- Improved accuracy
- Reduced human error

Industrial Robotics

An *industrial robot* is a general purpose programmable machine that possesses certain anthropomorphic features

- The most apparent anthropomorphic feature of an industrial robot is its mechanical arm, or manipulator
- Robots can perform a variety of tasks such as loading and unloading machine tools, spot welding automobile bodies, and spray painting
- Robots are typically used as substitutes for human workers in these tasks

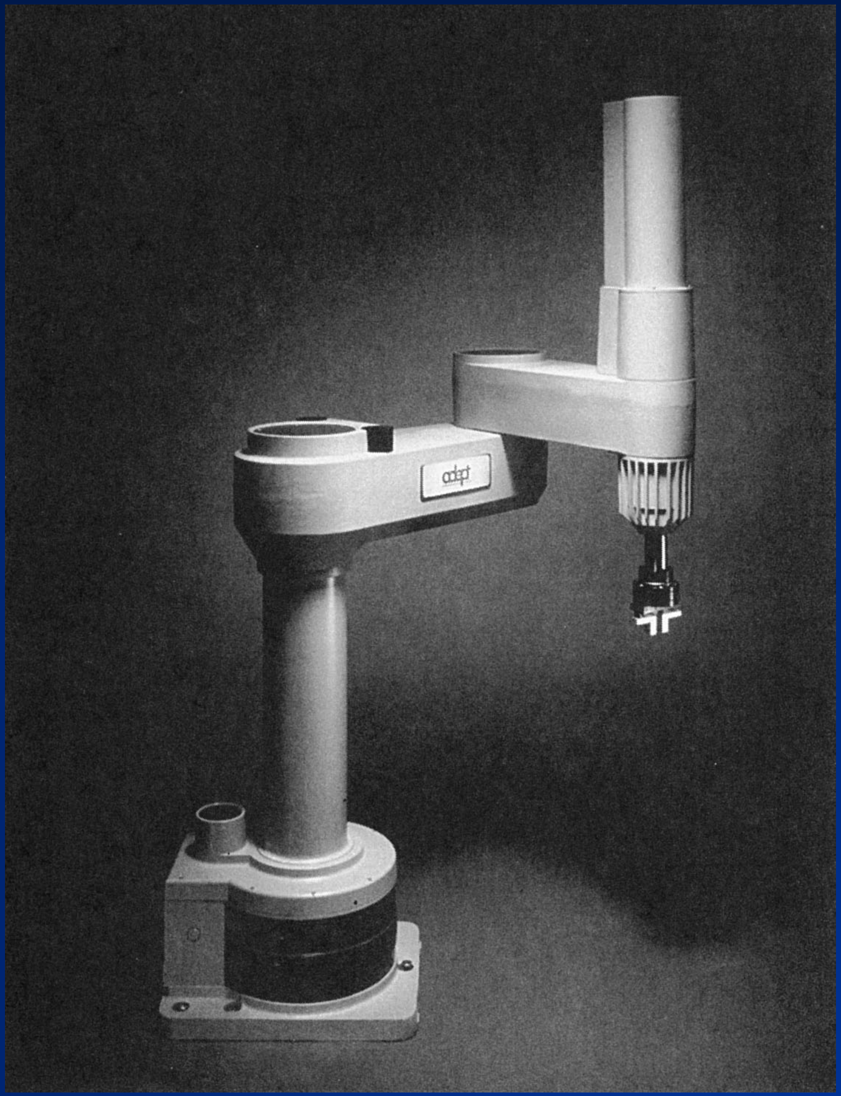
Robot Anatomy

- An industrial robot consists of a mechanical manipulator and a controller to move it and perform other related functions
  - The *mechanical manipulator* consists of joints and links to position and orient the end of the manipulator relative to its base
  - The *controller* operates the joints in a coordinated fashion to execute a programmed work cycle

Figure 38.8 -

The manipulator of a modern industrial robot

(photo courtesy of Adept Technology, Inc.)



Manipulator Joints and Links

- A robot joint is similar to a human body joint
  - It provides relative movement between two parts of the body
- Typical industrial robots have five or six joints
  - Manipulator joints: classified as linear or rotating
  - Each joint moves its output link relative to its input link
  - Coordinated movement of joints gives the robot its ability to move, position, and orient objects

Manipulator Design

- Robot manipulators can usually be divided into two sections:
  - Arm-and-body assembly - function is to *position* an object or tool
  - Wrist assembly - function is to properly *orient* the object or tool
- There are typically three joints associated with the arm-and-body assembly, and two or three joints associated with the wrist

Manipulator Wrist

- The wrist is assembled to the last link in any of these arm-and-body configurations
- The SCARA is sometimes an exception because it is almost always used for simple handling and assembly tasks involving vertical motions
  - A wrist is not usually present at the end of its manipulator
  - Substituting for the wrist on the SCARA is usually a gripper to grasp components for movement and/or assembly

End Effectors

The special tooling that connects to the robot's wrist to perform the specific task

- Two general types:
  1. Tools - used for a processing operation
     - Applications: spot welding guns, spray painting nozzles, rotating spindles, heating torches, assembly tools
  2. Grippers - designed to grasp and move objects
     - Applications: part placement, machine loading and unloading, and palletizing

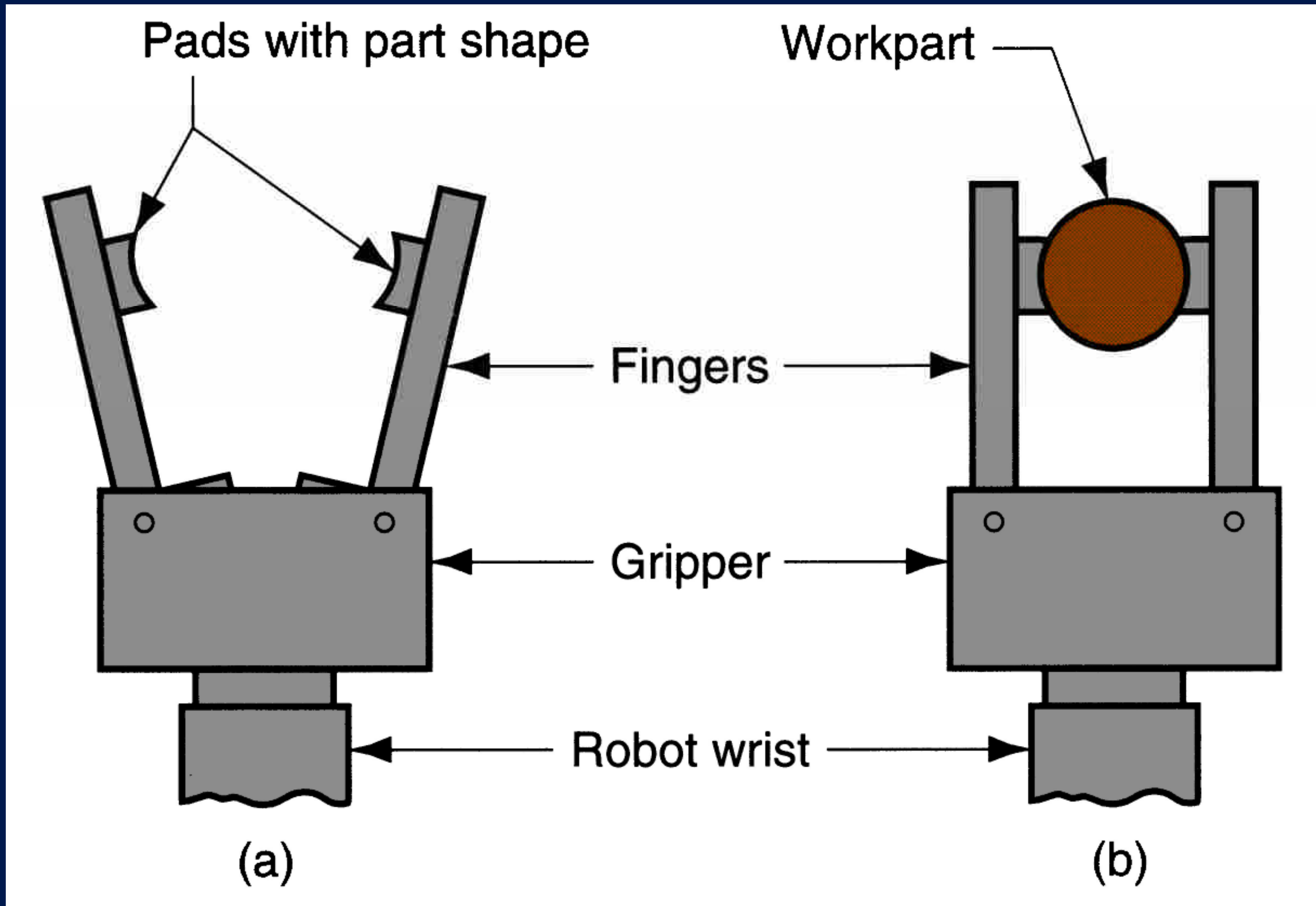


Figure 38.10 - A robot gripper:
(a) open and (b) closed to grasp a workpart

Robot Programming

- Robots execute a stored program of instructions which define the sequence of motions and positions in the work cycle
  - Much like a NC part program
- In addition to motion instructions, the program may include commands for other functions such as:
  - Interacting with external equipment
  - Responding to sensors
  - Processing data

Two Basic Teach Methods in Robot Programming

1. *Leadthrough programming* - "teach-by-showing" in which manipulator is moved through the sequence of positions in the work cycle and the controller records each position in memory for subsequent playback
2. *Computer programming languages* – robot program is prepared at least partially off-line for subsequent downloading to computer

Where Should Robots be Used in the Workplace?

- Work environment is hazardous for humans
- Work cycle is repetitive
- The work is performed at a stationary location
- Part or tool handling is difficult for humans
- Multi-shift operation
- Long production runs and infrequent changeovers
- Part positioning and orientation are established at the beginning of work cycle, since most robots cannot see

Applications of Industrial Robots

- Three basic categories:
  1. Material handling
  2. Processing operations
  3. Assembly and inspection

Programmable Logic Controller (PLC)

Microcomputer-based device that uses stored instructions in programmable memory to implement logic, sequencing, timing, counting, and arithmetic control functions, through digital or analog input/output modules, for controlling various machines and processes

- Introduced around 1969 in response to specifications proposed by General Motors Corporation
  - Controls manufacturers saw a commercial opportunity, and today PLCs are an important industrial controls technology

Why PLCs are Important

- Many automated systems operate by turning on and off motors, switches, and other devices to respond to conditions and as a function of time
- These devices use binary variables that have two possible values, 1 or 0, which means ON or OFF, object present or not present, high or low voltage
- Common binary devices used in industrial control: limit switches, photodetectors, timers, control relays, motors, solenoids, valves, clutches, and lights
- Some devices send a signal in response to a physical stimulus, while others respond to an electrical signal

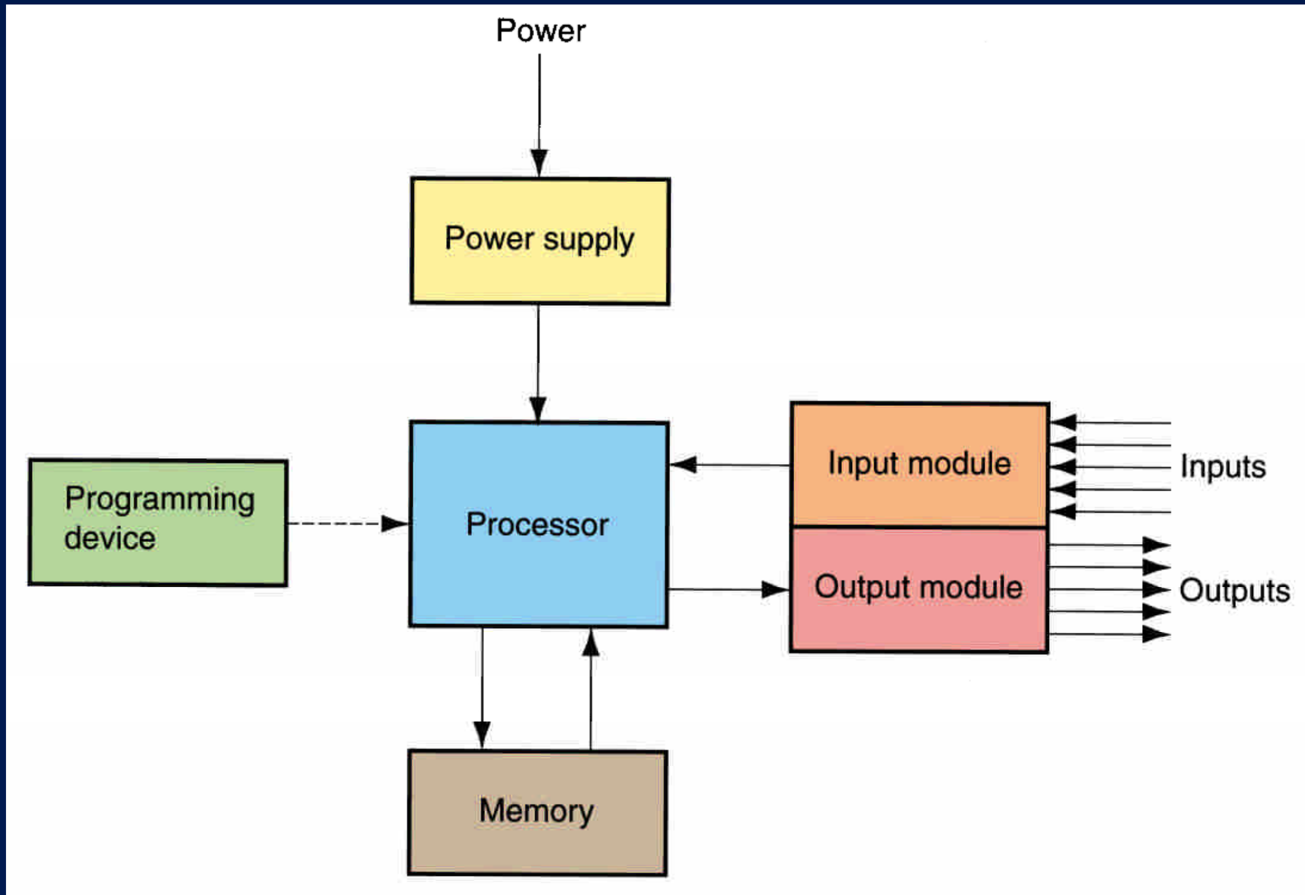


Figure 38.12 - Major components of a programmable logic controller

PLC Programming

- Most common control instructions include logical operations, sequencing, counting, and timing
- Many control applications require additional instructions for analog control, data processing, and computations
- A variety of PLC programming languages have been developed, ranging from ladder logic diagrams to structured text