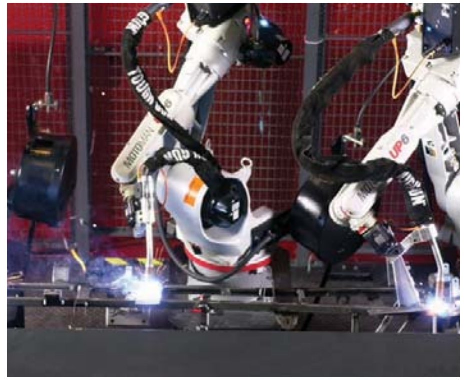


Chapter 2

Fundamentals of Robotics

Chapter Topics

Objectives

Upon completion of this chapter, you will be able to:

- Identify the parts of a robot.
- Explain degrees of freedom.
- Discuss the difference between servo and non-servo robots.
- Identify and explain the different robot configurations.

Technical Terms

actuator
Cartesian configuration
closed-loop system
controller
cylindrical configuration
degrees of freedom
direct-drive motor
end effector
error signal
hierarchical control
hydraulic drive
linear actuator
manipulator
non-servo robot
open-loop system
pitch
pneumatic drive
power supply
program
radial traverse
revolute configuration
roll
rotary actuator
rotational traverse
SCARA
servo amplifier
servo robot
spherical configuration
tachometer
teach pendant
trajectory
vertical traverse
work envelope
yaw

Overview

Even the most complex robotic system can be broken down into a few basic components, which provide an overview of how a robot works. These components are covered in this chapter, with more detail provided in later chapters. Freedom of motion and the resulting shape of the robot's work area are also addressed in this chapter.

2.1 Parts of a Robot

Robots come in many shapes and sizes. The industrial robots illustrated in **Figure 2-1** resemble an inverted human arm mounted on a base. Robots consist of a number of components, **Figure 2-2**, that work together: the controller, the manipulator, an end effector, a power supply, and a means for programming. The relationship among these five components is illustrated in **Figure 2-3**.

Figure 2-1. This robot has been designed expressly for use in precise path-oriented tasks such as deburring, milling, sanding, gluing, bonding, cutting, and assembly. (Reis Machines, Inc.)

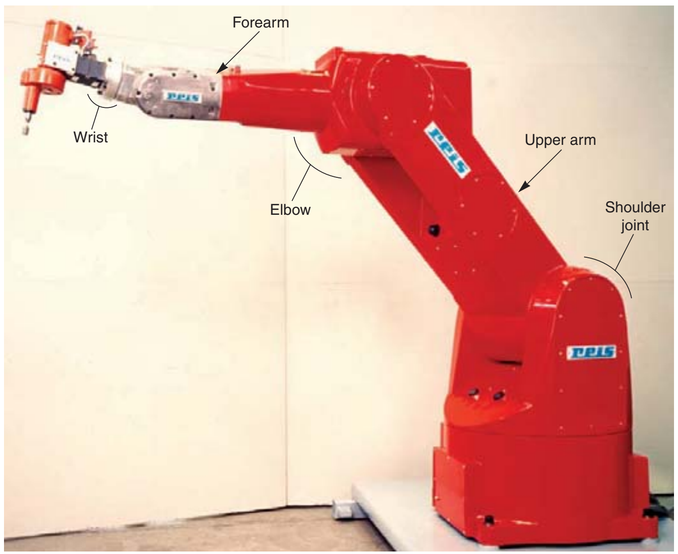


Figure 2-2. This robot illustrates the systems of a typical industrial robot. This electric robot can be used in a variety of industrial applications. (ABB Robotics)

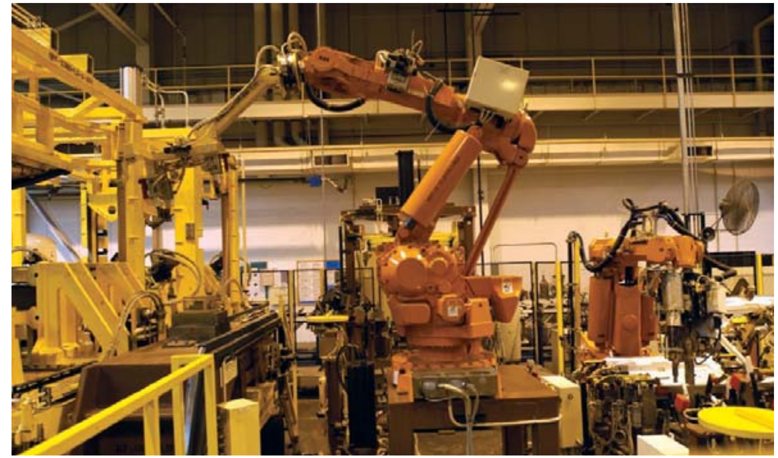
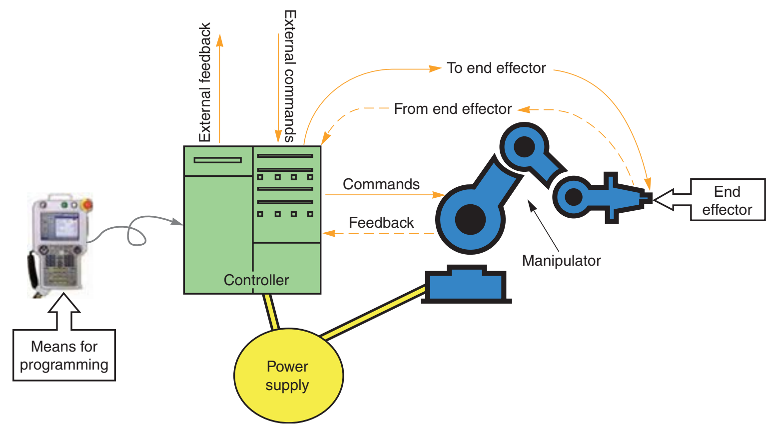


Figure 2-3. The relationships among the five major systems that make up an industrial robot are shown in this diagram.



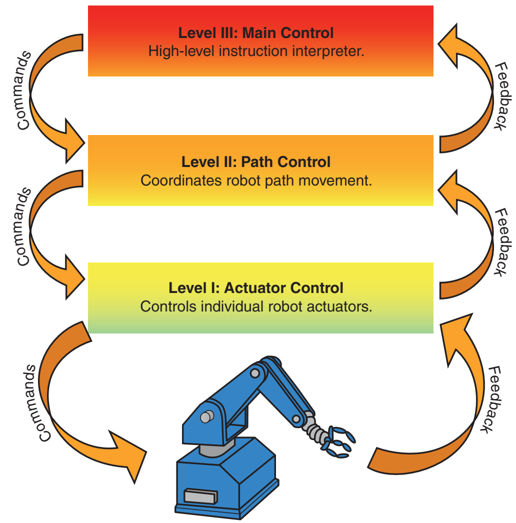
Controller

The ***controller*** is the part of a robot that coordinates all movements of the mechanical system, **Figure 2-4**. It also receives input from the immediate environment through various sensors. The heart of the robot's controller is generally a microprocessor linked to input/output and monitoring devices. The commands issued by the controller activate the motion control mechanism, consisting of various controllers, amplifiers, and actuators. An ***actuator*** is a motor or valve that converts power into robot movement. This movement is initiated by a series of instructions, called a ***program***, stored in the controller's memory.

The controller has three levels of ***hierarchical control***. Hierarchical control assigns levels of organization to the controllers within a robotic system. Each level sends control signals to the level below and feedback signals to the level above. The levels become more elemental as they progress toward the actuator. Each level is dependent on the level above it for instructions, **Figure 2-5**.

Figure 2-4. A controller/power supply with a teach pendant. (Motoman)

Figure 2-5. The three basic levels of hierarchical control.



The three levels are:

- **Level I—Actuator Control.** The most elementary level at which separate movements of the robot along various planes, such as the X, Y, and Z axes, are controlled. These movements will be explained in detail later in this chapter.
- **Level II—Path Control.** The path control (intermediate) level coordinates the separate movements along the planes determined in Level I into the desired ***trajectory*** or path.
- **Level III—Main Control.** The primary function of this highest control level is to interpret the written instructions from the human programmer regarding the tasks required. The instructions are then combined with various environmental signals and translated by the controller into the more elementary instructions that Level II can understand.

Manipulator

The manipulator consists of segments that may be jointed and that move about, allowing the robot to do work. The ***manipulator*** is the arm of the robot (see **Figures 2-2** and **2-3**) which must move materials, parts, tools, or special devices through various motions to provide useful work. A manipulator can be identified by method of control, power source, actuation of the joints, and other factors. These factors help identify the best type of robot for the task at hand. For example, you would not use an electric robot in an environment where combustible fumes exist and a spark could cause an explosion.

The manipulator is made up of a series of segments and joints much like those found in the human arm. Joints connect two segments together and allow them to move relative to one another. The joints provide either linear (straight line) or rotary (circular) movement, **Figure 2-6**.

The muscles of the human body supply the driving force that moves the various body joints. Similarly, a robot uses actuators to move its arm along programmed paths and then to hold its joints rigid once the correct position is reached. There are two basic types of motion provided by actuators: linear and rotary, **Figure 2-7**. ***Linear actuators*** provide motion along a straight line; they extend or retract their attached loads. ***Rotary actuators*** provide rotation, moving their loads in an arc or circle. Rotary motion can be converted into linear motion using a lead screw or other mechanical means of conversion. These types of actuators are also used outside the robot to move workpieces and provide other kinds of motion within the work envelope.

Figure 2-6. Both linear and rotary joints are commonly found in robots.

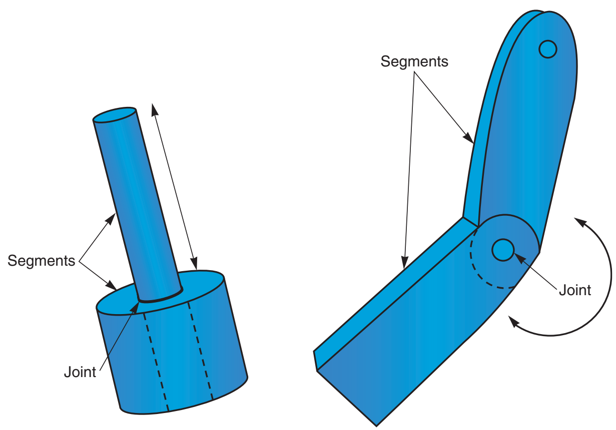


Figure 2-7. Actuators can be powered by electric motors, pneumatic (air) cylinders, or hydraulic (oil) cylinders. Linear actuators provide straight-line movement. Rotational movement around an axis is provided by the angular (rotary) actuator. (PHD, Inc.)

A ***tachometer*** is a device used to measure the speed of an object. In the case of robotic systems, a tachometer is used to monitor acceleration and deceleration of the manipulator's movements.

End Effector

The ***end effector*** is the robot's hand, or the end-of-arm tooling on the robot. It is a device attached to the wrist of the manipulator for the purpose of grasping, lifting, transporting, maneuvering, or performing operations on a workpiece. The end effector is one of the most important components of a robot system. The robot's performance is a direct result of how well the end effector meets the task requirements. The area within reach of the robot's end effector is called its ***work envelope***.

Power Supply

The ***power supply*** provides the energy to drive the controller and actuators. It may convert ac voltage to the dc voltage required by the robot's internal circuits, or it may be a pump or compressor providing hydraulic or pneumatic power. The three basic types of power supplies are electrical, hydraulic, and pneumatic.

The most common energy source available, where industrial robots are used, is electricity. The second most common is compressed air, and the least common is hydraulic power. These primary sources of energy must be converted into the form and amount required by the type of robot being used. The electronic part of the control unit, and any electric drive actuator, requires electrical power. A robot containing hydraulic actuators requires the conversion of electrical power into hydraulic energy through the use of an electric, motor-driven, hydraulic pump. A robot with pneumatic actuators requires compressed air, which is usually supplied by a compressor driven by an electric motor.

Means for Programming

The means for programming is used to record movements into the robot's memory. A robot may be programmed using any of several different methods. The ***teach pendant***, also called a teach box or hand-held programmer, **Figure 2-8**, teaches a robot the movements required to perform a useful task. The operator uses a teach pendant to move the robot through the series of points that describe its desired path. The points are recorded by the controller for later use.

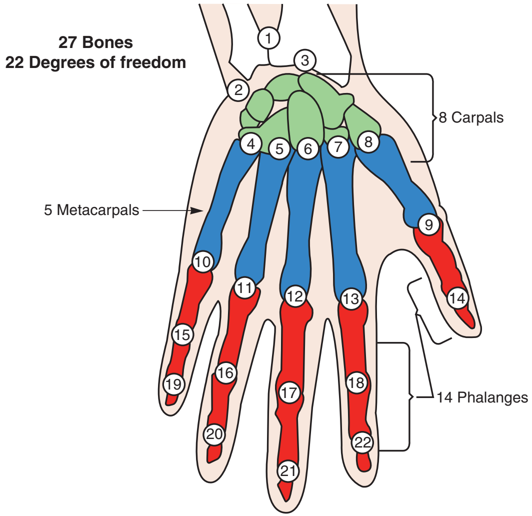
2.2 Degrees of Freedom

Although robots have a certain amount of dexterity, it does not compare to human dexterity. The movements of the human hand are controlled by 35 muscles. Fifteen of these muscles are located in the forearm. The arrangement of muscles in the hand provides great strength to the fingers and thumb for grasping objects. Each finger can act alone or together with the thumb. This enables the hand to do many intricate and delicate tasks. In addition, the human hand has 27 bones. **Figure 2-9** shows the bones found in the hand and wrist. This bone, joint, and muscle arrangement gives the hand its dexterity.

Degrees of freedom (DOF) is a term used to describe a robot's freedom of motion in three dimensional space—specifically, the ability to move forward and backward, up and down, and to the left and to the right. For each degree of freedom, a joint is required. A robot requires six degrees of

Figure 2-8. This teach pendant is connected to a controller and is used to teach a robot how to complete a task. (Motoman)

Figure 2-9. The arrangement of bones and joints found in the human hand provides dexterity. Each joint represents a degree of freedom; there are 22 joints, and thus, 22 degrees of freedom in the human hand.



freedom to be completely versatile. Its movements are clumsier than those of a human hand, which has 22 degrees of freedom.

The number of degrees of freedom defines the robot's configuration. For example, many simple applications require movement along three axes: X, Y, and Z. See **Figure 2-10**. These tasks require three joints, or three degrees of freedom. The three degrees of freedom in the robot arm are the rotational traverse, the radial traverse, and the vertical traverse. The ***rotational traverse*** is movement on a vertical axis. This is the side-to-side swivel of the robot's arm on its base. The ***radial traverse*** is the extension and retraction of the arm, creating in-and-out motion relative to the base. The ***vertical traverse*** provides up-and-down motion.

For applications that require more freedom, additional degrees can be obtained from the wrist, which gives the end effector its flexibility. The three degrees of freedom in the wrist have aeronautical names: pitch, yaw, and roll. See **Figure 2-11**. The ***pitch***, or bend, is the up-and-down movement of the wrist. The ***yaw*** is the side-to-side movement, and the ***roll***, or swivel, involves rotation.

Figure 2-10. The three basic degrees of freedom are associated with movement along the X, Y, and Z axes of the Cartesian coordinate system.

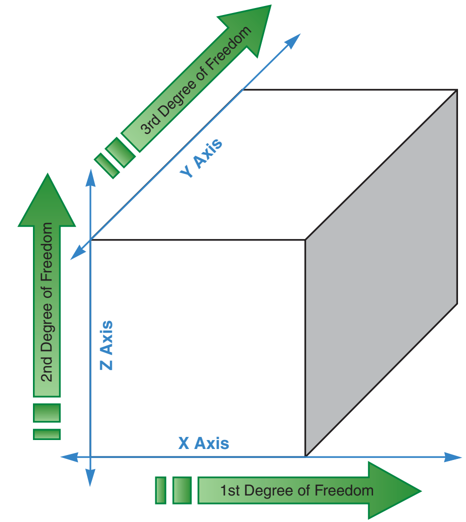
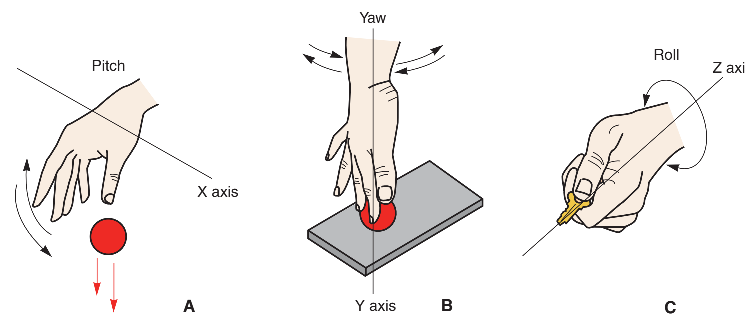


Figure 2-11. Three additional degrees of freedom—pitch, yaw, and roll—are associated with the robot's wrist. (Mack Corporation)



A robot requires a total of six degrees of freedom to locate and orient its hand at any point in its work envelope, **Figure 2-12**. Although six degrees of freedom are required for maximum flexibility, most applications require only three to five. When more degrees of freedom are required, the robot's motions and controller design become more complex. Some industrial robots have seven or eight degrees of freedom. These additional degrees are achieved by mounting the robot on a track or moving base, as shown in **Figure 2-13**. The track-mounted robot shown in **Figure 2-14** has a total of seven degrees of freedom. This addition also increases the robot's reach.

Although the robot's freedom of motion is limited in comparison with that of a human, the range of movement in each of its joints is considerably greater. For example, the human hand has a bending range of only about 165 degrees. The illustrations in **Figure 2-15** show the six major degrees of freedom by comparing those of a robot to a person using a spray gun.

2.3 Classifying Robots

Robots can be classified in various ways, depending on their components, configuration, and use. Three common methods of classifying robots are by the types of control system used, the type of actuator drive used, and the shape of the work envelope.

Figure 2-12. Six degrees of freedom provide maximum flexibility for an industrial robot.

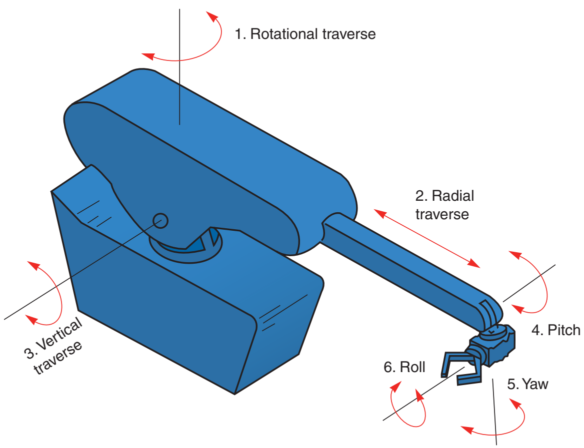


Figure 2-13. Using a gantry robot creates a large work envelope (A) because the manipulator arm is mounted on tracks (B). (Schunk)

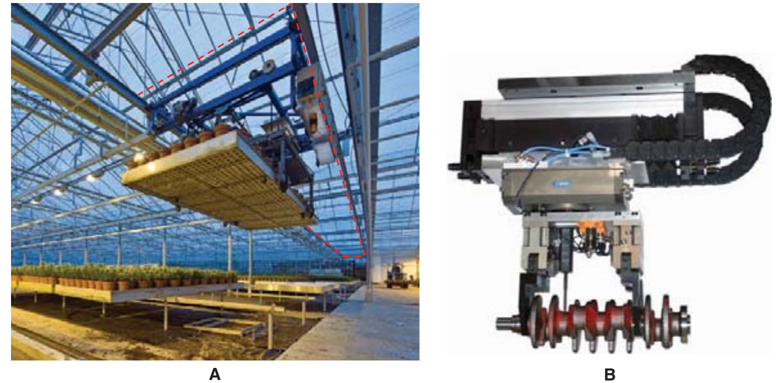
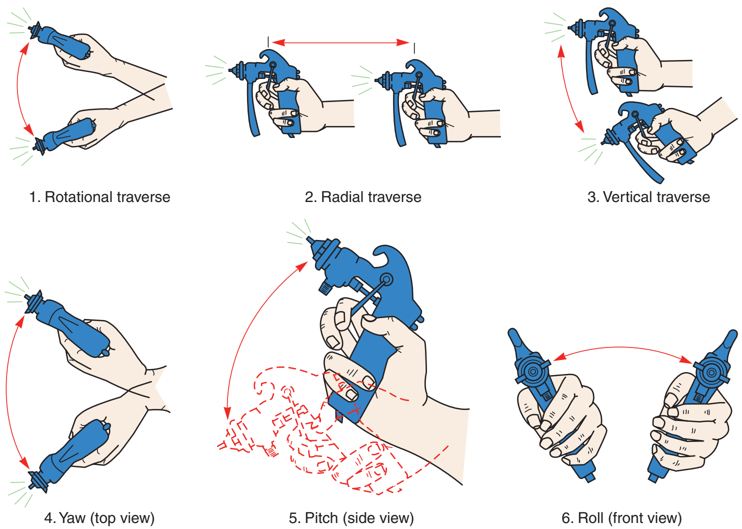


Figure 2-14. Mounting this robot on tracks gives the system seven degrees of freedom—six from the configuration of the robot and one additional degree from the track mount.

Figure 2-15. The six degrees of freedom, demonstrated by a person using a spray gun. Illustrations 1, 2, and 3 are arm movements. Illustrations 4, 5, and 6 are wrist movements.



Type of Control System

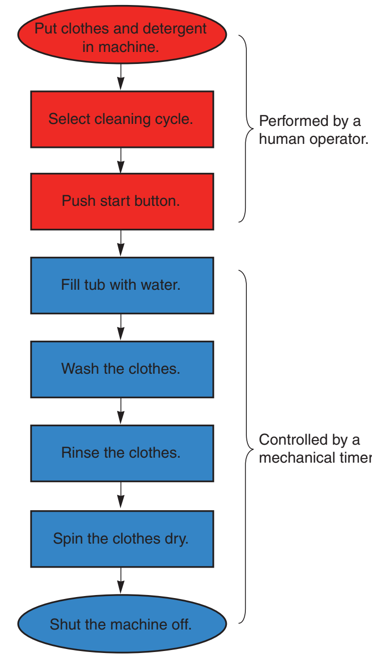
Robots may use one of two control systems—non-servo and servo. The earliest type of robot was non-servo, which is considered a non-intelligent robot. The second classification is the servo robot. These robots are classified as either intelligent or highly intelligent. The primary difference between an intelligent and highly intelligent robot is the level of awareness of its environment.

Non-Servo Robots

Non-servo robots are the simplest robots and are often referred to as "limited sequence," "pick-and-place," or "fixed-stop robots." The non-servo robot is an open-loop system. In an ***open-loop system***, no feedback mechanism is used to compare programmed positions to actual positions.

A good example of an open-loop system is the operating cycle of a washing machine, **Figure 2-16**. At the beginning of the operation, the dirty clothes and the detergent are placed in the machine's tub. The cycle selector is set for the proper

Figure 2-16. This block diagram depicts the sequence of steps performed by a washing machine. Notice that no feedback is used. In such an open-loop control system, the condition of the clothes during the washing operation is not monitored and used to alter the process.



cleaning cycle and the machine is activated by the start button. The machine fills with water and begins to go through the various washing, rinsing, and spinning cycles. The machine finally stops after the set sequence is completed. The washing machine is considered an open-loop system for two reasons:

- The clothes are never examined by sensors during the washing cycle to see if they are clean.
- The length of the cycle is not automatically adjusted to compensate for the amount of dirt remaining in the clothes. The cycle and its time span are determined by the fixed sequence of the cycle selector.

Non-servo robots are also limited in their movement and these limitations are usually in the form of a mechanical stop. This form of robot is excellent in repetitive tasks, such as material transfer. One may question if the non-servo robots qualify as a robot based on the definition provided by the Robot Institute of America. However, if these robots are equipped with a programmable logic controller (PLC) they easily meet the requirement of a reprogrammable device, thus allowing them to be classified as a robot.

The diagram in **Figure 2-17** represents a pneumatic (air-controlled), non-servo robot.

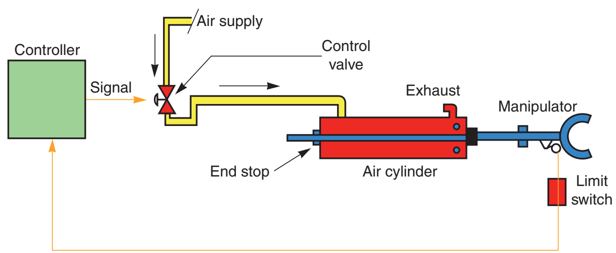
1. At the beginning of the cycle, the controller sends a signal to the control valve of the manipulator.
2. As the valve opens, air passes into the air cylinder, causing the rod in the cylinder to move. As long as the valve remains open, this rod continues to move until it is restrained by the end stop.
3. After the rod reaches the limit of its travel, a limit switch tells the controller to close the control valve.
4. The controller sends the control valve a signal to close.
5. The controller then moves to the next step in the program and initiates the necessary signals. If the signals go to the robot's end effector, for example, they might cause the gripper to close in order to grasp an object.

The process is repeated until all the steps in the program have been completed.

Characteristics of non-servo robots:

- Relatively inexpensive compared to servo robots.
- Simple to understand and operate.
- Precise and reliable.

Figure 2-17. In a non-servo system, movement is regulated by devices such as a limit switch, which signals the controller when it is activated.



- Simple to maintain.
- Capable of fairly high speeds of operation.
- Small in size.
- Limited to relatively simple programs.

Servo Robots

The ***servo robot*** is a closed-loop system because it allows for feedback. In a ***closed-loop system***, the feedback signal sent to the ***servo amplifier*** affects the output of the system. A servo amplifier translates signals from the controller into motor voltage and current signals. Servo amplifiers are used in motion control systems where precise control of position or velocity is necessary. In a sense, a servomechanism is a type of control system that detects and corrects for errors. **Figure 2-18** shows a block diagram of a servo robot system.

The principle of servo control can be compared to many tasks performed by human beings. One example is cutting a circle from a piece of stock on a power bandsaw, shown in **Figure 2-19**. The machine operator's eye studies the position of the stock to be cut in relation to the cutting edge of the blade. The eye transmits a signal to the brain. The brain compares the actual position to the desired position. The brain then sends a signal to the arms to move the stock beneath the cutting edge of the blade. The eyes are used as a feedback sensing device, while the brain compares desired locations with

Figure 2-18. A servo robot system, such as the one depicted in this block diagram, might be classified as intelligent or highly intelligent, depending on the level of sensory data it can interpret. Components in the shaded area are part of the control system.

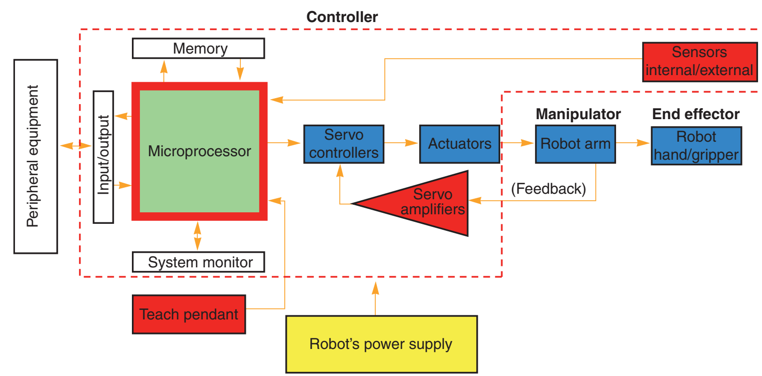
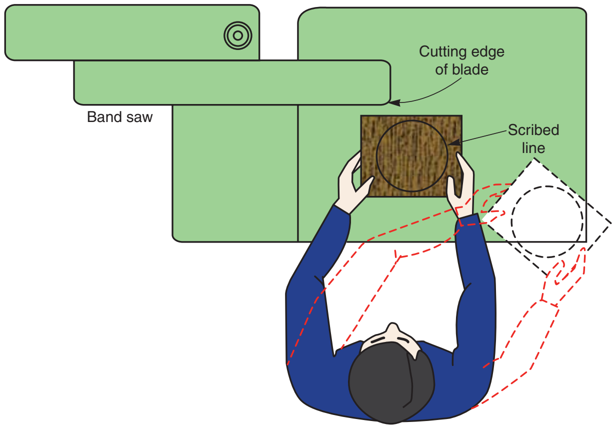


Figure 2-19. Human beings make use of the servomechanism principle for many tasks, such as cutting a circle on a bandsaw.

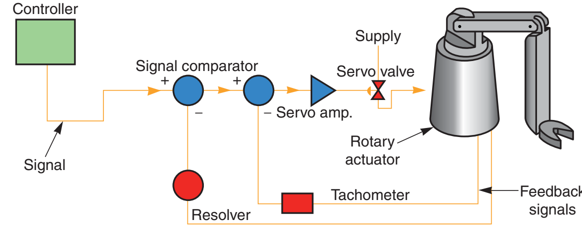


actual locations. The brain sends signals to the arms to make necessary adjustments. This process is repeated as the operator follows the scribed line during the sawing operation.

The diagram in **Figure 2-20** details one of the axes used in a hydraulic robot and helps to explain its operation.

1. When the cycle begins, the controller searches the robot's programming for the desired locations along each axis.
2. Using the feedback signals, the controller determines the actual locations on the various axes of the manipulator.
3. The desired locations and actual locations are compared.
4. When these locations do not match, an ***error signal*** is generated and fed back to the servo amplifier. The greater the error, the higher the intensity of the signal.
5. These error signals are increased by the servo amplifier and applied to the control valve on the appropriate axis.
6. The valve opens in proportion to the intensity of the signal received. The opened valve admits fluid to the proper actuator to move the various segments of the manipulator.
7. New signals are generated as the manipulator moves.

Figure 2-20. Feedback signals from sensors allow the system to make corrections whenever the actual speed or position of the robot does not agree with the values contained in the robot's program.



8. The servo control valves close when there are no more error signals, shutting off the flow of fluid.
9. The manipulator comes to rest at the desired position.
10. The controller then addresses the next instruction in the program, which may be to move to another location or operate some peripheral equipment.

The process is repeated until all steps of the program are completed. Characteristics of servo robots:

- Relatively expensive to purchase, operate, and maintain.
- Use a sophisticated, closed-loop controller.
- Wide range of capabilities.
- Can transfer objects from one point to another, as well as along a controlled, continuous path.
- Respond to very sophisticated programming.
- Use a manipulator arm that can be programmed to avoid obstructions within the work envelope.

Type of Actuator Drive

One common method of classifying robots is the type of drive required by the actuators.

- Electrical actuators use electric power.
- Pneumatic actuators use pneumatic (air) power.
- Hydraulic actuators, **Figure 2-21**, use hydraulic (fluid) power.

Figure 2-21. A large hydraulic actuator provides up-and-down motion to the manipulator arm of this industrial robot. (FANUC Robotics)

Electric Drive

Three types of motors are commonly used for electric actuator drives: ac servo motors, dc servo motors, and stepper motors. Both ac and dc servo motors have built-in methods for controlling exact position. Many newer robots use servo motors rather than hydraulic or pneumatic ones. Small and medium-size robots commonly use dc servo motors. Because of their high torque capabilities, ac servo motors are found in heavy-duty robots, **Figure 2-22**. A stepper motor is an incrementally controlled dc motor. Stepper motors are rarely used in commercial industrial robots, but are commonly found in educational robots, **Figure 2-23**.

Conventional, electric-drive motors are quiet, simple, and can be used in clean-air environments. Robots that use electric actuator drives require less floor space, and their energy source is readily available. However, the conventionally geared drive causes problems of backlash, friction, compliance, and wear. These problems cause inaccuracy, poor dynamic response, need for regular maintenance, poor torque control capability, and limited maximum speed on longer moves. Loads that are heavy enough to stall (stop) the motor can cause damage. Conventional electric-drive motors also have poor output power compared to their weight. This means that a larger, heavier motor must be mounted on the robot arm when a large amount of torque is needed.

Figure 2-22. This heavy-duty industrial robot uses two ac servo motors in the operation of its manipulator arm. (Motoman)

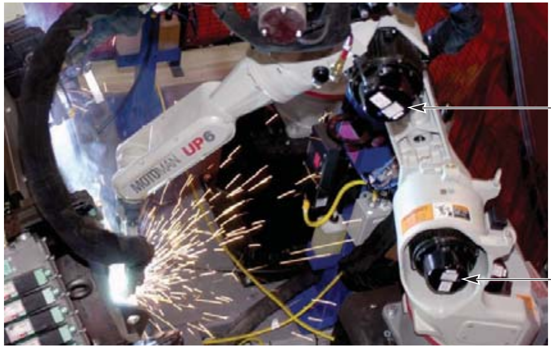


Figure 2-23. DC stepper motors are used on this tabletop educational robot. (Techno, Inc.)

The rotary motion of most electric actuator drives must be geared down (reduced) to provide the speed or torque required by the manipulator. However, manufacturers are beginning to offer robots that use ***direct-drive motors***, which eliminate some of these problems. These high-torque motors drive the arm directly, without the need for reducer gears. The prototype of a direct-drive arm was developed by scientists at Carnegie-Mellon University in 1981.

The basic construction of a direct-drive motor is shown in **Figure 2-24**. Coupling the motor with the arm segment to be manipulated eliminates backlash, reduces friction, and increases the mechanical stiffness of the drive mechanism. Compare the design of a robot arm using a direct-drive motor in **Figure 2-25** to one with a conventional electric-drive (**Figure 2-22**). Using direct-drive motors in robots results in a more streamlined design. Maintenance requirements are also reduced. Robots that use direct-drive motors operate at higher speeds, with greater flexibility, and greater accuracy than those that use conventional electric-drive motors.

Applications currently being performed by robots with direct-drive motors are mechanical assembly, electronic assembly, and material handling. These robots will increasingly meet the demands of advanced, high-speed, precision applications.

Hydraulic Drive

Many earlier robots were driven by hydraulic actuator drives. A ***hydraulic drive*** system uses fluid and consists of a pump connected to a reservoir tank,

Figure 2-24. This drawing shows the basic construction of a direct-drive motor.

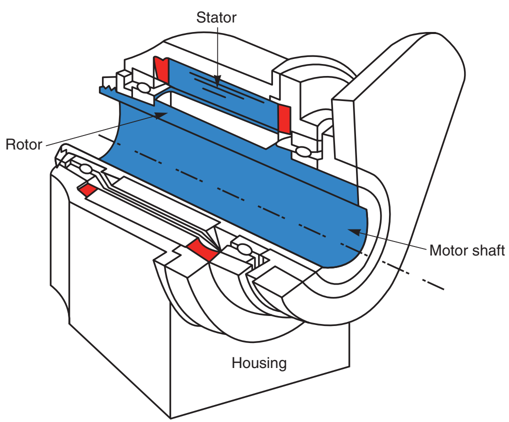


Figure 2-25. Note the simplified mechanical design of this direct-drive robot as compared to the conventional electric-drive robot shown in Figure 2-22. (Adept Technology, Inc.)

control valves, and a hydraulic actuator. Hydraulic drive systems provide both linear and rotary motion using a much simpler arrangement than conventional electric-drive systems, **Figure 2-26**. The storage tank supplies a large amount of instant power, which is not available from electric-drive systems.

Hydraulic actuator drives have several advantages. They provide precise motion control over a wide range of speeds. They can handle heavy loads on the end of the manipulator arm, can be used around highly explosive materials, and are not easily damaged when quickly stopped while carrying a heavy load. However, they are expensive to purchase and maintain and are not energy efficient. Hydraulic actuator drivers are also noisier than electric-drive actuators and are not recommended for clean-room environments due to the possibility of hydraulic fluid leaks.

Pneumatic Drive

Pneumatic drive systems make use of air-driven actuators. Since air is also a fluid, many of the same principles that apply to hydraulic systems are applicable to pneumatic systems. Pneumatic and hydraulic motors and cylinders are very similar. Since most industrial plants have a compressed

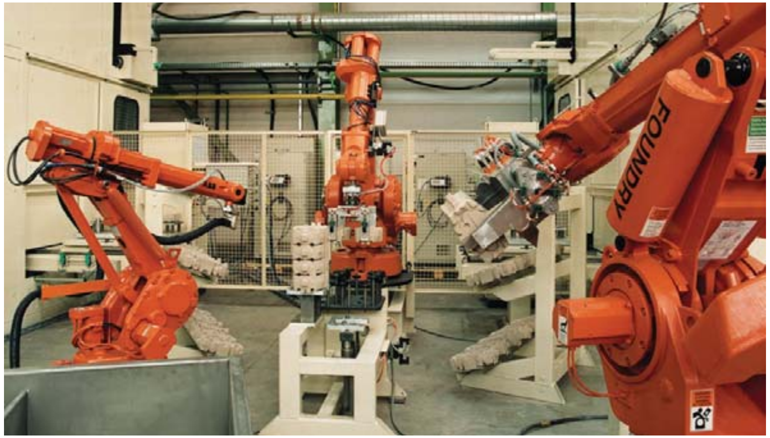


Figure 2-26. Large robots that use hydraulic drive systems perform a demonstration at a manufacturing trade show. (ABB Robotics)

air system running throughout assembly areas, air is an economical and readily available energy source. This makes the installation of robots that use pneumatic actuator drives easier and less costly than that of hydraulic robots. For lightweight pick-and-place applications that require both speed and accuracy, a pneumatic robot is potentially a good choice.

Pneumatic actuator drives work at high speeds and are most useful for small-to-medium loads. They are economical to operate and maintain and can be used in explosive atmospheres. However, since air is compressible, precise placement and positioning require additional components to achieve the smooth control possible with a hydraulic system. These components are discussed in later chapters. It is also difficult to keep the air as clean and dry as the control system requires. Robots that use pneumatic actuator drives are noisy and vibrate as the air cylinders and motors stop.

Shape of the Work Envelope

Robots come in many sizes and shapes. The type of coordinate system used by the manipulator also varies. The type of coordinate system, the arrangement of joints, and the length of the manipulator's segments all help determine the shape of the work envelope. To identify the maximum work area, a point on the robot's wrist is used, rather than the tip of the

gripper or the end of the tool bit. Therefore, the work envelope is slightly larger when the tip of the tool is considered.

Work envelopes vary from one manufacturer to another, depending on the exact design of the manipulator arm. Combining different configurations in a single robot can result in another set of possible work envelopes. Before choosing a particular robot configuration, the application must be studied carefully to determine the precise work envelope requirements.

Some work envelopes have a geometric shape; others are irregular. One method of classifying a robot is by the configuration of its work envelope. Some robots may be equipped for more than one configuration. The four major configurations are: revolute, Cartesian, cylindrical, and spherical. Each configuration is used for specific applications.

Revolute Configuration (Articulated)

The ***revolute configuration***, or jointed-arm, is the most common. These robots are often referred to as anthropomorphic because their movements closely resemble those of the human body. Rigid segments resemble the human forearm and upper arm. Various joints mimic the action of the wrist, elbow, and shoulder. A joint called the *sweep* represents the waist.

A revolute coordinate robot performs in an irregularly shaped work envelope. There are two basic revolute configurations: vertically articulated and horizontally articulated.

The vertically articulated configuration, shown in **Figure 2-27**, has five revolute (rotary) joints. A vertically articulated robot is depicted in **Figure 2-28**. The jointed-arm, vertically articulated robot is useful for painting applications because of the long reach this configuration allows.

The horizontally articulated configuration generally has one vertical (linear) and two revolute joints. Also called the ***SCARA*** (selective compliance assembly robot arm) configuration, it was designed by Professor Makino of Yamanashi University, Japan. The primary objective was a configuration that would be fairly yielding in horizontal motions and rather rigid in vertical motions. The basic SCARA configuration, **Figure 2-29**, is an adaptation of the cylindrical configuration. The SCARA robot shown in **Figure 2-30** is designed for clean-room applications, such as wafer and disk handling in the electronics industry.

SCARA robots are ideally suited for operations in which the vertical motion requirements are small compared to the horizontal motion requirements. Such an application would be assembly work where parts are picked up from a parts holder and moved along a nearly horizontal path to the unit being assembled.

The revolute configuration has several advantages. It is, by far, the most versatile configuration and provides a larger work envelope than the Cartesian, cylindrical, or spherical configurations. It also offers a more flexible reach than the other configurations, making it ideally suited to welding and spray painting operations.

However, there are also disadvantages to the revolute configuration. It requires a very sophisticated controller, and programming is more complex than for the other three configurations. Different locations in the work envelope

Figure 2-27. These five revolute (rotary) joints are associated with the basic manipulator movements of a vertically articulated robot. (Adept Technology, Inc.)

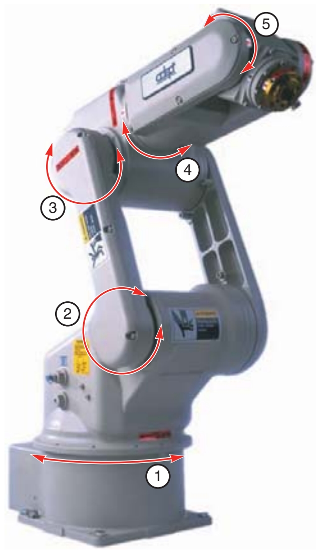


Figure 2-28. A—This painting robot is vertically articulated. (ABB Graco Robotics, Inc.) B—The shaded areas represent a top view of the work envelope for this robot.

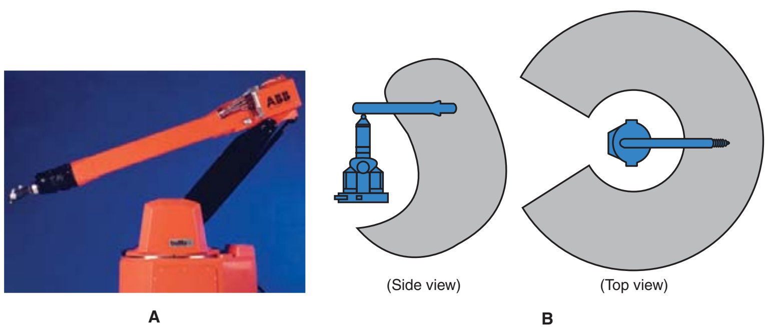


Figure 2-29. A—This is an example of a basic SCARA robot configuration. Note the three rotary joints and the single vertical joint used in this horizontally articulated configuration. B—This is a top view of the work envelope of a typical SCARA horizontally articulated robot configuration. This work envelope is sometimes referred to as the folded book configuration. (Adept Technology, Inc.)

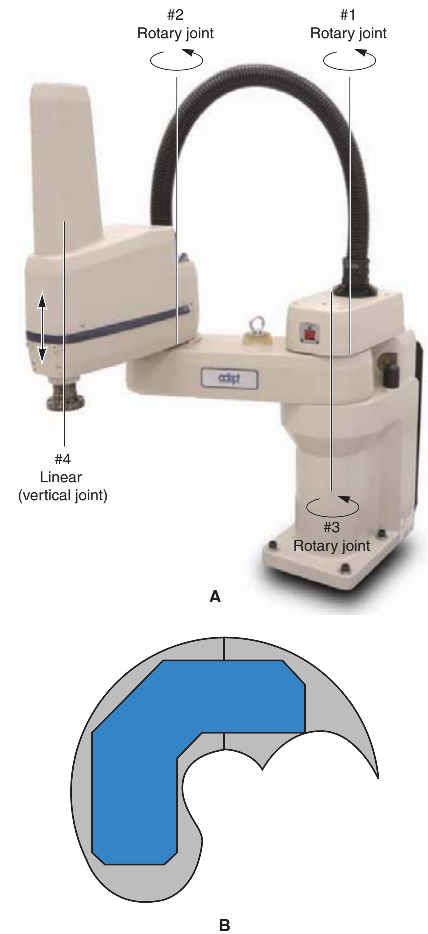


Figure 2-30. This SCARA robot is specifically designed for clean-room applications. (Adept Technology, Inc.)

can affect accuracy, load-carrying capacity, dynamics, and the robot's ability to repeat a movement accurately. This configuration also becomes less stable as the arm approaches its maximum reach. Industrial applications of revolute configurations are discussed in more detail in Chapter 4.

Typical applications of revolute configurations include the following:

- Automatic assembly
- Parts and material handling
- Multiple-point light machining operations
- In-process inspection
- Palletizing
- Machine loading and unloading
- Machine vision
- Material cutting
- Material removal
- Thermal coating
- Paint and adhesive application
- Welding
- Die casting

Cartesian Configuration

The arm movement of a robot using the ***Cartesian configuration*** can be described by three intersecting perpendicular straight lines, referred to as the X, Y, and Z axes (**Figure 2-31**). Because movement can start and stop simultaneously along all three axes, motion of the tool tip is smoother. This allows the robot to move directly to its designated point, instead of following trajectories parallel to each axis, **Figure 2-32**. The rectangular work envelope of a typical Cartesian configuration is illustrated in **Figure 2-33**. (Refer to **Figure 2-13** for an example of a Cartesian gantry robot.)

One advantage of robots with a Cartesian configuration is that their totally linear movement allows for simpler controls, **Figure 2-34**. They also have a high degree of mechanical rigidity, accuracy, and repeatability. They can carry heavy loads, and this weight lifting capacity does not vary at different locations within the work envelope. As to disadvantages, Cartesian robots are generally limited in their movement to a small, rectangular work space.

Typical applications for Cartesian robots include the following:

- Assembly
- Machining operations
- Adhesive application
- Surface finishing
- Inspection
- Waterjet cutting
- Welding
- Nuclear material handling
- Robotic X-ray and neutron radiography
- Automated CNC lathe loading and operation
- Remotely operated decontamination
- Advanced munitions handling

Figure 2-31. A robot with a Cartesian configuration moves along X, Y, and Z axes. (Yamaha)

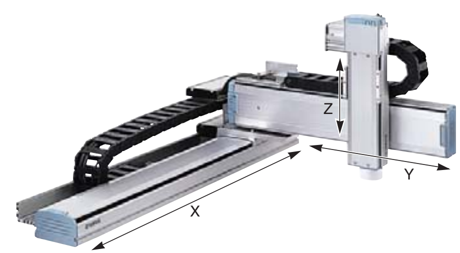


Figure 2-32. With a Cartesian configuration, the robot can move directly to a designated point, rather than moving in lines parallel to each axis. In this example, movement is along the vector connecting the point of origin and the designated point, rather than moving first along the X axis, then Y, then Z.

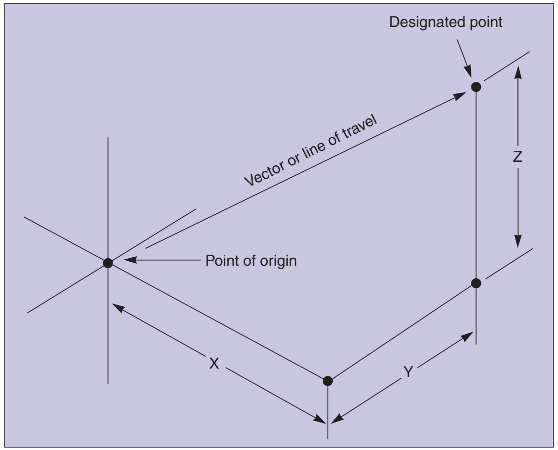


Figure 2-33. In either the standard or gantry construction, a Cartesian configuration robot creates a rectangular work envelope.

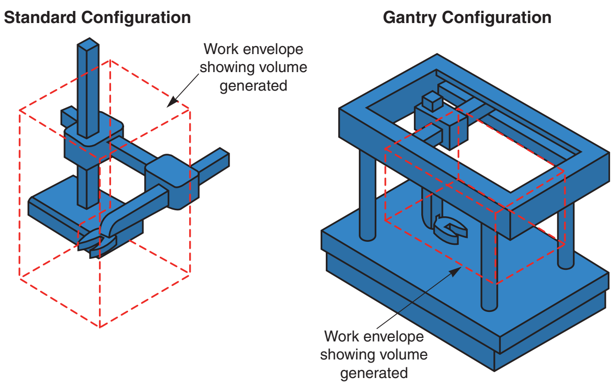


Figure 2-34. This robot has a Cartesian configuration and is used for high-precision jobs. (Adept Technology, Inc.)

Cylindrical Configuration

A ***cylindrical configuration*** consists of two orthogonal slides, placed at a 90° angle, mounted on a rotary axis, **Figure 2-35**. Reach is accomplished as the arm of the robot moves in and out. For vertical movement, the carriage moves up and down on a stationary post, or the post can move up and down in the base of the robot. Movement along the three axes traces points on a cylinder, **Figure 2-36**.

A cylindrical configuration generally results in a larger work envelope than a Cartesian configuration. These robots are ideally suited for pick-and-place operations. However, cylindrical configurations have some disadvantages. Their overall mechanical rigidity is reduced because robots with a rotary axis must overcome the inertia of the object when rotating. Their repeatability and accuracy is also reduced in the direction of rotary movement. The cylindrical configuration requires a more sophisticated control system than the Cartesian configuration.

Typical applications for cylindrical configurations include the following:

- Machine loading and unloading
- Investment casting
- Conveyor pallet transfers
- Foundry and forging applications

Figure 2-35. The basic configuration for a cylindrical robot includes two slides for movement up and down or in and out and is mounted on a rotary axis.

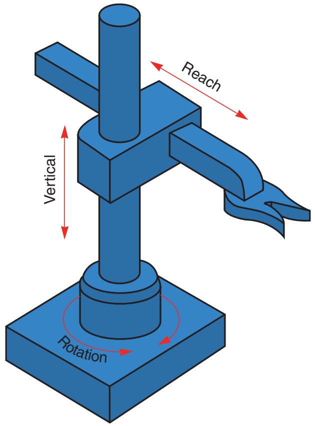
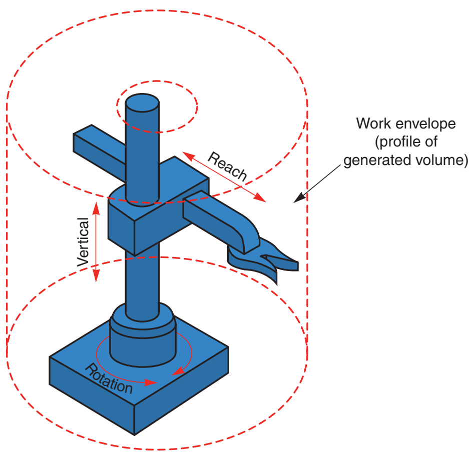


Figure 2-36. Motion along the three axes traces points on a cylinder to form the work envelope.



- General material handling and special payload handling and manipulation
- Meat packing
- Coating applications
- Assembly
- Injection molding
- Die casting

Spherical Configuration (Polar)

The ***spherical configuration***, sometimes referred to as the polar configuration, resembles the action of the turret on a military tank. A pivot point gives the robot its vertical movement, and a telescoping boom extends and retracts to provide reach, **Figure 2-37**. Rotary movement occurs around an axis perpendicular to the base. **Figure 2-38** illustrates the work envelope profile of a typical spherical configuration robot.

The spherical configuration generally provides a larger work envelope than the Cartesian or cylindrical configurations. The design is simple and provides good weight lifting capabilities. This configuration is suited to applications where a small amount of vertical movement is adequate, such as loading and unloading a punch press. Its disadvantages include reduced mechanical rigidity and the need for a more sophisticated control system than either the Cartesian or cylindrical configurations. The same problems occur with inertia and accuracy in this configuration as they do in the cylindrical configuration. Vertical movement is limited, as well.

Figure 2-37. A pivot point enables the spherical configuration robot to move vertically. It also can rotate around a vertical axis.

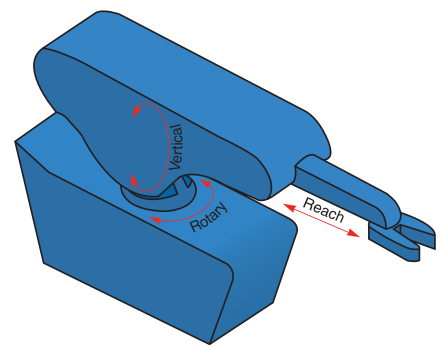
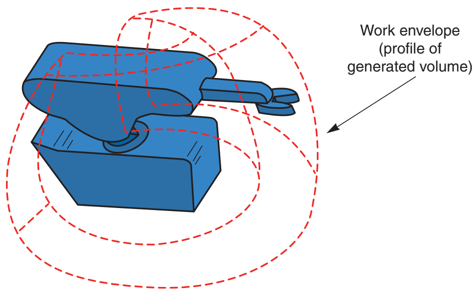


Figure 2-38. The work envelope of this robot takes the shape of a sphere.



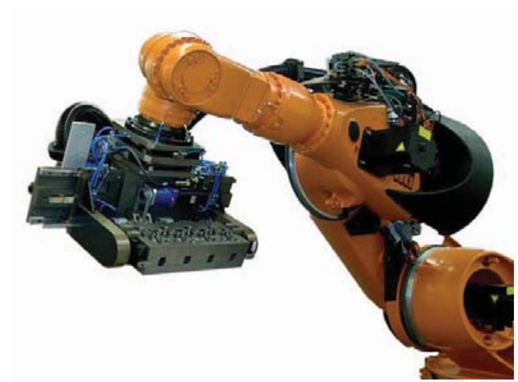
Typical applications of spherical configurations include the following:

- Die casting
- Injection molding
- Forging
- Machine tool loading
- Heat treating
- Glass handling
- Parts cleaning
- Dip coating
- Press loading
- Material transfer
- Stacking and unstacking

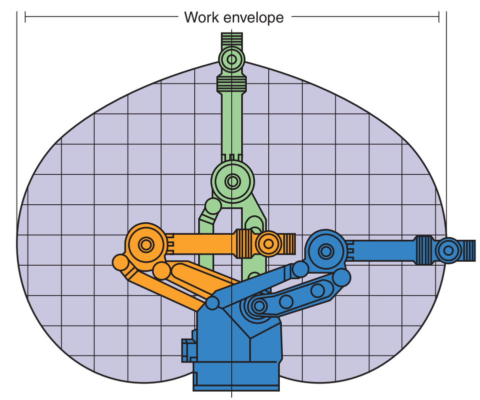
Special Configurations

Many industrial robots use combinations or special modifications of the four basic configurations. The robot pictured in **Figure 2-39A** uses an articulated configuration, but its base does not rotate horizontally. It is designed to literally bend over backwards in order to grasp objects behind it. This feature makes it possible to install these robots very close to other equipment, which minimizes space requirements, while maintaining a large, effective work envelope, **Figure 2-39B**. These robots are used in applications such as spot welding and material handling.

Figure 2-39. A—This heavy-duty robot literally bends over backward. (Schunk) B—The work envelope for this robot is large.



A



B

Review Questions

Write your answers on a separate sheet of paper. Do not write in this book.

1. Identify the five major components of a robot and explain the purpose of each.
2. What is the technical name for the robot's hand?
3. Name the three types of power supplies used to power robots. List the advantages and disadvantages of each.
4. In terms of degrees of freedom, explain why the human hand is able to accomplish movements that are more fluid and complex than a robot's gripper.
5. List and explain the six degrees of freedom used for robots.
6. Servo robots can be classified as intelligent or highly intelligent. Explain the difference between these two classifications.
7. What type of robots are considered open-loop? Explain what *open-loop* means?
8. Servo robots are considered closed-loop. Sketch a diagram of a closed-loop system and explain how it works.
9. What determines the shape of the robot's work envelope?
10. Why should you be concerned about the work envelope shape when installing a robot for a particular application?
11. What are the common work configurations used by robots? List some advantages and disadvantages of each.

Learning Extensions

1. Visit Fanuc Robotics at www.fanucrobotics.com and select videos from the side menu. This Web site provides a number of different robots performing various tasks. As you watch these video files, try to identify the robot configuration that is performing the task.
2. Visit the following robot manufacturers' Web sites. Locate the products they manufacturer and identify the robots by the configurations discussed in this chapter.
   - www.adept.com (Adept Technology, Inc.)
   - www.motoman.com (Motoman, Inc.)
   - www.apolloseiko.com (Apollo Seiko)
   - www.kawasakirobotics.com (Kawasaki Robotics (USA), Inc.)
   - www.abb.com/robots (ABB)
3. From the above Web searches, did you find any robot configuration that is manufactured more than the others. If so, identify this robot configuration and explain why you believe this to be the case.