Table of Contents

INTRODUCTION TO ROBOTICS

Lesson One

Robotics in Automated Manufacturing

TPC Training Systems

50101

Lesson

1 Robotics in Automated Manufacturing

TOPICS

Evolution of Robotics
What is an Industrial Robot?
Essential Characteristics
Robots and Automated Manufacturing
Project Manufacturing
Job Shop
Batch Manufacturing
Repetitive (Flow) Manufacturing
Continuous Manufacturing
Robot Safety

OBJECTIVES

After studying this lesson, you should be able to…

- Identify why robots did not appear in large numbers in manufacturing until the late 1970s.
- State the Robot Industries Association's definition of an industrial robot and explain the two key words.
- Describe how industrial robots are used in batch production systems.
- Explain how industrial robots are used in repetitive manufacturing systems that utilize transfer lines.
- List at least three factors that should be considered as part of a risk assessment when a robot system is in the development stage.
- Describe and contrast the following guarding methods: barrier, presence-sensing device, awareness device, warning system.
- Define the term *zero-energy state*.

KEY TECHNICAL TERMS

Microprocessor 1.01 integrated circuit built on silicon chip

Robot 1.05 reprogrammable, multifunctional machine designed to manipulate materials, parts, tools, or specialized devices through variable programmed motions for performance of tasks

Reprogrammable 1.07 capable of accepting change in program, which changes robot's functional actions

Multifunctional 1.07 capable of performing more than one function

Integrator 1.08 person or company that will help develop robot system and customize it for specific applications

Batch manufacturing 1.21 manufacturing system in which small quantities of different items are completed on same production line

Flexible manufacturing system (FMS) 1.23 highly automated form of batch manufacturing

Transfer line 1.29 special form of repetitive manufacturing

Work envelope 1.40 robot's working space

Zero-energy state 1.49 involves locking out electric power as well as neutralizing stored-energy devices

Axes (plural of axis) 1.49 point about which object rotates

Many people are surprised to discover that the technology of robotics is not new. In fact, many of the concepts used in the construction of today's robots and automated systems appeared decades ago. Industrial robots are not unique from a mechanical standpoint. All of their mechanical components appear in other machinery. A robot is simply a collection of electrical, mechanical, and electronic systems. What sets a robot apart from other systems is its flexibility.

This lesson presents an overview of industrial robots and explores ways in which they fit into the major manufacturing systems in use today. The lesson concludes with essential information on robot safety.

Evolution of Robotics

1.01 In the early 1940s, most people thought of production equipment that could operate with little assistance from the operator as automatic machinery, or *automation*. The term "robot" implied a mobile machine of more or less human form because of the popularity of science fiction stories. It was not until the 1970s, with the development of the *microprocessor*, that truly functional industrial robots began to emerge.

1.02 Up to that point, industrial robots were controlled by mechanical controllers or minicomputers, which were bulky and slow by today's standards. The robots of the early 1970s were also fairly restricted in the industrial tasks they could perform. They were unable, for example, to track weld seams. This operation requires a more sophisticated path control and programming language than those on which the early robots operated.

1.03 Microprocessors permitted robot manufacturers to build smaller, more powerful controllers that allowed robots to do more manufacturing tasks. For example, one manufacturer used a single minicomputer for all the control required in its early robot system. In a new version, the control requirements are assigned to a computer network of over ten microprocessors inside the robot system.

1.04 The microprocessor gave manufacturers the means of making robots smarter and faster, and making their movements more reliably repeatable. These improvements, in turn, made the machines capable of many more manufacturing tasks. The robots of the late 1970s could do more than their predecessors and offered an economic advantage over manual labor in the production process. Consequently, interest in robot applications increased in proportion.

What is an Industrial Robot?

1.05 Webster's Dictionary defines a *robot* as "an automatic device that performs functions normally ascribed to humans or a machine in the form of a human." The Robot Industries Association (RIA) developed the following definition to help identify machines that can be classified as *industrial robots:*

> *A robot is a reprogrammable, multifunctional machine designed to manipulate materials, parts, tools, or specialized devices, through variable programmed motions for the performance of a variety of tasks.*

1.06 In addition to industrial robots, some robots are classified as *service robots*. These devices are used in such diverse applications as automated milking systems and robotic-assisted surgery. *Mobile robots* are not fixed to one physical location. They are used in security systems, mail delivery, and even vacuum cleaners and lawn mowers. Although all robots have certain characteristics in common, it is the industrial robot that is the focus of this course.

Essential Characteristics

1.07 The key words in the industrial robot definition above are "reprogrammable" and "multifunctional." *Reprogrammable* indicates that the robot is a machine whose actions are controlled by a stored program. It also means that the program can be changed to fit the requirements of the job. *Multifunctional* means capable of performing more than one function. That is, a robot is not produced to perform one specific manufacturing task. The same robot can be used in widely varying manufacturing jobs within the same factory or in different industries.

1.08 When the manufacturer ships a robot to a customer, the robot is not prepared to do any specific task. It becomes an integral part of the manufacturing system only when the customer or a robotic system integrator prepares it for production. An *integrator* is a person or company that helps develop a robot system and customize it for a company's applications.

1.09 Suppose, for example, the robot is to be used in die-casting. A gripper that can hold parts produced in a die-casting machine must be mounted on the robot arm. The robot must also be programmed to unload the die-cast part.

1.10 Suppose further that a trim press is added to the die-casting area later. The robot can be reprogrammed with additional moves to take the die-cast parts to the press to be trimmed. If the need for die-casting diminishes in the plant, the robot can be moved to another manufacturing area to perform a different task. A robot that spent its first five years tending a die-casting machine might be retooled, reprogrammed, and used for the next five years to load pallets with finished parts.

Robots and Automated Manufacturing

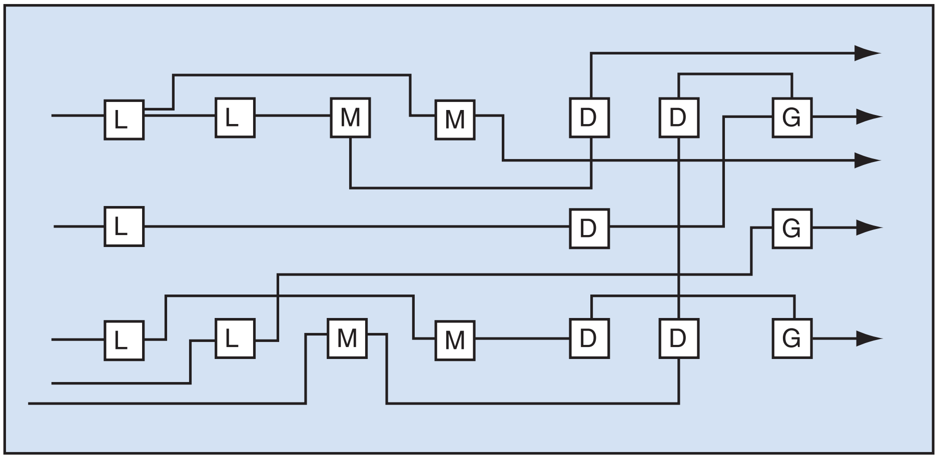
1.11 According to the International Federation of Robotics, about 1 million industrial robots were working in factories worldwide at the end of 2007. By the end of 2010 it is predicted that the total number of operational robots will reach 1.2 million units worldwide. The automotive industry remains the largest user of industrial robots. This industry uses one robot for every ten human workers, mainly in welding applications. There is, however, a worldwide trend toward the use of robotics in other industries, including metals and glass, food and beverage, pharmaceuticals, and many others. The robots shown in Fig. 1-1 are assembling alternators for use in automobiles.

1.12 Many small- to mid-size companies are becoming first-time robot users. Competitive pricing and ease of use and programming are making robot systems very attractive.

1.13 The large increase in the use of robots over the last decade can be attributed to their multifunctional nature and their ability to be reprogrammed. They are well suited for tasks that are repetitive, dangerous, or difficult. They perform well when lifting, loading, dispensing, painting, welding, manipulating, and assembling. And they can repeat these tasks day-after-day, accurately and without errors caused by boredom or fatigue.

Fig. 1-1. Assembly robots

Fig. 1-2. Traditional job shop parts flow



1.14 Before considering the relationship between robots and automated manufacturing, you should first understand some of the basics of manufacturing processes and scales of production. Some plants manufacture one-of-a-kind products. Others produce identical products day after day. Still others have great flexibility and often modify or entirely change the product they produce. Selection of a particular system is based on the variety of product, required flexibility, and expected volume. All manufacturing operations today can be classed in one of the following categories:

- project
- job shop
- batch
- repetitive
- continuous.

Project Manufacturing

1.15 *Project manufacturing*, also sometimes called "one-off," is a complex, nonrepetitive activity. It tends to produce large-scale, one-of-a-kind, made-to-order products. An example of this type of manufacturing might be the building of a bridge.

Job Shop

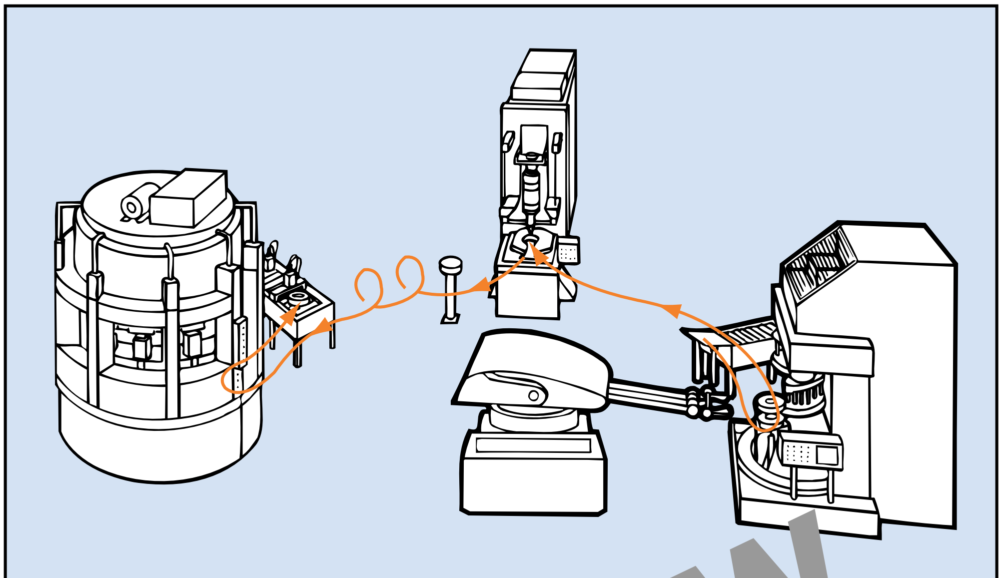
1.16 A *job-shop manufacturing* environment involves small-scale unit or lot production that varies according to customer needs. It is characterized by very high variety, flexibility, and unit cost, and very low output volume. One machine partially completes the product, which than moves to other machines for subsequent processing. The product must be moved from one machine to another until it is completed. Although job-shop production offers great flexibility and low initial cost for general-purpose machinery, it is less efficient than other methods.

1.17 Figure 1-2 diagrams the flow of parts through a machining operation with a traditional job-shop organization. Note that all the lathes (L) are in one area, the mills (M) in another, the drill presses (D) in another, and the grinders (G) in still another. The lines show the path of the parts that move through the machining area. In a system like this, it is difficult for automation to make any significant gains in efficiency. One reason is that the different parts require many different combinations of machining. Another difficulty is the long time that parts spend in transit from one machine to another.

1.18 Robots can be used with this type of operation, however, to automate individual machines or groups of machines. They work especially well with machines that are numerically controlled and have relatively short operating cycles.

1.19 The robot shown in Fig. 1-3, on the following page, supports the automated operation of three machines. It picks up the incoming part from the conveyor on the right and places it on the vertical mill. When the milling operation is complete, the robot

Fig. 1-3. Robot tending three machines



places the part on the center machine for another operation. From the center machine, the part is moved to a holding device so that the robot can change its grip on the part.

1.20 Then, holding the part from a different angle, the robot inserts the part into the multistation machine on the left for finish cutting. With all machining operations complete, the robot puts the finished part on the exit conveyor on the left. Note that the conveyor has sensors to inspect the parts as they leave the automated work cell. A *work cell*, or *production cell*, is a group of one or more machines, usually consisting of a production machine, material-handling hardware, quality-assurance devices, a sensor, and a work-cell controller.

Batch Manufacturing

1.21 *Batch manufacturing* produces approximately 75% of all goods sold in the world. It is characterized by small to moderate quantities of many different items, produced in batches and moving along a single production line. Production must be stopped, equipment reconfigured, and output tested between batches. Batch manufacturing is especially useful for seasonal items or where demand is difficult to forecast, because one line can produce several products or variations of product. A good example might be shoe manufacturing, which produces batches of the same style in a variety of colors and sizes.

1.22 In a batch manufacturing situation, machines may have to produce 150 different parts, with production quantities as low as two parts. This manufacturing system falls between job shop and repetitive manufacturing in terms of output volume and flexibility.

1.23 A *flexible manufacturing system* (FMS) provides batch production with a higher degree of automation. It is basically a transport system with automated production machines. FMS involves production and material-handling systems under computer control. It offers the greatest scope for robot applications in automated manufacturing.

1.24 The major characteristics of FMS are:

- parts movement by automated carrier
- automatic warehousing of raw materials and finished products
- fully automated production cells
- work cells capable of producing a family of parts
- a network of computers and computer-controlled machines
- robots performing many production functions.

1.25 The flexible manufacturing system illustrated in Fig. 1-4 has many of the components listed above. It can cut 600 different machined fittings in small to medium lots. The system includes eight machining centers that feature automatic tool changing, an automated cleaning station, and two measuring stations to check the dimensions of machined parts. The material is moved around the FMS by four robot carriers, which shuttle parts, pallets, tools, raw material, and other equipment.

Repetitive (Flow) Manufacturing

1.26 *Repetitive manufacturing*, sometimes called "hard automation" or "mass production," produces high volumes of a single product or a few standardized products, with little or no customization possible. Approximately 20% of all goods sold in the United States are produced in this way. Examples of mass-produced items are disposable cigarette lighters and razors.

1.27 Repetitive manufacturing makes use of a machine or machines that have been designed and built specifically to turn out large quantities of a single product. This highly specialized hardware (which might include robots) requires a large capital investment. In addition, the machine offers minimum flexibility for product change or improvement. Few small companies engage in this type of manufacturing, because most companies cannot produce only one product in huge numbers as styles change.

Fig. 1-4. Flexible manufacturing system

A = machining centers (8)
B = automated cleaning station
C = measuring (quality control) stations to check dimensions of machined parts (2)
D = robot carriers to move materials around (4)

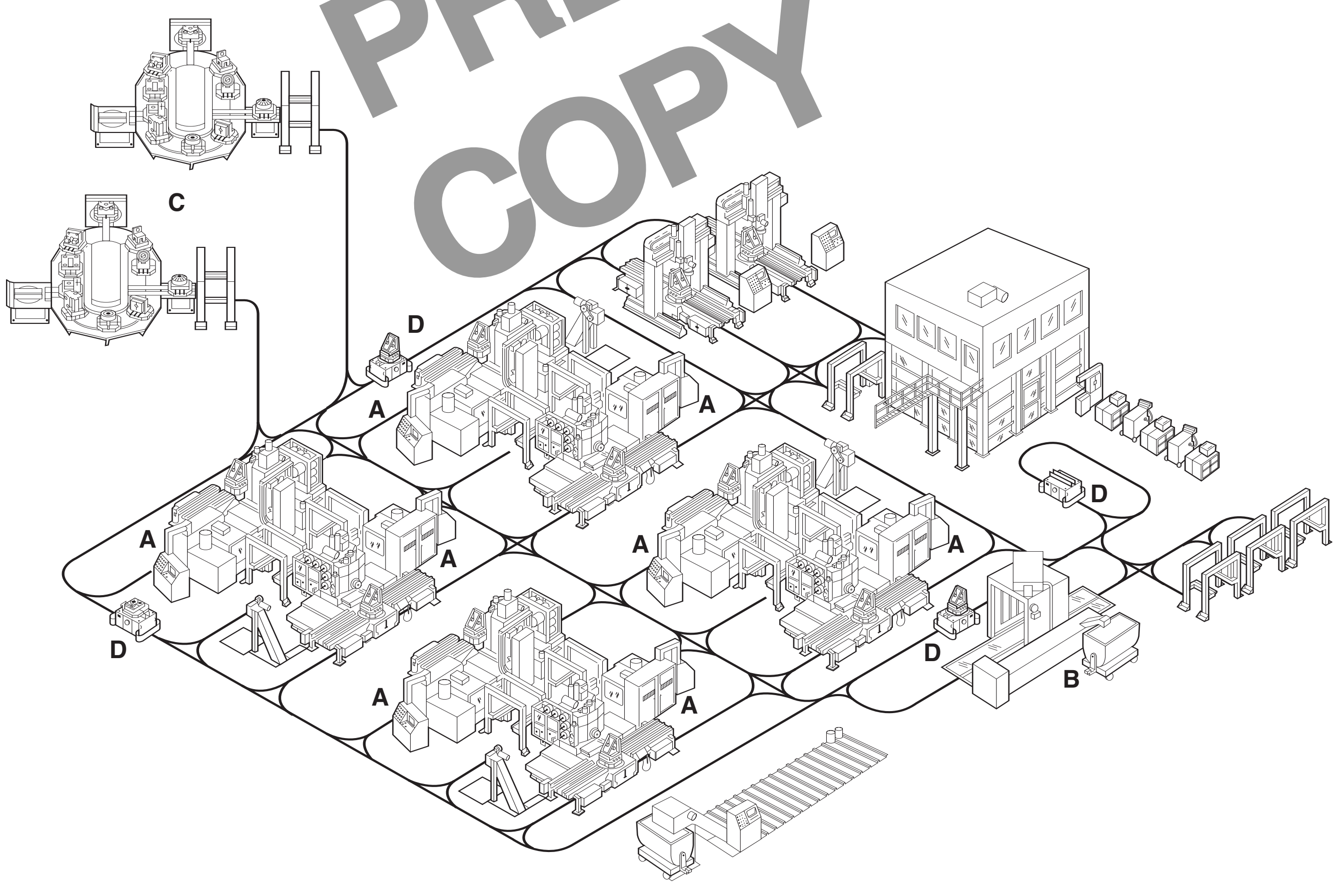
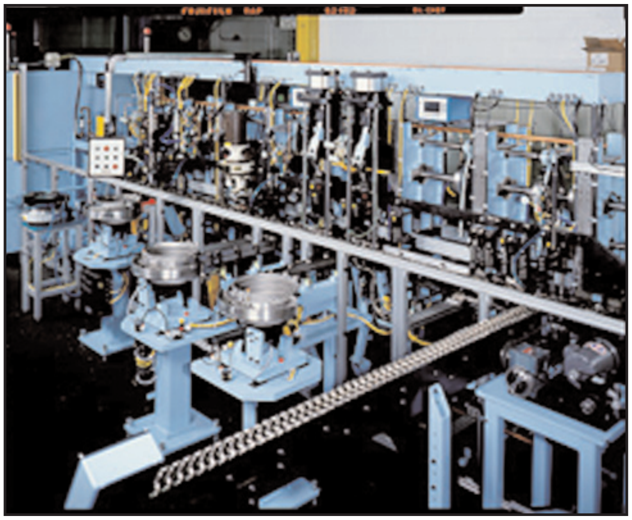


Fig. 1-5. Indexing-carousel, high-speed assembly machine



1.28 Repetitive manufacturing machines do provide very low labor cost per product unit. The specialized equipment typically performs its narrow range of functions very efficiently. The quality of their production is uniformly good. Loss due to defective units, therefore, is low. The assembly machine shown in Fig. 1-5 is an example of a complex machine dedicated to the high-speed production of a high-volume product.

1.29 *Transfer lines* are a special form of repetitive manufacturing. They share the disadvantage of limitation to a single product. The process used to achieve the high production output, however, is slightly different.

1.30 Figure 1-6 is a drawing of a transfer line that produces rear axle housings for large trucks. The first 12 stations (A) move the parts through on pallets. Note the pallet return loop that brings empty pallets back to the starting point on the far right-hand side of the machine. The middle station (B) between the two sections reorients the parts before they enter the last seven stations (C) in the production process.

1.31 Transfer lines, such as the one shown in Fig. 1-6, are specially built, with production machines interconnected with transfer devices to move the item through the process. Raw material or castings enter at one end, and a finished part exits at the other end.

1.32 In repetitive manufacturing systems, the transfer line offers a better opportunity for robot applications than hard automation does. The transfer line diagramed in Fig. 1-7 combines robots and single-purpose automation machines. It produces valve followers and injector followers for the automotive industry.

1.33 One robot (A) loads two milling machines and passes the finished parts through an inspection station. All parts that pass the gauging test are placed in the transfer conveyor for delivery to the second robot station.

Fig. 1-6. Transfer line

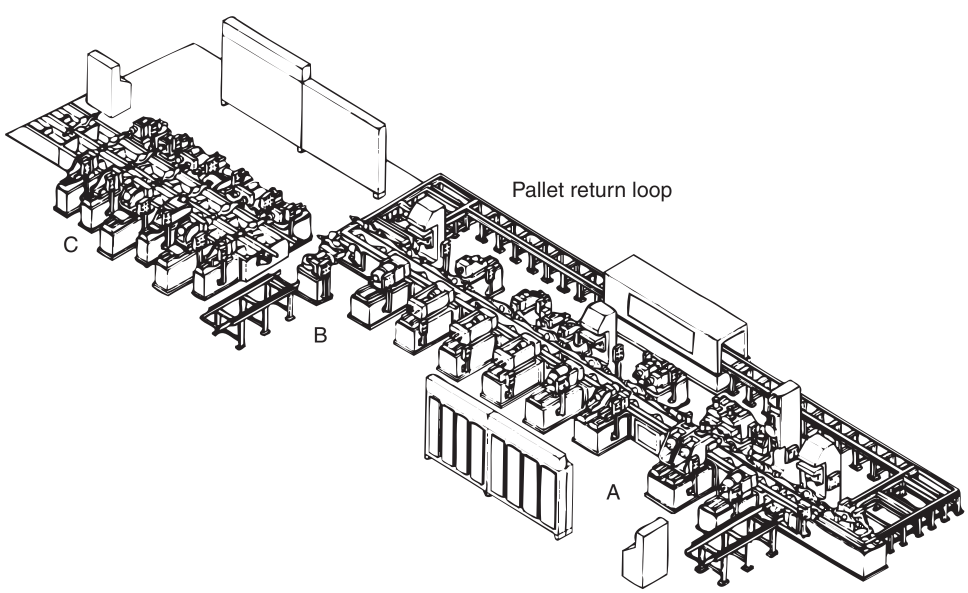
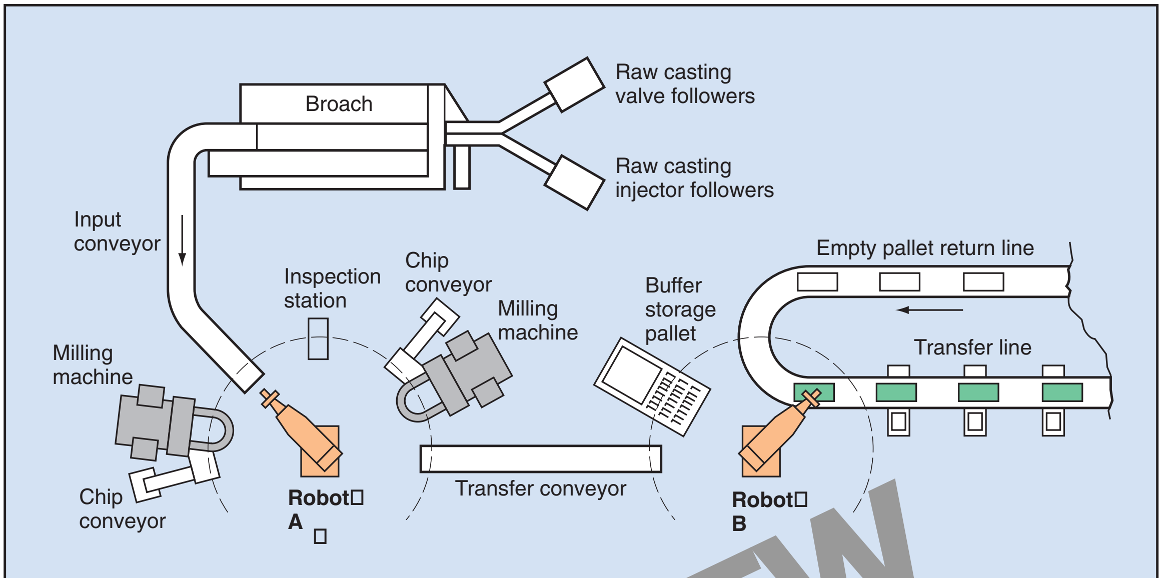


Fig. 1-7. Transfer line with robots



1.34 The second robot (B) loads the parts on pallets for shipping. Robot B can also place finished parts on a buffer storage pallet if the pallet transfer line is down. All upstream systems can then continue to operate while the pallet system is repaired. If an upstream machine needs work at a later time, the second robot can unload the buffer storage and keep the shipping pallet system operating.

Continuous Manufacturing

1.35 *Continuous manufacturing* is characterized by a very high volume and very low variety of nondiscrete products. Specialized equipment performs a narrow range of functions very efficiently. The narrow product range results in better quality control. This type of manufacturing does not lend itself to the use of robots. An example might be the production of yarn for a textile operation. Table 1-1 summarizes the types of manufacturing just discussed.

The Programmed Exercises on the following page will tell you how well you understand the material you have just read. Before starting the exercises, remove the REVEAL KEY from the back of your book. Read the instructions printed on the Reveal Key. Follow these instructions as you work through the Programmed Exercises.

Table 1-1. Characteristics of manufacturing types

	Project/Job Shop	Batch	Repetitive	Continuous
Flexibility	Very high	Moderate	Low	Very low
Cost per Unit	Very high	Moderate	Low	Very low
Output Volume	Very low	Low	High	Very high

1-1. The development of the ________ allowed manufacturers to make robots that were smarter and faster.	1-1. MICROPROCESSOR Ref: 1.04
1-2. "Reprogrammable" refers to a machine whose actions are controlled by a(n) ________.	1-2. STORED PROGRAM Ref: 1.07
1-3. A person or company that helps develop and customize a robot system for a company's applications is called a(n) ________.	1-3. INTEGRATOR Ref: 1.08
1-4. The automotive industry uses one robot for every ________ workers, mainly in ________ applications.	1-4. TEN; WELDING Ref: 1.11
1-5. In a job-shop environment, robots work especially well with machines that are ________ controlled or have ________ operating cycles.	1-5. NUMERICALLY; SHORT Ref: 1.18
1-6. Approximately 75% of all goods sold in the world are produced by ________ manufacturing.	1-6. BATCH Ref: 1.21
1-7. FMS involves ________ and ________ systems under computer control.	1-7. PRODUCTION; MATERIAL-HANDLING Ref: 1.23
1-8. In repetitive manufacturing, the ________ offers a better opportunity for robot applications than hard automation does.	1-8. TRANSFER LINE Ref: 1.32

Robot Safety

1.36 Although robots are reliable industrial workers, capable of saving time and money, they can inflict serious injury to workers in their vicinity as well as cause damage to equipment. They perform fast, powerful movements through a large area. Proper safeguarding and training are essential if operators and maintenance personnel are to work safely near these powerful machines. An effective safety system protects everyone who could potentially be exposed to the hazards associated with a robot's operation. Often a combination of methods is used, especially if a robot can create extremely hazardous conditions.

1.37 Most US companies adhere to the ANSI/RIA R15.06 safety standard. Although not legally required, OSHA refers to it when discussing robots. This standard provides information about safety for various robot configurations. Robot manufacturers and integrators follow standards when creating work cells. Companies often implement additional safety measures.

1.38 The first step in the design of a safe robot system should be a risk assessment (hazard analysis) based on the operation of the particular robot. This step may be undertaken by maintenance personnel, a safety management team, or shift personnel. Factors to be considered include:

- the task the robot is to perform
- the location of the robot
- start-up and programming procedures
- normal mode of operation
- possible malfunctions and corrective actions
- electrical/hydraulic/pneumatic/mechanical/stored energy hazards
- shutdown and lockout/tagout procedures.

Only when hazards have been identified can options be considered to guard against them.

1.39 Most people probably think of robot accidents happening during normal operation. Studies have shown, however, that more accidents occur during programming, testing, inspection, and repair. These are times when the operator, programmer, or maintenance worker may be within the robot's working area while power is available to the robot system. Accidents related to robots typically involve personnel being caught, struck, pinned, or flung by a moving part of the robot.

1.40 **Guarding methods.** Unauthorized access to a robot's working area (also known as the *work envelope*) can be hazardous, especially if the person

Fig. 1-8. Barrier surrounding robot installation

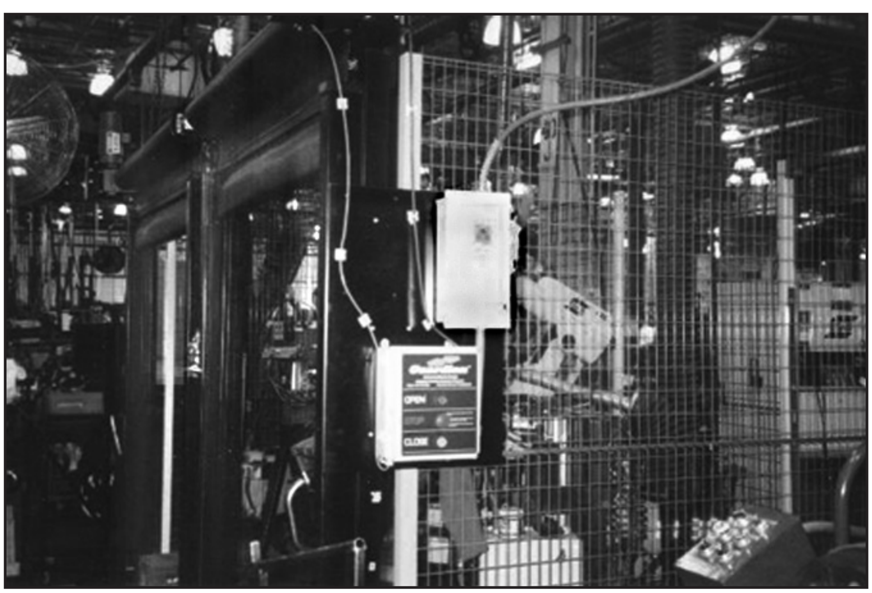
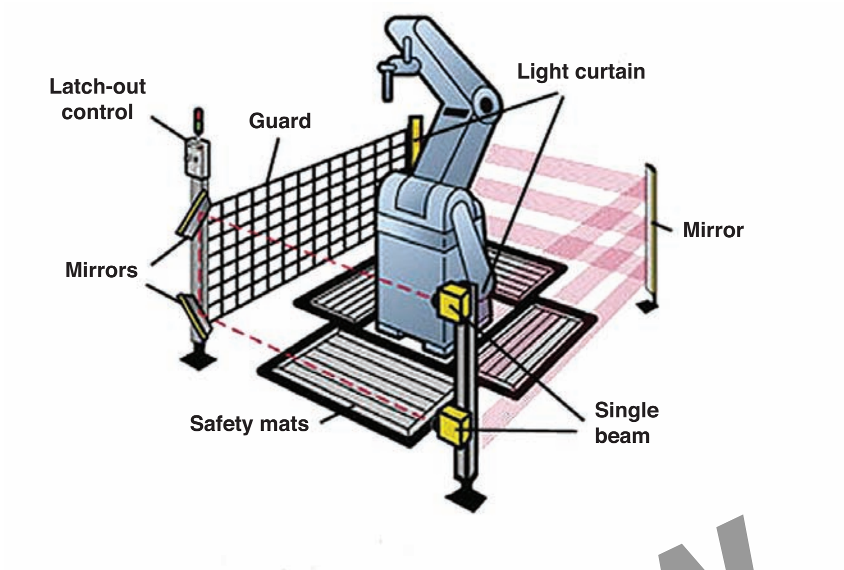


Fig. 1-9. Robot installation incorporating several safeguards



involved is not familiar with the robot and its operation. Several methods are used to guard against the accidental entry of a person into a robot's work envelope. The simplest is a *fixed barrier*, a fence that prevents access through, over, under, or around. It typically requires a key or tools for removal so that it is not easily bypassed. An example of a fixed barrier is shown in Fig. 1-8, on the previous page. An *interlocked barrier* is similar to a fixed barrier in that it prevents easy access to the work envelope. However, it uses a gate or gates equipped with interlocks. When a gate is opened, the robot and all associated equipment will stop. This interlocking is also shown in Fig. 1-8. Restarting the equipment requires closing the gate and reactivating a control switch located outside of the barrier.

1.41 The most common *presence-sensing devices* are pressure mats and light curtains. These devices detect the entry of a person into a hazardous area and stop all motion of the robot. *Emergency braking* slows the motion of a robot rather than completely cutting off power. Braking is sometimes safer because it counteracts the effects of robot arm inertia. Cutting off all power could create hazards such as a sudden dropping of a robot's arm or flinging of a workpiece. Figure 1-9 shows a robot installation using perimeter guards, light devices, safety mats, and a latch-out reset unit.

1.42 An *awareness device* is a simple railing or suspended chain used to define a safety perimeter. It is intended to avoid accidental entry into a work envelope, but does not actually prevent entry. Such devices are acceptable only where the hazard is minimal or other guards are not practical. Audible and visible *warning systems* may be used in addition to positive safeguards, but cannot be used alone.

1.43 **Control devices.** The main control panel should be located outside the work envelope but within sight of the robot. All control devices should be clearly marked so that their purpose is obvious. Those that control power or motion should be guarded to prevent accidental operation. Readily accessible emergency stops should be located in all zones where needed. Their location and use should be a prominent part of personnel training. Emergency stops override all other controls. The portable programming control device must also contain an emergency stop.

1.44 A robot should stop automatically if its speed becomes excessive or it begins to move outside its operating envelope. The control system should prevent a robot from automatically restarting after power is restored following a power failure. Control systems must be properly grounded and wired for hazardous locations, if necessary.

1.45 **Installation.** As with all industrial equipment, improper robot installation can cause problems. To operate safely, a robot must be installed according to the manufacturer's guidelines and applicable codes. (This may include both national and local machine wiring codes and electrical codes.) Power to the robot must conform to the manufacturer's specifications.

1.46 The robot must be mounted properly to

- prevent tipping or movement from vibration
- avoid the creation of hazardous situations, such as exposed pinch points or energized conductor contact with robot components.

Following installation, markings may be made on the robot itself, on walls, or on floors indicating the zones of movement of the robot and advising caution in the vicinity.

1.47 **Maintenance.** One of the best ways to ensure the trouble-free operation of a robot system is to follow the robot manufacturer's preventive maintenance schedule. This should include a periodic check of all safety equipment, connections, terminations, and communications.

1.48 Working on a robot system can bring you in contact with a variety of hazards. Electrical hazards exist in the form of electric shock and fire from electrical overload. Mechanical hazards include the release of stored energy. Unexpected environmental hazards may also be present.

1.49 Before performing maintenance on the system, make sure there is an established lockout/tagout (LOTO) procedure in place and that you understand how to comply with it. Follow it carefully for both preventive maintenance and repair operations. LOTO should bring the system to a zero-energy state. A *zero-energy state* not only locks out electric power, but also neutralizes stored-energy devices such as springs and accumulators and pneumatic/hydraulic systems. Stops may be placed on the system's *axes* to prevent movement. Human errors can cause unpredicted movement of the robot arm.

1.50 **Programming.** When in the *teach mode*, only a qualified programmer should have control of a robot and access to the work envelope. All robot motion initiated from a teach pendant within the work envelope should be at a slow speed—approximately 10 in/sec (250 mm/sec). Two teach pendants are shown in Fig. 1-10.

1.51 **Training.** Effective safety programs must include training. All employees must be made aware of the hazards that exist and the safeguarding measures in place to guard against them. Training should include work practices necessary for the trainee to perform his or her assigned job safely.

1.52 A company that uses robots in its operations should have a written robotics safety policy and should explain it to all personnel who will be working with or near robots. This policy should clearly spell out which employees are authorized to work with the robots. Only workers who have received adequate training in hazard recognition and the control of

Fig. 1-10. Teach pendants

robots should be allowed to program or operate a robot or to perform maintenance on it.

1.53 If it is necessary for an authorized worker to be within the envelope while a robot is energized, for example during programming or maintenance, training should include:

- avoiding hazardous areas
- familiarization with the robot system's energy sources
- use of slow robot speeds
- location of emergency stops
- lockout/tagout procedures.

1.54 **Protect the robot.** Because robots are major investments, it is important to protect them as well as those employees who work in their vicinity. *Vision systems* work like eyes to protect and inform the robot. These software-based devices can be taught to react to unusual situations or foreign objects. Vision systems will be covered in more detail in a later lesson.

1-9. The ANSI/RIA R15.06 standard provides information about robot ________.	1-9. SAFETY Ref: 1.37
1-10. What is the first step in the design of a safe robot system?	1-10. RISK ASSESSMENT or HAZARD ANALYSIS Ref: 1.38
1-11. When a(n) ________ barrier is in use, opening a gate will cause the robot and associated equipment to stop.	1-11. INTERLOCKED Ref: 1.40
1-12. Pressure mats and light curtains are the most common ________ devices.	1-12. PRESENCE-SENSING Ref: 1.41
1-13. A robot's main control panel should be located ________ the work envelope but within ________ of the robot.	1-13. OUTSIDE; SIGHT Ref: 1.43
1-14. When a robot is installed, it must be mounted properly to prevent tipping or movement from ________.	1-14. VIBRATION Ref: 1.46
1-15. Before performing maintenance on a robot system, make sure there is an established ________ procedure in place and that you know how to comply with it.	1-15. LOCKOUT/TAGOUT (LOTO) Ref: 1.49
1-16. The locking out of electric power and neutralizing of stored-energy devices brings a system to a(n) ________ state.	1-16. ZERO-ENERGY Ref: 1.49

Answer the following questions by marking an "X" in the box next to the best answer.

1-1. The technological breakthrough in the early 1970s that most influenced the emergence of functional industrial robots was the

- ☐ a. development of the laser
- ☐ b. development of the microprocessor
- ☐ c. development of the minicomputer
- ☐ d. invention of numerical control

1-2. The above breakthrough was important because

- ☐ a. numerical control simplified robot pro- gramming
- ☐ b. the laser gave robots "sight"
- ☐ c. the minicomputer made it possible to build more powerful robots
- ☐ d. with microprocessors, robots became smarter and faster

1-3. The two key words in the RIA definition of an industrial robot are

- ☐ a. manipulator and multifunctional
- ☐ b. multifunctional and programmed
- ☐ c. reprogrammable and manipulator
- ☐ d. reprogrammable and multifunctional

1-4. Which industry is the largest user of robots?

- ☐ a. Automotive
- ☐ b. Food processing
- ☐ c. Oil and gas refining
- ☐ d. Pharmaceutical

1-5. Robots have the greatest application in which type of manufacturing?

- ☐ a. Continuous
- ☐ b. FMS
- ☐ c. Job shop
- ☐ d. Project

1-6. In repetitive manufacturing systems, you are likely to find robots integrated into

- ☐ a. FMS
- ☐ b. hard automation
- ☐ c. traditional job shops
- ☐ d. transfer lines

1-7. The first step in the design of a safe robot system is to

- ☐ a. make use of both fixed and movable guards
- ☐ b. perform a risk assessment
- ☐ c. purchase all components from one manufacturer
- ☐ d. utilize only non-electric power

1-8. A robot's control system should

- ☐ a. automatically restart equipment following a power failure
- ☐ b. be guarded to prevent accidental operation
- ☐ c. be located within the work envelope
- ☐ d. include a single emergency stop button

1-9. Locking out electric power and neutralizing stored-energy devices will bring a robot system to a ________ state.

- ☐ a. hazardous
- ☐ b. programming-ready
- ☐ c. teach-mode
- ☐ d. zero-energy

1-10. When in the teach mode, who should have access to a robot's work envelope?

- ☐ a. A maintenance technician
- ☐ b. A qualified programmer
- ☐ c. All department personnel
- ☐ d. The scheduled operator

SUMMARY

The arrival of the microprocessor marked the introduction of the first truly functional industrial robots. Microprocessors permitted manufacturers to build smaller, more powerful controllers that allowed robots to do more tasks. They also gave manufacturers the means of making robots smarter and faster, and their movements more reliably repeatable.

A robot can be defined as reprogrammable, meaning its actions are controlled by a stored program that can be changed to fit requirements. It can also be multifunctional, or capable of performing more than one function. The same robot can be used in widely varying jobs within the same factory or in different industries. The automotive industry remains the largest user of industrial robots. Many small- to mid-size companies are becoming first-time robot users as a result of competitive pricing and ease of use and programming.

All manufacturing operations today can be classed as one of the following: project, job shop, batch, repetitive, and continuous. Flexible manufacturing systems, a type of batch manufacturing, offer the greatest scope for robot applications.

Answers to Self-Check Quiz

1-1. b. Development of the microprocessor. Ref: 1.01

1-2. d. With microprocessors, robots became smarter and faster. Ref: 1.04

1-3. d. Reprogrammable and multifunctional. Ref: 1.07

1-4. a. Automotive. Ref: 1.11

1-5. b. FMS. Ref: 1.23

1-6. d. Transfer lines. Ref: 1.32

1-7. b. Perform a risk assessment. Ref: 1.38

1-8. b. Be guarded to prevent accidental operation. Ref: 1.43

1-9. d. Zero-energy. Ref: 1.49

1-10. b. A qualified programmer. Ref: 1.50

Contributions from the following sources are appreciated:

Figure 1-1.	DENSO Robotics
Figure 1-5.	ATW Bodine
Figure 1-8.	Frommelt Safety
Figure 1-9.	Rockford Systems, Inc.
Figure 1-10.	DENSO Robotics