Chapter 9

End Effectors

Outline

9.1 End Effector Movement
9.2 Types of End Effectors
9.3 Changeable End Effectors
9.4 End Effector Design

Objectives

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

- Discuss the types of movements an end effector can perform.
- Describe the types of end effector grippers and end effector tools.
- Identify the benefits of changeable end effectors.
- List important factors and desirable characteristics to be considered in the design of end effectors.

Technical Terms

automatic tool changer
collet gripper
compliance
cylindrical grip
electromechanical gripper
expandable gripper
gripper
hook movement
lateral grip
magnetic gripper
mechanical finger gripper
nonprehensile movement
oppositional grip
overload sensor
palmar grip
prehensile movement
remote center compliance (RCC) device
spherical grip
spread movement
tool
vacuum gripper

Overview

A key component in robot design is the end effector, or end-of-arm tooling. End effectors are devices attached to the wrist of a manipulator. They can grasp, lift, transport, maneuver, or perform operations on a workpiece. This chapter discusses the two general types of end effectors and factors that influence end effector design.

9.1 End Effector Movement

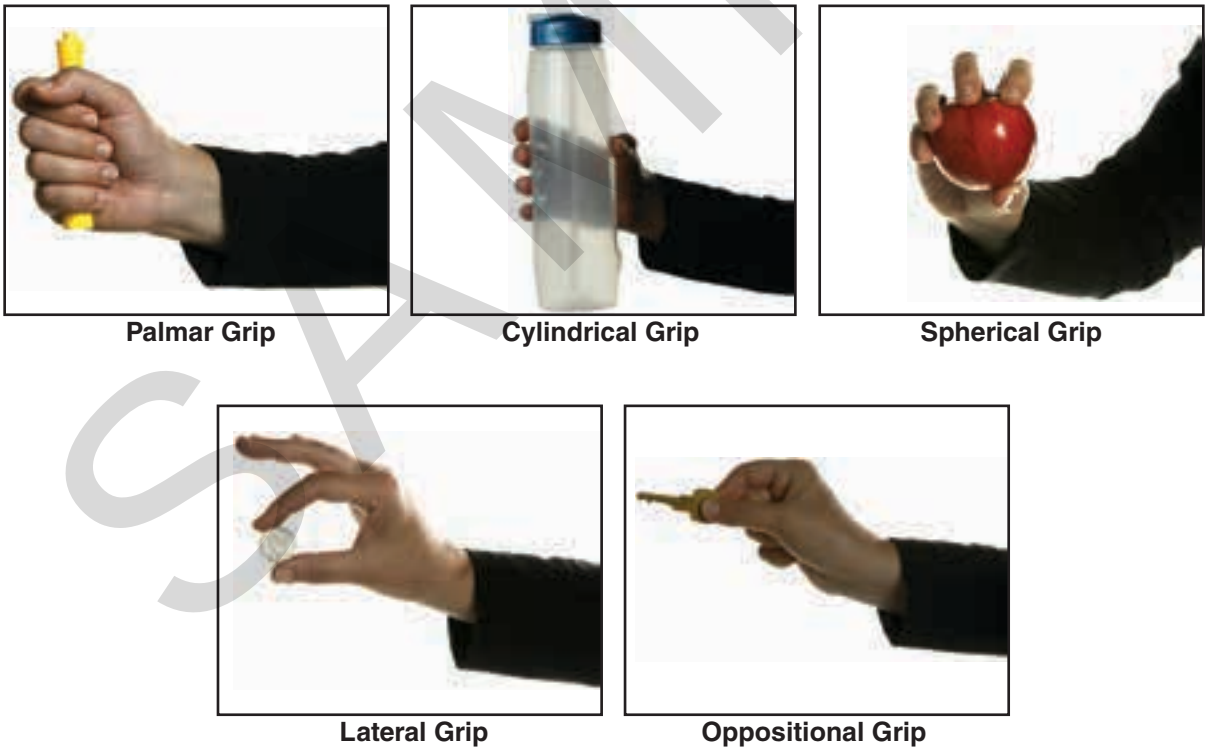
The robot's end effector can perform many of the same movements as the human hand. The human hand and an end effector have the ability to adjust, grasp, pick up, and rotate objects. Both prehensile and nonprehensile movements are used. ***Prehensile movements*** are actions that require the use of the thumb and fingers to grasp objects. ***Nonprehensile movements*** are actions that do not require particular finger dexterity or use of the thumb.

9.1.1 Prehensile Movements

Fingers that can curl and an opposable thumb provide the dexterity needed for prehensile movements. The opposable thumb is very important because it enables humans and robots to pick up and manipulate very small objects.

People have the ability to use their hands for various grips, **Figure 9-1**. The hand makes the following five basic prehensile (gripping) movements:

- ***Palmar grip.*** Wrapping the fingers and thumb around an object, such as a highlight marker, to grasp the object.
- ***Cylindrical grip.*** Forming a C shape with the fingers and thumb to grasp a cylindrical object, such as a drinking glass or water bottle.
- ***Spherical grip.*** Using the fingers and thumb to hold round objects, such as holding a ball.



Goodheart-Willcox Publisher

Figure 9-1. The human hand is capable of five basic prehensile grips: palmar, cylindrical, spherical, lateral, and oppositional.

- ***Lateral grip.*** Grasping flat objects from the sides with the fingers and thumb rather than around the object. Holding a quarter by the edges is an example of using a lateral grip.
- ***Oppositional grip.*** Using the tip of the index finger and the thumb to hold an object, such as a key.

9.1.2 Nonprehensile Movements

Nonprehensile movements do not require finger dexterity or use of the opposable thumb. These movements include pushing, poking, punching, and hooking. Two specific types of nonprehensile movements are hook and spread, **Figure 9-2**. The ***hook movement*** involves curling the tips of the fingers to pull or lift objects. To perform the ***spread movement***, the fingers and thumb are extended outward until they make contact with the interior walls of a hollow object. The force of the fingers against the walls of the object allows it to be picked up and carried.

9.2 Types of End Effectors

End effectors can be classified as grippers or tools. ***Grippers*** are end effectors that perform prehensile movements by grasping objects and moving them. ***Tools*** are end effectors that execute nonprehensile movements to perform specific tasks, such as welding or painting.

9.2.1 Grippers

Robots use a variety of grippers to grasp, handle, and transport parts, **Figure 9-3**. Some common types of grippers are presented in the sections that follow.

Hook

Spread

Goodheart-Willcox Publisher

Figure 9-2. Nonprehensile movements, such as hook and spread, do not depend on movement of the thumb.

Gripper End Effectors			
Gripper Type	**Gripper Configuration**	**Gripper Movement**	**Internal/External Gripping**
Mechanical finger	Two-finger Three-finger Four-finger	Parallel or angular	Internal and external
Collet	Round Square Hexagonal	360° clamping contact	Internal and external
Vacuum	One or more suction cups	Vacuum/suction	External
Electromechanical	Permanent magnet Electromagnet	Magnetic attraction	External

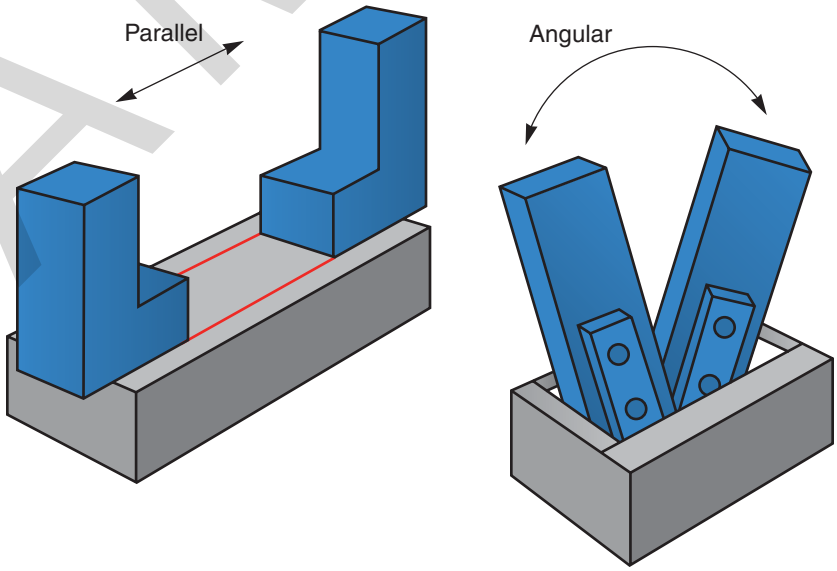
Goodheart-Willcox Publisher

Figure 9-3. This classification scheme can be used for mechanical grippers.

Mechanical Finger Grippers

Mechanical finger grippers are end effectors that are most commonly used for grasping objects. Mechanical finger grippers are generally used for grasping parts within a confined space, reaching into channels, or picking and placing any object that has a simple shape. The fingers typically move in a parallel or angular motion to grasp an object, **Figure 9-4**. The gripper fingers are opened and closed using mechanical linkages, gears, cables, chains, or pneumatic actuators. Grippers can have two, three, or four fingers.

Two-Finger Grippers. Two-finger grippers have two stiff fingers that simulate the motions of the human thumb and index finger, **Figure 9-5.** One or both of the fingers may move. For an additional degree of freedom and more flexibility during operations, a two-finger gripper may be equipped with a rotating joint, **Figure 9-6**.



Goodheart-Willcox Publisher

Figure 9-4. Two types of motion are made by mechanical grippers: parallel and angular.

SCHUNK Intec Inc.

Figure 9-5. This two-finger internal gripper is hydraulically operated with parallel motion and is designed to grasp heavy loads.

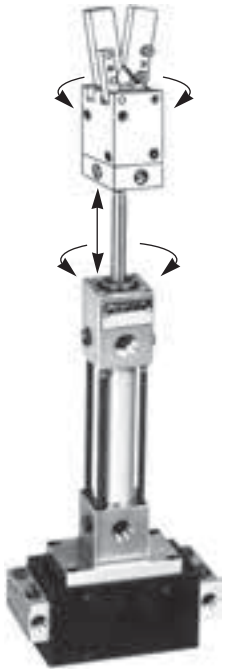
To handle objects with different shapes, fingers can be interchanged. For grasping cylindrical objects, V-shaped fingers are recommended, **Figure 9-7**. The V shape has two points of contact on each finger, ensuring that the object is centered. Self-aligning, padded fingers are used to grip flat objects. Fingers may also have cavities of more than one size or shape. Multi-cavity fingers may be necessary if an object changes shape or size during processing.

Three-Finger Grippers. Three-finger grippers simulate the action of the human thumb, index finger, and third finger, **Figure 9-8**. This configuration is better than that of two-finger grippers for grasping curved, spherical, or cylindrical workpieces.

Four-Finger Grippers. Four-finger grippers can grasp square and rectangular parts. The four fingers close simultaneously to permit easier part orientation. Four-finger grippers are often constructed from a pair of two-finger grippers.

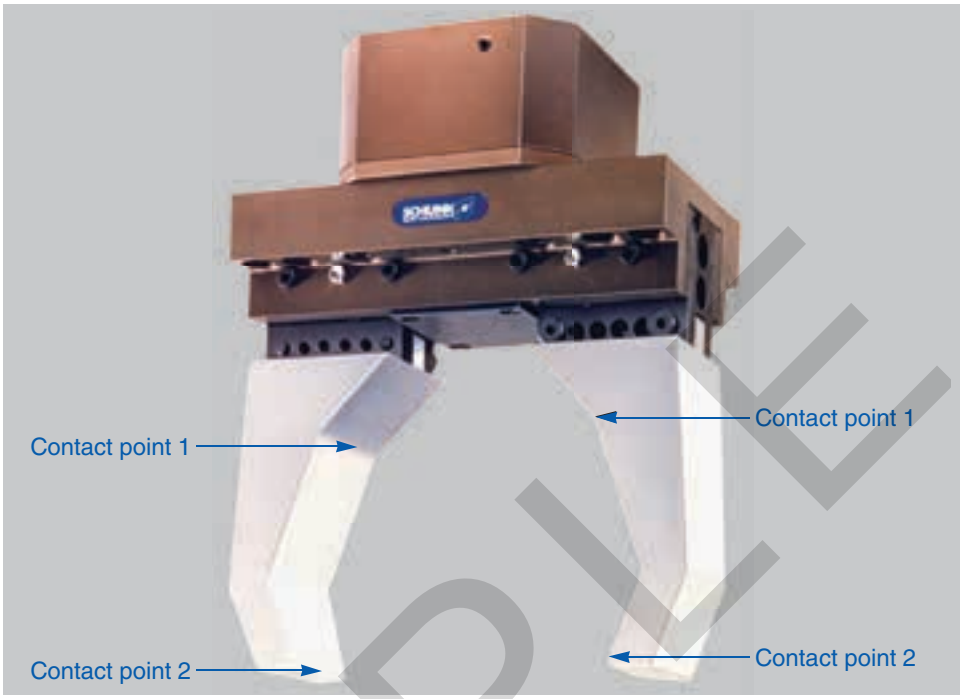
Collet Grippers

Collet grippers are end effectors used to pick and place cylindrical parts that are uniform in size. Unlike finger grippers, collet grippers deliver 360° of clamping contact. They have a strong clamping force that allows rapid part



PHD, Inc.

Figure 9-6. A rotary joint gives this gripper one additional degree of freedom.



Schunk-USA

Figure 9-7. This two-finger gripper has two points of contact per finger, which allows it to grasp large cylindrical objects securely.

SCHUNK GmbH & Co. KG

Figure 9-8. Three-finger grippers can grasp and handle objects of various shapes.

transfer. They are also used for grinding and deburring operations. Collet grippers are typically controlled by a solenoid and have excellent repeatability. They are available in round, square, or hexagonal shapes.

Vacuum Grippers

Vacuum grippers are end effectors that use suction (vacuum) to pick up an object. They consist of one or more suction cups made of natural or synthetic rubber. They are extremely lightweight and simple in construction. The number, size, and type of suction cups used depends on the weight, size, shape, and type of material being handled. Multi-cup vacuum grippers increase the contact surface area, which allows workpieces of increased size and weight to be handled, **Figure 9-9**. Vacuum grippers can be used on curved and contoured surfaces as well as on flat surfaces.

The flexibility of the suction cups provides the robot with a certain amount of adaptability. Therefore, exact positioning is not as critical as with some other types of grippers. To

Pacific Robotics, Inc.

Figure 9-9. When an object with large surface area must be grasped, a multi-cup vacuum gripper is often used. The gripper pictured also has curved fingers to provide additional support when moving large objects.

allow for unevenness in a part surface, some vacuum cups are spring-loaded or mounted on a ball joint.

Electromechanical Grippers

Electromechanical grippers, also called ***magnetic grippers***, are end effectors that use a magnetic field created by a permanent magnet or an electromagnet to pick up an object. Objects that have flat, smooth, clean surfaces are the easiest to handle.

Grippers that operate using a permanent magnet are well suited for explosive environments because they do not require an electric power source that could spark. Once a part is moved, it is released from the gripper by exerting force to pull it away from the magnetic field.

An electromagnetic gripper is energized by a dc power source. An object is released from the gripper when the power source is interrupted. To speed up release time, the current is not cut off. Instead, the direction of current flow is momentarily reversed.

There are certain disadvantages associated with using electromechanical grippers. These grippers can only be used to handle materials containing iron, which limits possible applications and locations. Metal shavings and other small metal particles are attracted to the magnet when parts are machined. If these metal particles accumulate on the magnet, they can scratch the surface of a part or cause misalignment of parts. The temperature of a workpiece must also be considered. The effectiveness of magnetic force declines when workpieces are heated to several hundred degrees, as may be the case in some processing operations.

Electromechanical grippers have certain advantages over vacuum grippers. An electromechanical gripper has a longer life and can handle hotter and heavier objects. Also, electromechanical grippers immediately grip a part, while vacuum grippers require time to build up the necessary pressure to grip a part. Electromechanical grippers are custom designed for specific applications. Few are available as off-the-shelf items.

9.2.2 Tools

A robot's arm can be equipped with various types of tools to perform specific tasks. Some of the common tools used on robots are spot welding guns, inert gas arc welders, stud welders, gluing guns, spray guns, drills, milling heads, deburrers, polishers, pneumatic screwdrivers, and nut-drivers. The tools used for robotic applications may be categorized as:

- Welding tools.
- Material application tools.
- Machining and assembly tools.

Welding Tools

Welding tools vary according to the type of welding operation performed. Welding robots may have tool changers that provide flexibility and improve productivity. An ***automatic tool changer*** is a device that has more than one end effector and can change end effectors when needed to execute operations, **Figure 9-10**. This automated option reduces the downtime required to change an end effector and decreases the risk of operator injury that can occur when a manual change is performed. One representative type of welding tool is an arc welding torch attached to a robot arm. For this application, a proximity sensor could be used to aid in positioning the end effector.

Spot welding operations can also be performed with robotic systems. Tool changers allow a spot weld device to be attached to a robot arm so multiple functions can be performed within a work cell. In addition, laser and gun welding systems may be used with the proper tool changers.

Material Application Tools

Material application tools are also used in palletizing, packaging, and handling operations. Businesses are very concerned about productivity, so tool changers must be efficient to avoid equipment downtime. Rapid tool changing during material handling automates and improves the process.

Machining and Assembly Tools

Tooling operations performed for machining and assembly use robots to perform multiple tasks that require several different types of tools. These tasks include operations such as drilling and milling machining processes. Rapid tool changing is critical to productivity for these operations, as is the repeatability of every production cycle. Robots can change tooling quickly with tool changers that connect the robot arm to the necessary tool in only a few seconds. Sensors can be attached to the robot arm. For example, a proximity sensor can provide feedback about the distance between the end effector and an object. This feedback helps protect equipment from being damaged due to colliding with objects in the work area.

A B

Schunk-USA

Figure 9-10. Typical automatic tool changer applications. A—An automatic tool changing system permits this robot to execute three operations automatically: cleaning, primer coating, and gluing. B—A large gantry robot is equipped with an automatic tool changing system. Note the extra-long fingers on the gripper that allow the clamping of large rings.

9.3 Changeable End Effectors

Robots used in manufacturing require either multipurpose or changeable end effectors. This type of tooling increases the effectiveness and flexibility of a robotic system. Equipping the manipulator with a multifunction end effector allows a single end effector to perform multiple tasks in a single process or on a single workpiece. Another option is to design an easily changeable end effector, which is also called quick-change tooling.

Quick-change tooling offers several end effector options that can be readily attached and removed from the manipulator as the process requires. With quick-change tooling capabilities, a robot can handle parts of various shapes and perform a wide range of assembly tasks and machining operations. Adding this flexibility in the robotic system increases overall productivity.

When designing a robotic system with changeable end effectors, two considerations must be addressed. The interface adapters must be standardized, and operators must be able to change end effectors with minimum downtime. To make interface adapters standard for use with many different end effectors, they must have compatible mounting and securing systems. All the connectors for electric, hydraulic, and pneumatic components should be provided with the adapters. Since robots come in different sizes, different sizes of standard adapters may need to be provided as well.

9.4 End Effector Design

To determine the type of end effector needed to do a job, a study must be performed to evaluate the operation, the workpiece(s), and the environment. The end effector may be subjected to extreme temperatures or make contact with abrasive or corrosive materials. Special protective materials and shielding devices may be necessary to protect the manipulator.

Objects to be moved may vary in shape, size, and weight. The workpieces may also change in shape, size, or weight during a process. The end effector must be able to adjust to such changes. Other conditions to be considered are the fragility of the workpiece, the surface finish, and the type of material used to construct the workpiece. For example, if an object is made of ferrous material (one that contains iron), a magnetic gripper may be used.

Additional considerations, such as problems involving inertia, center of mass, gripping force, or friction between the part and the gripper, may need to be addressed. Other concerns might involve part orientation, gripper sensing capabilities, or interaction with other equipment.

9.4.1 Desirable Characteristics

End effectors should be designed with the appropriate desirable characteristics. The end effector should have the strength necessary to carry out the required tasks and be able to withstand rigorous use.

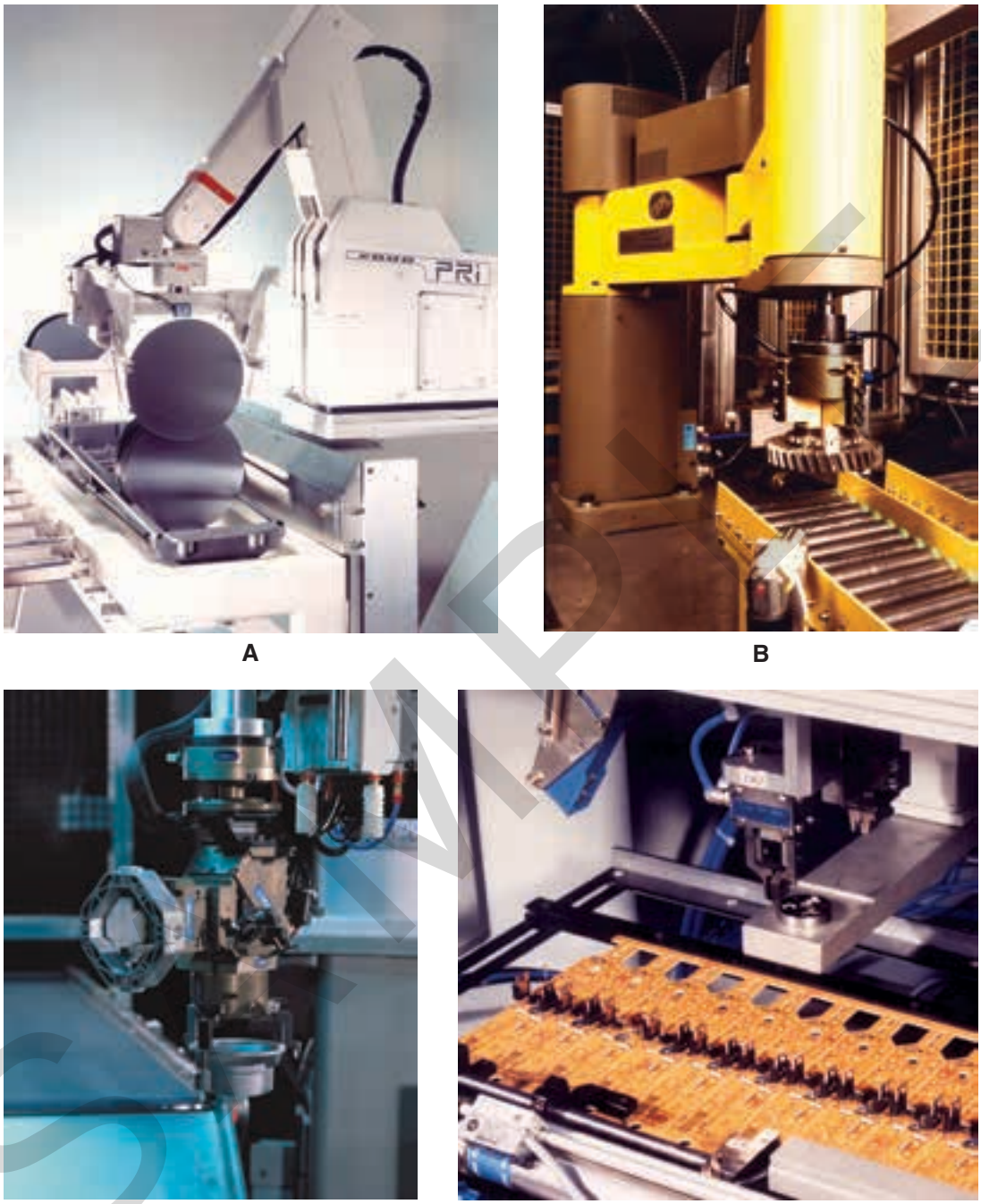
End effectors should be equipped with measures to guard against damage from strain. Breakaway devices remove the end effector from the work area using mechanical fuses, detents, or preloaded springs. A breakaway device should be installed to prevent damage to the robot's arm or wrist if the end effector becomes stuck. End effectors that use friction to hold objects are not typically prone to damage caused by excessive strain because the grasped object will slip out of the gripper when an opposing force is applied. However, an opposing force of this type could cause joint slippage and alter the accuracy of the robot's positioning.

Robots may use overload sensors. An ***overload sensor*** is a device that detects obstructions or overload conditions within fractions of a second. The sensor signals the controller to shut down the robot before damage occurs. Unlike breakaway joints, an overload sensor does not have parts to be replaced after it operates and does not require reprogramming.

Another desirable characteristic is compliance. ***Compliance*** is the ability of an end effector to tolerate misalignment of mating parts. For the assembly of close-fitting parts, this characteristic is essential. Compliance prevents the part from jamming, wedging, and wearing. Some end effectors have a certain amount of compliance built into their design. End effectors that lack this capability may use a ***remote center compliance (RCC) device***. This device is installed in the wrist of the robot and helps to compensate for workpiece misalignment or irregularities. Robots equipped with an RCC device can perform precise tasks, such as inserting bearings into a housing with a clearance of only 0.0005" (0.013 mm).

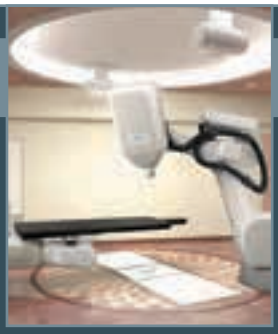
9.4.2 Custom-Designed End Effectors

In addition to standard grippers and tools, custom end effectors can be designed for a particular application, **Figure 9-11**. Custom-designed end effectors broaden the range of tasks that robotic equipment can perform.



PRI-Precision Robots, Inc.; Schunk-USA

Figure 9-11. Custom-designed end effectors. A—The gripper on this robot transfers large silicon wafers from one container to another. B—This three-fingered, internal gripping end effector is used in a production line for machining precision gears. C—This dual end effector has internal and external gripping capabilities. D—A parallel-motion gripper is used to insert components into a printed circuit board prior to soldering.



The end effector of the CyberKnife System is a linear accelerator that is used to treat tumors anywhere on the human body.

Robotics in Society: CyberKnife® System

The CyberKnife System is a robotic radiosurgery system available from Accuray® Incorporated. This system offers a non-invasive treatment option for patients with cancerous tumors. The manipulator of the CyberKnife® System has an extensive range of motion, which allows the end effector (a linear accelerator) to be positioned anywhere on the body. Additionally, high-resolution image detectors continuously track the position and location of the target tissue during the treatment session. This information is communicated to the manipulator, which automatically adjusts the end effector to compensate for movement of the patient or tissue. The continuous tracking capabilities of the CyberKnife® System provide accurate treatment and reduce damage from the radiation beams to surrounding tissues.

Traditional radiosurgery systems are confined to treating tumors in the head and neck. Accuray® made use of new technologies to develop a flexible and precise robotic radiosurgery system that offers a wide range of patients an effective option in the fight against cancer.

Image used with permission from Accuray Incorporated

De-STA-Co

Figure 9-12. This gripper is equipped with a vision guidance system that allows the robot to find objects that are not placed symmetrically. This type of device can also be used in environments with changing conditions, such as lighting levels, and for locating and gripping objects that are placed randomly.

Grippers that are designed to handle fragile objects are an example of custom end effectors. End effectors with soft, flexible cups have been developed for delicate applications, such as handling lightbulbs and eggs. Custom-designed end effectors may combine gripper types or be uniquely shaped to meet the needs of a particular operation, **Figure 9-12**.

Expandable grippers are end effectors that clamp irregularly shaped workpieces using mechanical fingers equipped with hollow rubber envelopes that enlarge when pressurized. The envelopes ensure even distribution of surface pressure. One type of expandable gripper surrounds an object, gripping it from the outside. Another type grips hollow objects from the inside. Expandable grippers are ideal for handling fragile parts or parts that vary a great deal in size.

Summary

- End effectors are devices attached to the wrist of a robot manipulator. They are used to grasp, lift, transport, maneuver, or perform operations on a workpiece.
- End effectors for robots perform many of the same movements as a human hand.
- Prehensile movements require the use of the thumb to grasp objects and include palmar grip, cylindrical grip, spherical grip, lateral grip, and oppositional grip.
- Nonprehensile movements do not require the movement of a thumb and include pushing, poking, punching, hooking, and spread movements.
- End effectors are classified as grippers or tools. Grippers perform prehensile movements, and tools execute nonprehensile movements.
- Types of grippers include mechanical finger grippers (two-, three- or four-finger), collet grippers, vacuum grippers, and electromechanical grippers.
- Tools attached to a robot arm are used for welding, material application (palletizing, packaging, or handling operations), and machining and assembly operations.
- Robots used in manufacturing require either multipurpose or changeable tooling. An automatic tool changer can change end effectors when needed to execute operations.
- End effector design must include study of the type of operation to be performed, the workpieces, and the work environment.
- End effectors should be designed with the appropriate desirable characteristics, such as strength, durability, strain and overload protection, and compliance.
- Custom-designed end effectors can be made for specific operations, such as handling fragile objects or grasping parts that vary greatly in size.

Know and Understand

Answer the following questions using the information provided in this chapter.

1. Which of the following describes prehensile movements of an end effector?
   A. Actions that require the use of the thumb and fingers to grasp objects.
   B. Actions that do not require particular finger dexterity or use of the thumb.
   C. Actions that require large amounts of force to lift heavy objects.
   D. Actions that require very small amounts of force to lift objects.
2. Which of the following describes nonprehensile movements of an end effector?
   A. Actions that require the use of the thumb and fingers to grasp objects.
   B. Actions that do not require particular finger dexterity or use of the thumb.
   C. Actions that require large amounts of force to lift heavy objects.
   D. Actions that require very small amounts of force to lift objects.

3. Which of the following is *not* one of the five types of gripping movements an end effector can make?
   A. Palmar
   B. Cylindrical
   C. Spherical
   D. Pinch
4. Which of these best describes the hook movement of an end effector?
   A. Curling the tips of the fingers to pull or lift objects
   B. Extending the fingers and thumb outward until they make contact with the interior walls of a hollow object
   C. Wrapping the fingers and thumb around an object
   D. Forming a "C" shape with the fingers and thumb
5. Which of these best describes the spread movement of an end effector?
   A. Curling the tips of the fingers to pull or lift objects
   B. Extending the fingers and thumb outward until they make contact with the interior walls of a hollow object
   C. Wrapping the fingers and thumb around an object
   D. Forming a "C" shape with the fingers and thumb
6. *True or False?* Pinchers and grippers are the two major classifications of end effectors.
7. For which of these tasks are mechanical finger grippers typically used?
   A. Grasping objects
   B. Picking and placing cylindrical parts
   C. Moving objects with the use of suction
   D. Moving metal parts with magnetic fields
8. _____ grippers simulate the action of a human thumb, index finger, and third finger.
   A. Two-finger
   B. Three-finger
   C. Four-finger
   D. Collet
9. For which of these tasks are vacuum grippers typically used?
   A. Grasping objects
   B. Picking and placing cylindrical parts
   C. Moving objects with the use of suction
   D. Moving metal parts with magnetic fields
10. What is a major disadvantage of using electromechanical grippers?
   A. They can only be used to handle plastic parts.
   B. They can only be used to handle parts that contain iron.
   C. They are not able to be used with parts that contain iron.
   D. They can only be used to handle wooden parts.

11. Which of these is *not* one of the three categories of tools used for robotic applications?
    A. Welding tools
    B. Material application tools
    C. Painting tools
    D. Machining and assembly tools
12. What are the advantages of using automatic tool changers?
    A. Increases productivity by allowing the robot to perform multiple operations.
    B. Slows down production jobs because the operator must change out the tools.
    C. Allows the robot to lift heavier loads.
    D. Increases the speed at which a robot can home itself.
13. *True or False?* When designing a robotic system with changeable end effectors, the interface adapters must be standardized.
14. Which of the following best describes how breakaway devices and overload sensors provide protection for robotic systems?
    A. They break to prevent strain on more expensive parts of the system.
    B. They are made of strong materials that do not break easily so that excess strain is transferred to more expensive components.
    C. They use sensors to locate parts that need to be moved.
    D. They send a signal to the controller when a misaligned part is detected.
15. Which of the following best describes *compliance*?
    A. When a robot does what it is told to do.
    B. When a robot meets all production standards.
    C. The ability of an end-effector to tolerate the misalignment of mating parts.
    D. The ability of a robot to auto tool change.
16. How can compliance of an end effector be increased?
    A. By adding a Mobile proximity warning system
    B. By adding a remote center bearing (RCB) system
    C. By increasing the amount of "play" in the gripper system
    D. By adding a remote center compliance (RCC) device
17. _____ grippers are end effectors that clamp irregularly-shaped workpieces using mechanical fingers equipped with hollow rubber envelopes.
    A. Electromechanical
    B. Collet
    C. Expandable
    D. Vacuum

Apply and Analyze

1. Pay particular attention to the movements of your hands in the course of a day. Make note of common movements by identifying them as either prehensile or nonprehensile. Name the grip or movement and list the task you performed with the hand movement.
2. Conduct an Internet search to identify end effector manufacturers. Develop a list of the types of end effectors you find and categorize them into common types.
3. Select a specific type of robot operation and describe in detail the design of the end effector used to accomplish the operation.

Critical Thinking

1. Prepare a description of the operation of moving assembled cardboard boxes from one location to another using a robot. In particular, describe the type of end effector used.
2. Prepare a description of the operation of drilling three different-diameter holes in a metal workpiece using a robot. In particular, describe the type of end effector used.
3. Prepare a description of the operation of moving fragile parts of various sizes from one location to another using a robot. In particular, describe the type of end effector used.