# Automation in Manufacturing

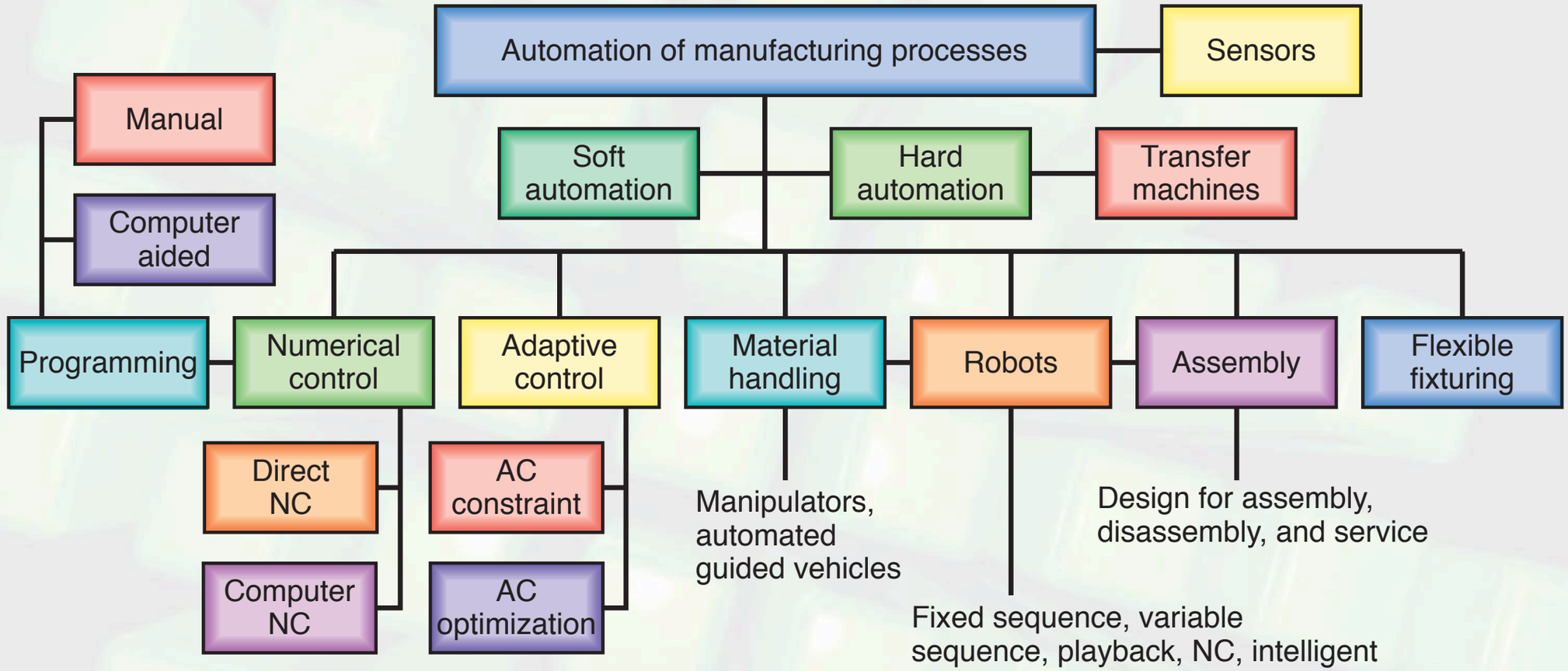
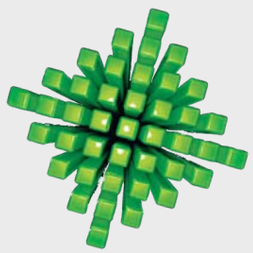



FIGURE 14.1 Outline of topics described in this chapter.



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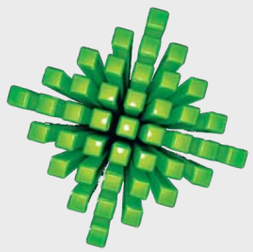
# History of Automation

| Date | Development |
|---|---|
| 1500-1600 | Water power for metalworking; rolling mills for coinage strips. |
| 1600-1700 | Hand lathe for wood; mechanical calculator. |
| 1700-1800 | Boring, turning, and screw cutting lathe, drill press. |
| 1800-1900 | Copying lathe, turret lathe, universal milling machine; advanced mechanical calculators. |
| 1808 | Sheet-metal cards with punched holes for automatic control of weaving patterns in looms. |
| 1863 | Automatic piano player (Pianola). |
| 1900-1920 | Geared lathe; automatic screw machine; automatic bottle-making machine. |
| 1920 | First use of the word robot. |
| 1920-1940 | Transfer machines; mass production. |
| 1940 | First electronic computing machine. |
| 1943 | First digital electronic computer. |
| 1945 | First use of the word automation. |
| 1947 | Invention of the transistor. |
| 1952 | First prototype numerical control machine tool. |
| 1954 | Development of the symbolic language APT (Automatically Programmed Tool); adaptive control. |
| 1957 | Commercially available NC machine tools. |
| 1959 | Integrated circuits; first use of the term group technology. |
| 1960 | Industrial robots. |
| 1965 | Large-scale integrated circuits. |
| 1968 | Programmable logic controllers. |
| 1970s | First integrated manufacturing system; spot welding of automobile bodies with robots; microprocessors; minicomputer-controlled robot; flexible manufacturing system; group technology. |
| 1980s | Artificial intelligence; intelligent robots; smart sensors; untended manufacturing cells. |
| 1990-2000s | Integrated manufacturing systems; intelligent and sensor-based machines; telecommunications and global manufacturing networks; fuzzy-logic devices; artificial neural networks; Internet tools; virtual environments; high-speed information systems. |

TABLE 14.1 Developments in the history of automation and control of manufacturing processes. (See also Table 1.1.)



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# Flexibility and Productivity

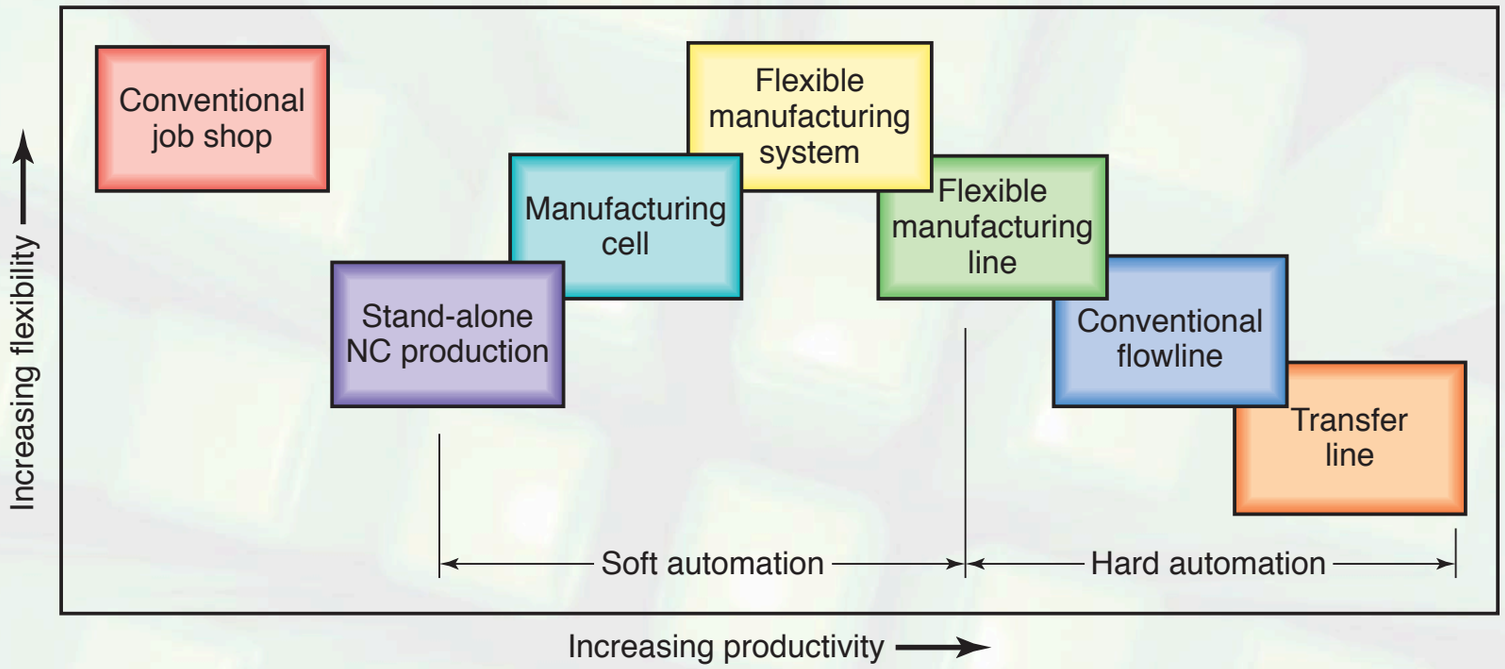
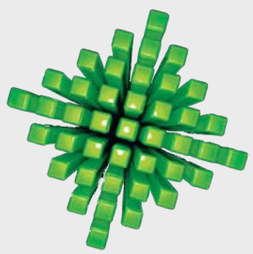



FIGURE 14.2 Flexibility and productivity of various manufacturing systems. Note the overlap between the systems, which is due to the various levels of automation and computer control that are applicable in each group. See also Chapter 15 for more details.

| Type of production | Number produced | Typical products |
|---|---|---|
| Experimental or prototype | 1-10 | All types |
| Piece or small batch | < 5000 | Aircraft, machine tools, dies |
| Batch or high quantity | 5000-100,000 | Trucks, agricultural machinery, jet engines, diesel engines, orthopedic devices |
| Mass production | 100,000+ | Automobiles, appliances, fasteners, bottles, food and beverage containers |

TABLE 14.2 Approximate annual quantity of production.



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# Characteristics of Production

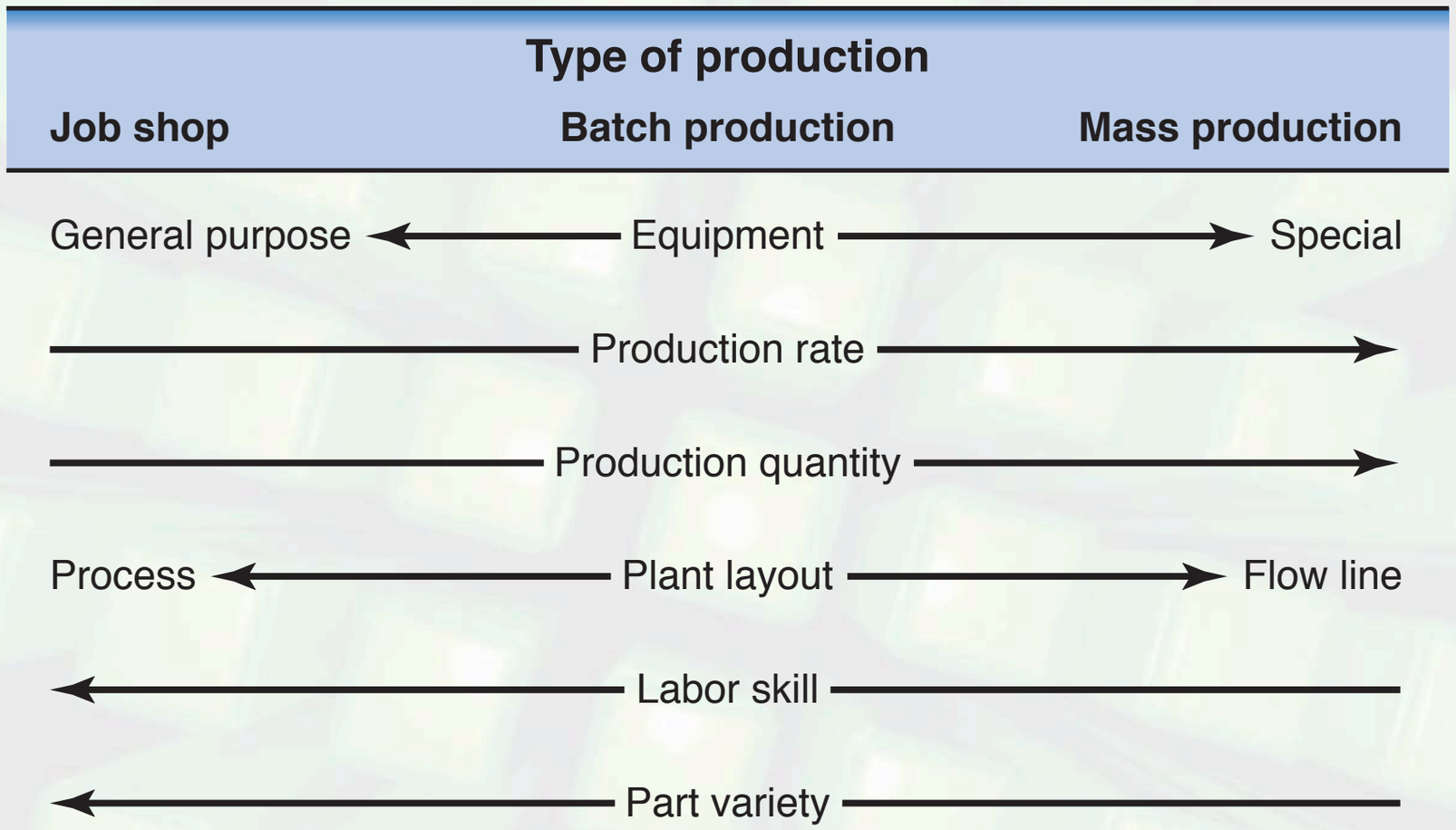


FIGURE 14.3 General characteristics of three types of production methods: job shop, batch production, and mass production.

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# Transfer Mechanisms

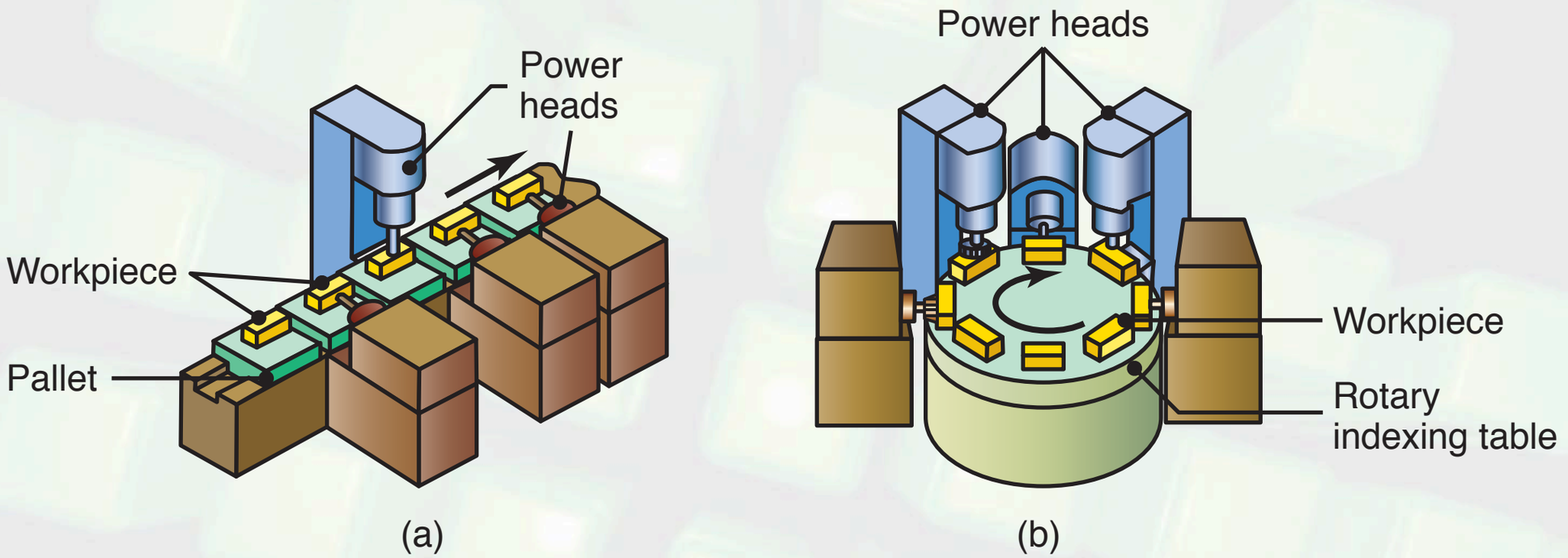


FIGURE 14.4 Two types of transfer mechanisms: (a) straight, and (b) circular patterns.

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# Transfer Line

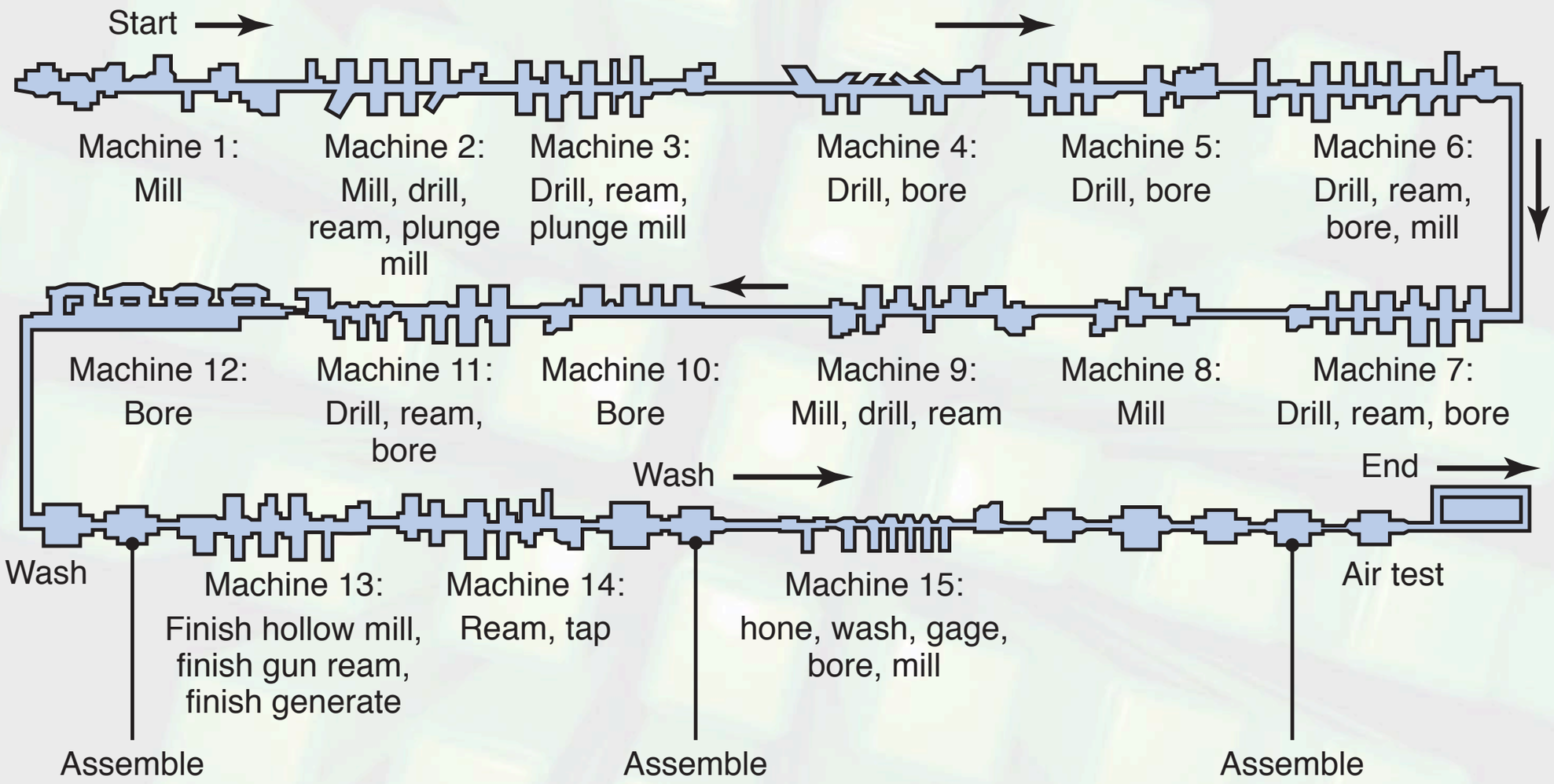
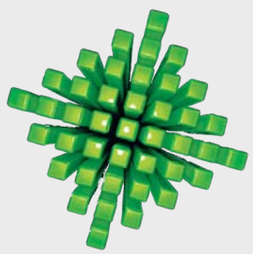



FIGURE 14.5 A traditional transfer line for producing engine blocks and cylinder heads. *Source:* Ford Motor Company.



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# Dimensioning Example

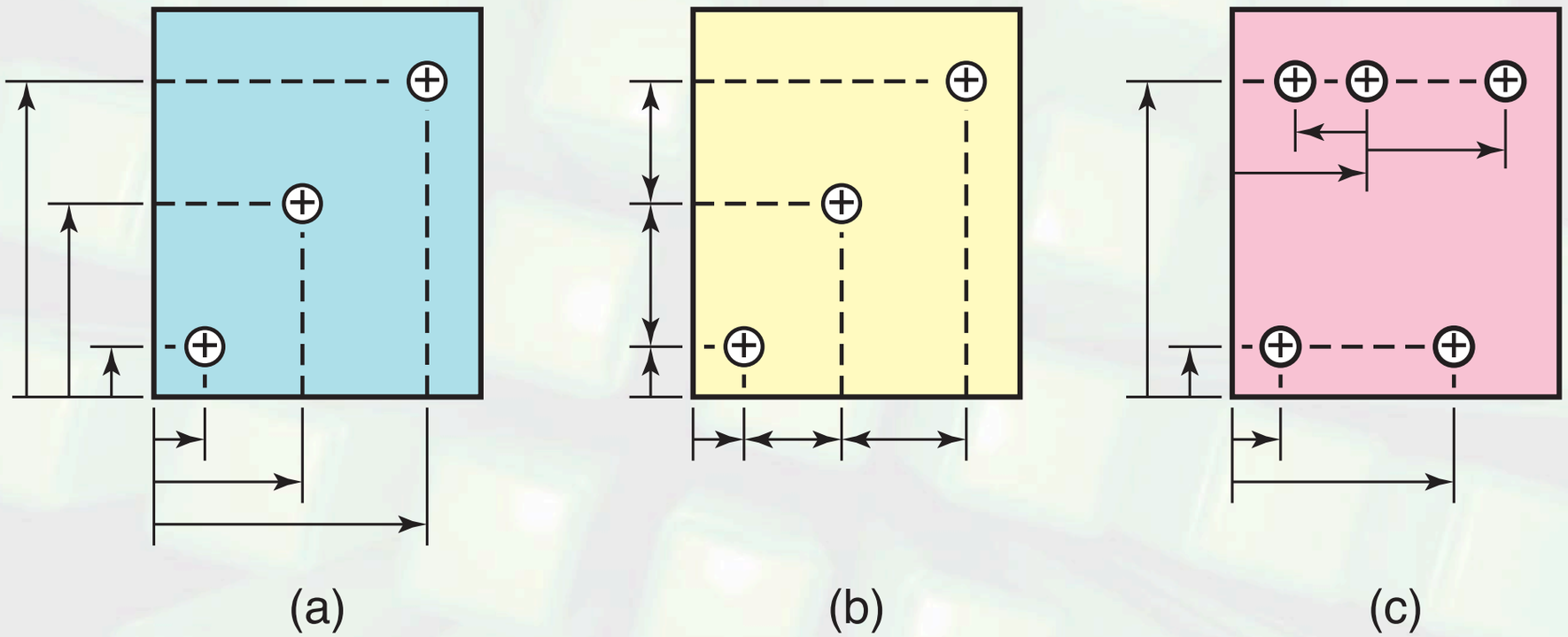
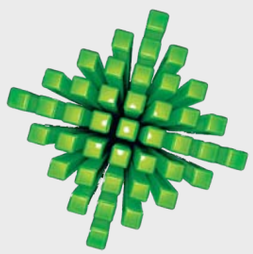



FIGURE 14.6 Positions of drilled holes in a workpiece. Three methods of measurements are shown: (a) absolute dimensioning, referenced from one point at the lower left of the part; (b) incremental dimensioning, made sequentially from one hole to another; and (c) mixed dimensioning, a combination of both methods.



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# Numerical Control

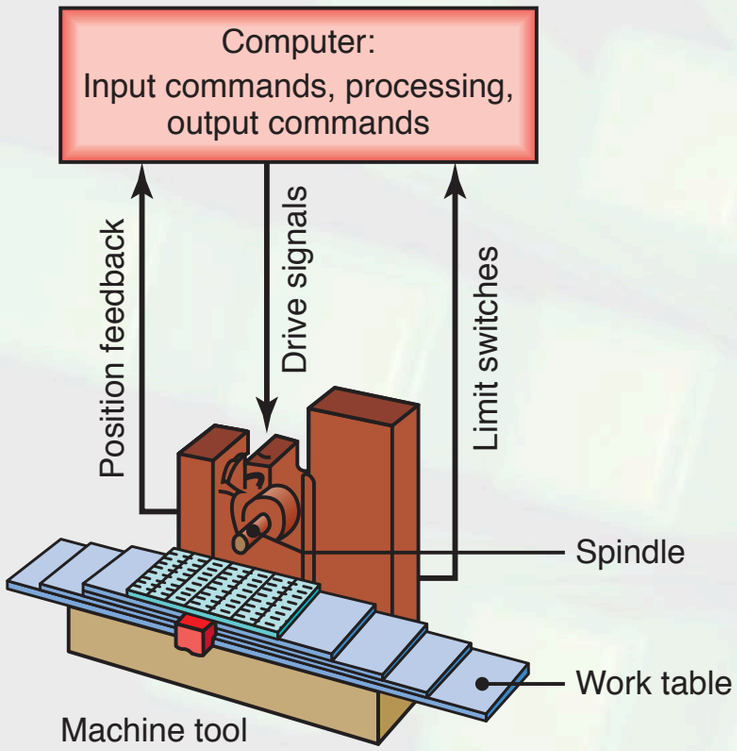



FIGURE 14.7 Schematic illustration of the major components of a numerical control machine tool.

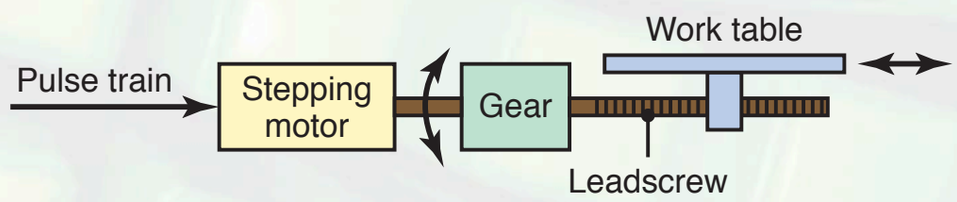
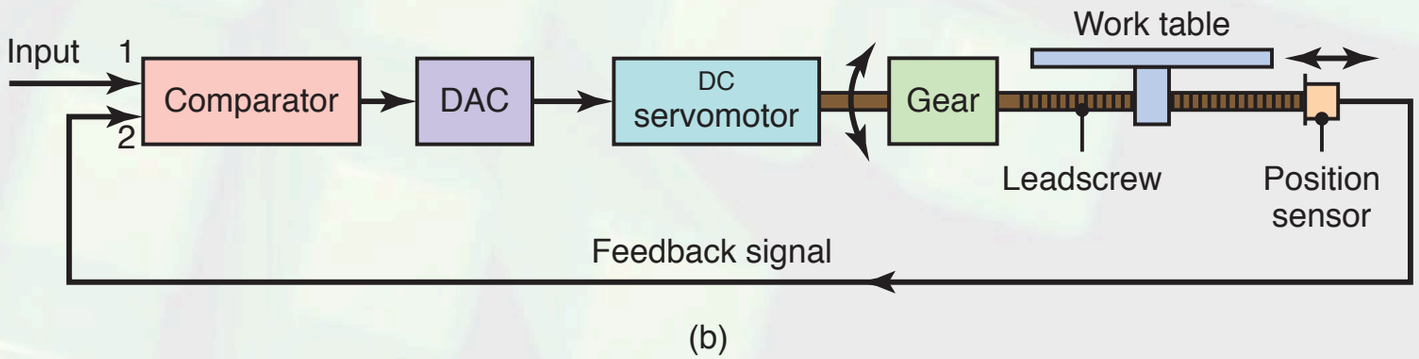



FIGURE 14.8 Schematic illustration of the components of (a) an open-loop, and (b) a closed-loop control system for a numerical control machine. (DAC is digital-to-analog converter.)

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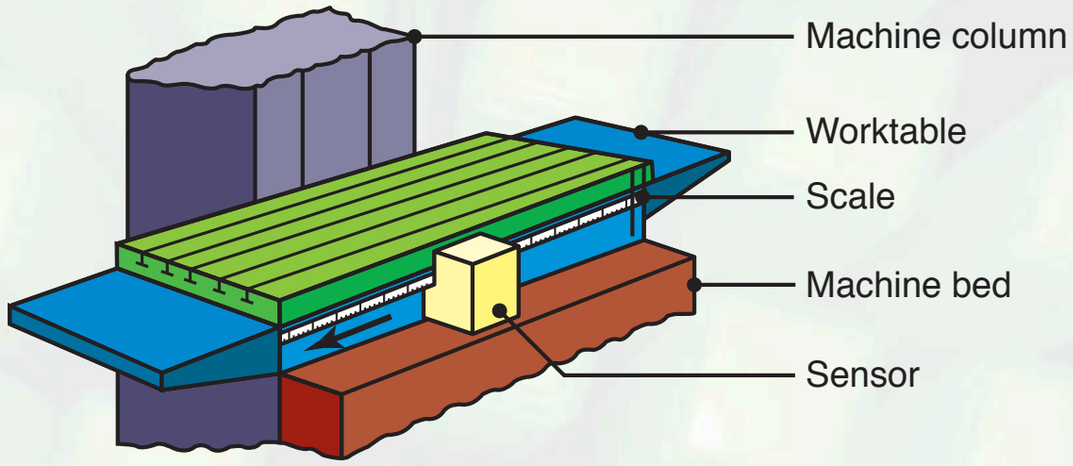
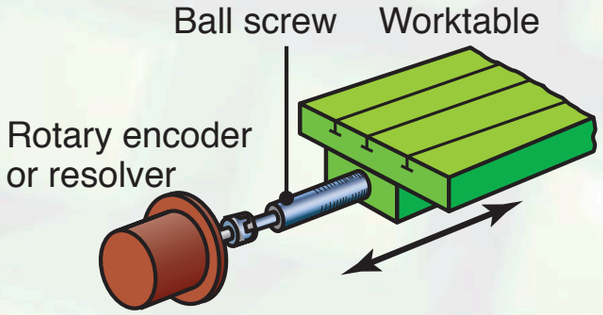
# Displacement Measurement




(a)

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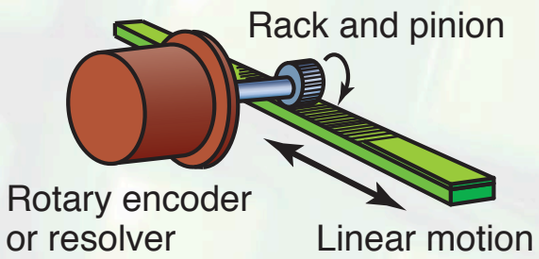
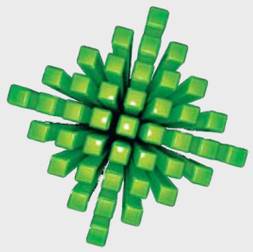



(c)

FIGURE 14.9 (a) Direct measurement of the linear displacement of a machine-tool worktable. (b) and (c) Indirect measurement methods.



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# Tool Movement & Interpolation

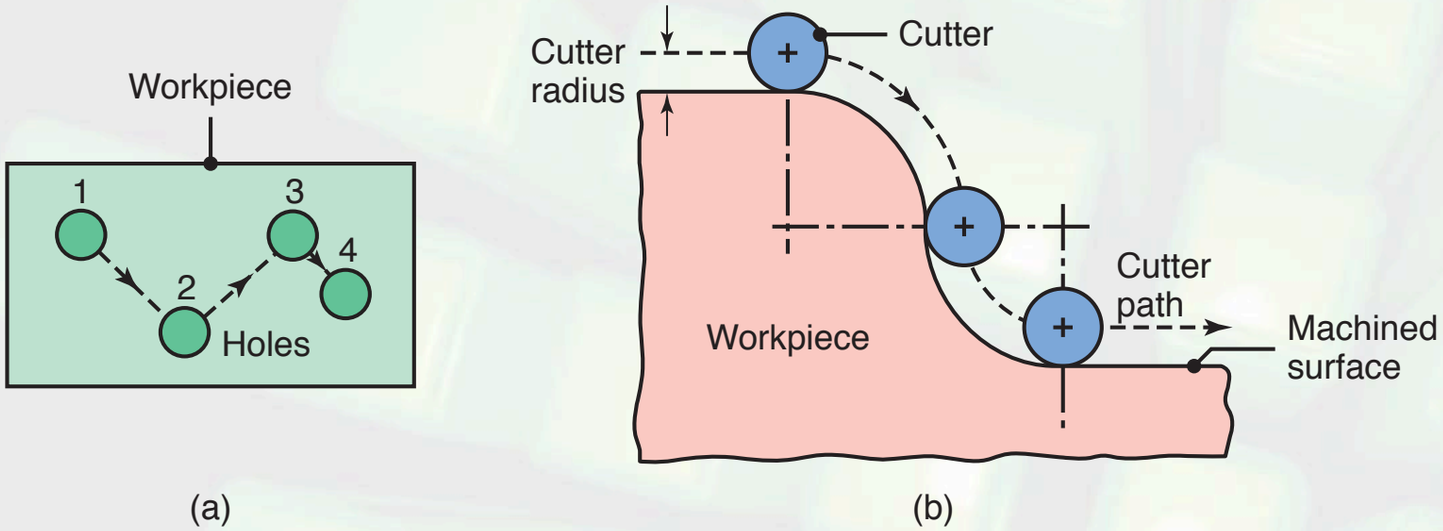
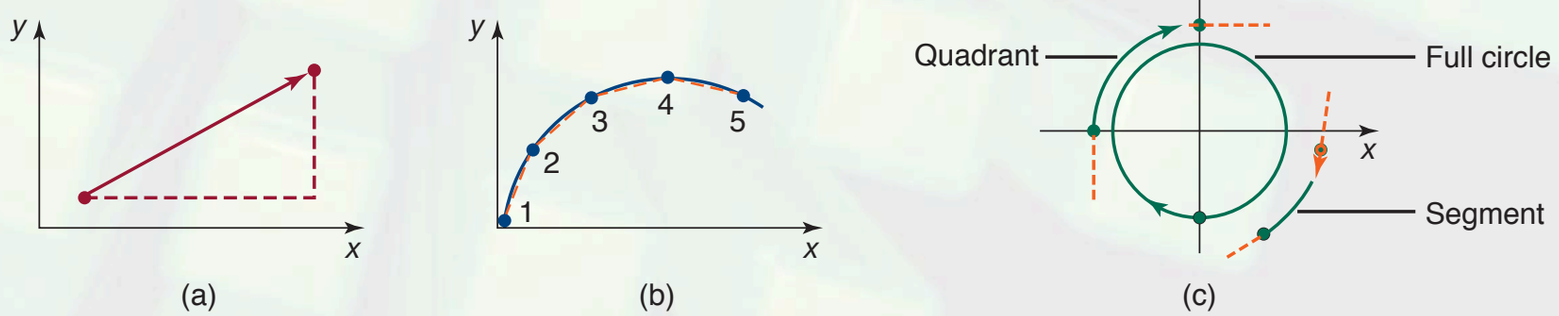



FIGURE 14.10 Movement of tools in numerical control machining. (a) Point-to-point system: The drill bit drills a hole at position 1, is then retracted and moved to position 2, and so on. (b) Continuous path by a milling cutter; note that the cutter path is compensated for by the cutter radius. This path can also compensate for cutter wear.

FIGURE 14.11 Types of interpolation in numerical control: (a) linear; (b) continuous path approximated by incremental straight lines; and (c) circular.

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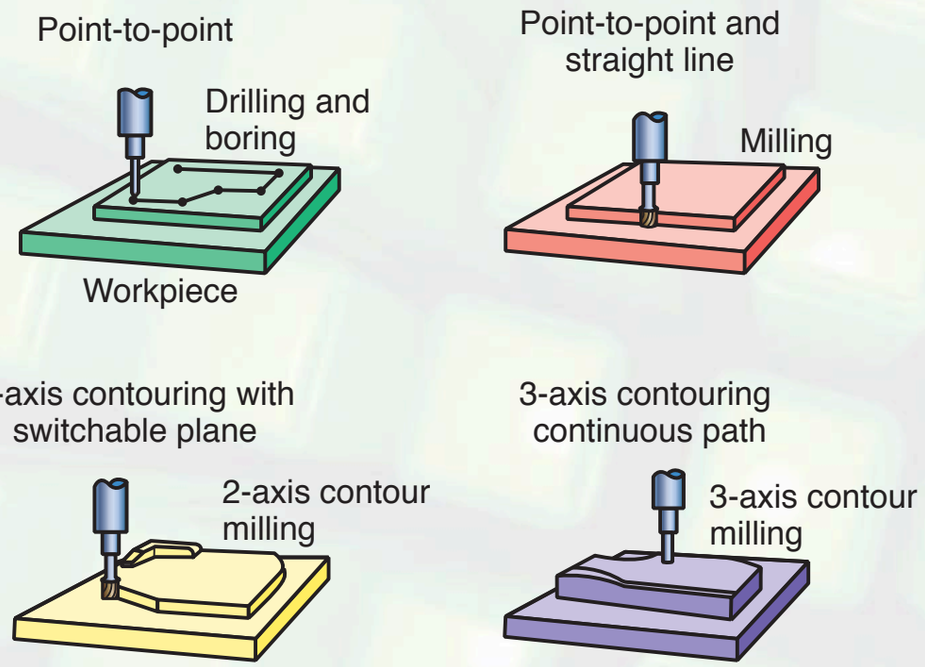
# CNC Operations



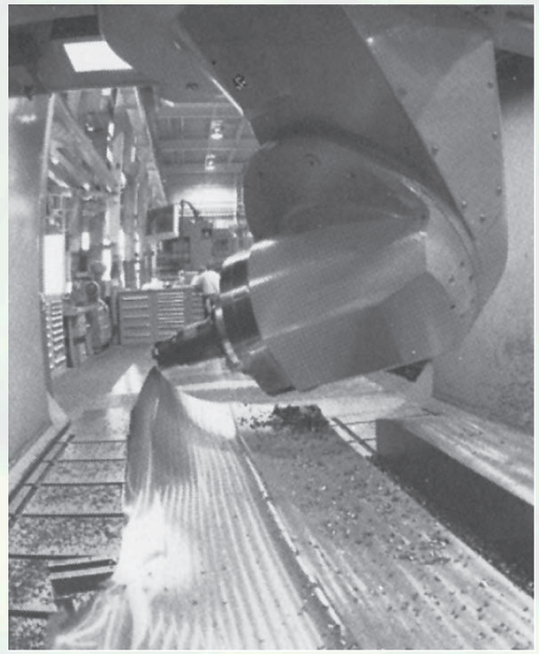
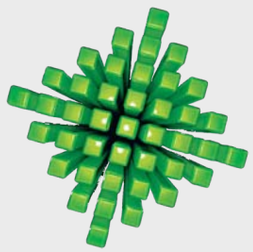


(b)

FIGURE 14.12 (a) Schematic illustration of drilling, boring, and milling operations with various cutter paths. (b) Machining a sculptured surface on a five-axis numerical control machine. *Source:* The Ingersoll Milling Machine Co.



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# Adaptive Control

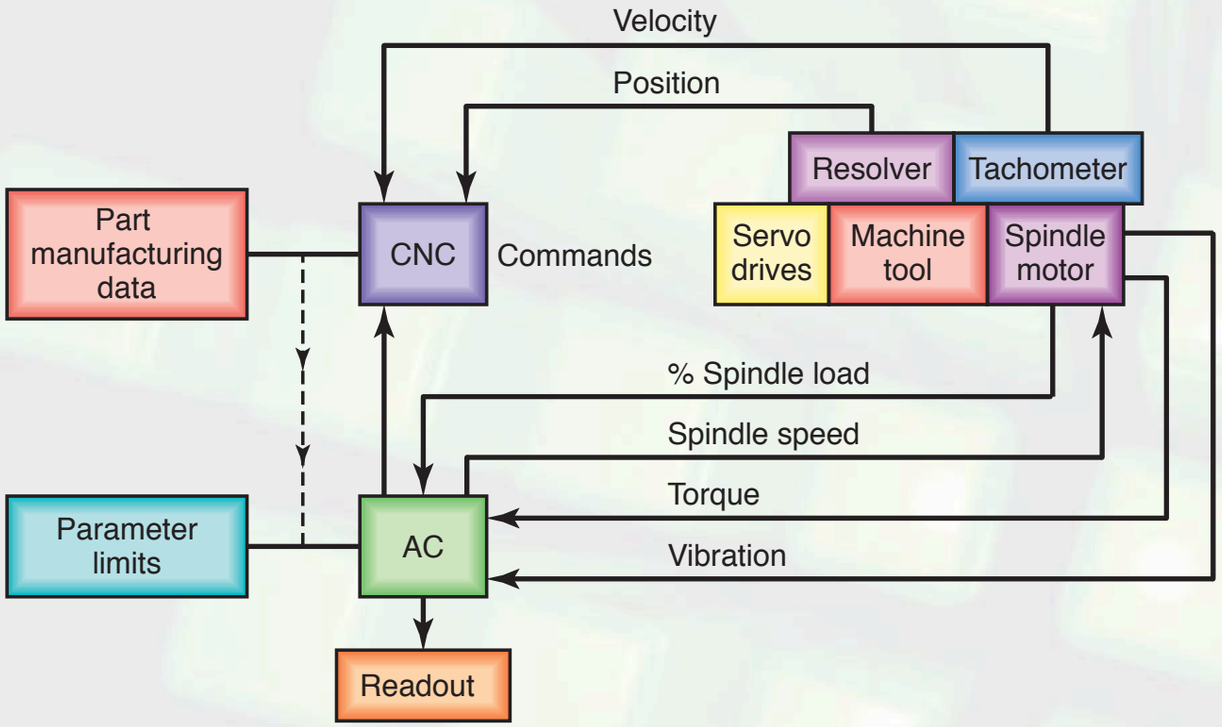
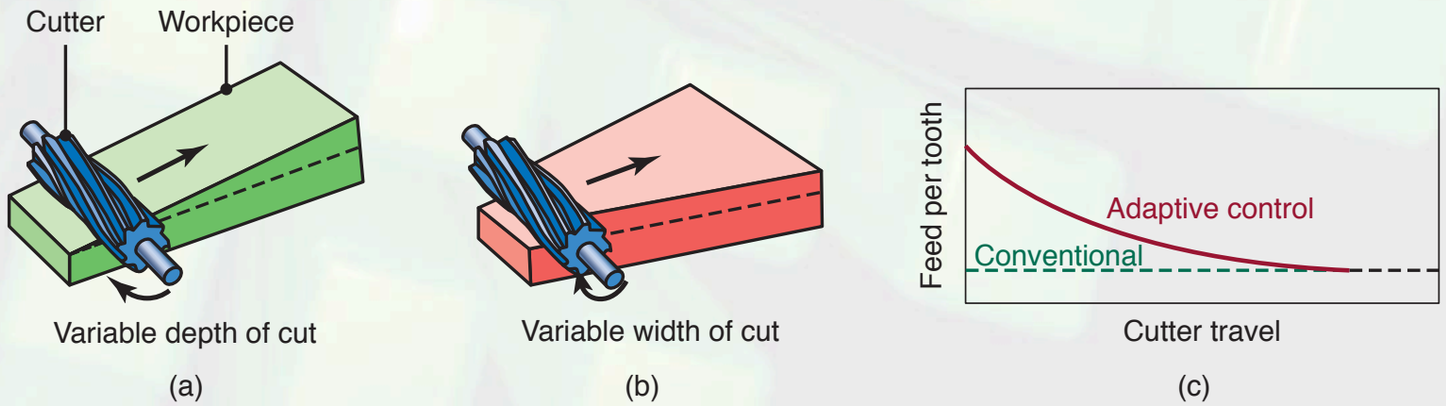
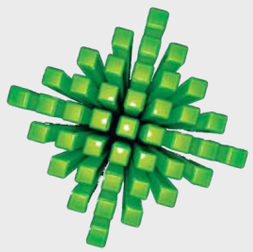



FIGURE 14.13 Schematic illustration of the application of adaptive control (AC) for a turning operation. The system monitors such parameters as cutting force, torque, and vibrations; if they are excessive, AC modifies process variables, such as feed and depth of cut, to bring them back to acceptable levels.

FIGURE 14.14 An example of adaptive control in slab milling. As the depth of cut or the width of cut increases, the cutting forces and the torque increase; the system senses this increase and automatically reduces the feed to avoid excessive forces or tool breakage. *Source:* After Y. Koren.



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# In-Process Inspection

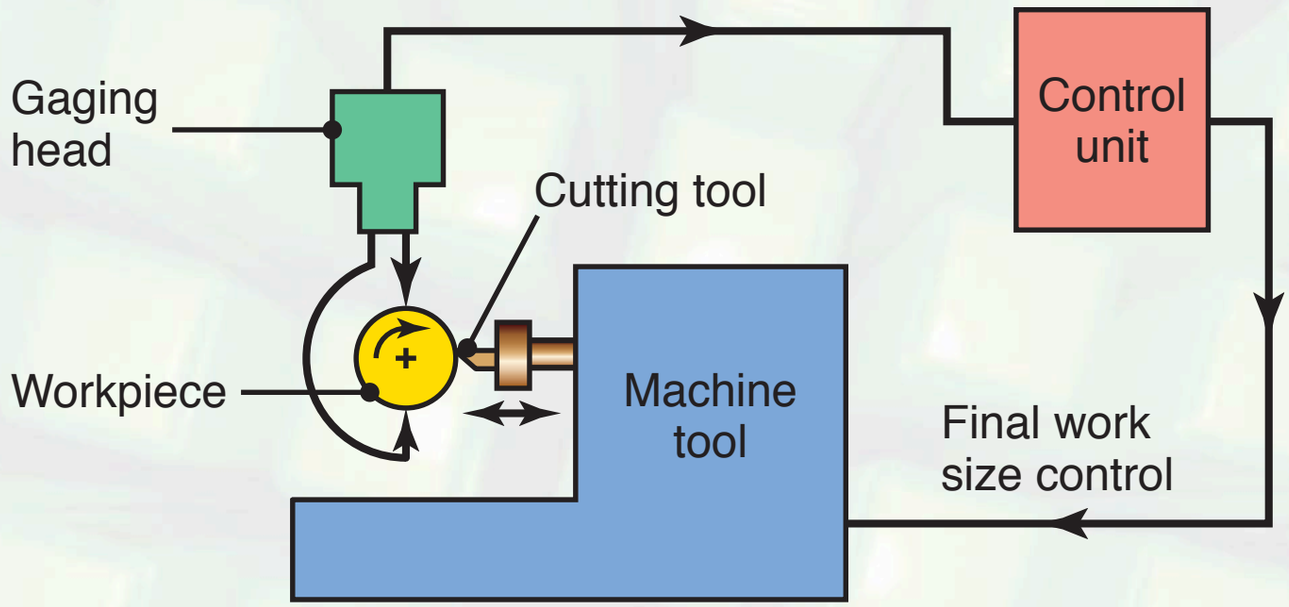
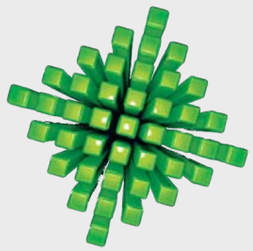



FIGURE 14.15 In-process inspection of workpiece diameter in a turning operation. The system automatically adjusts the radial position of the cutting tool in order to machine the correct diameter.



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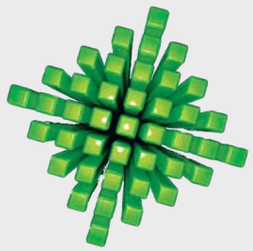
# Self-Guided Vehicle

(a)

(b)

FIGURE 14.16 (a) A self-guided vehicle (Tugger type). This vehicle can be arranged in a variety of configurations to pull caster-mounted cars; it has a laser sensor to ensure that the vehicle operates safely around people and various obstructions. (b) A self-guided vehicle configured with forks for use in a warehouse. *Source:* Courtesy of Egemin, Inc.



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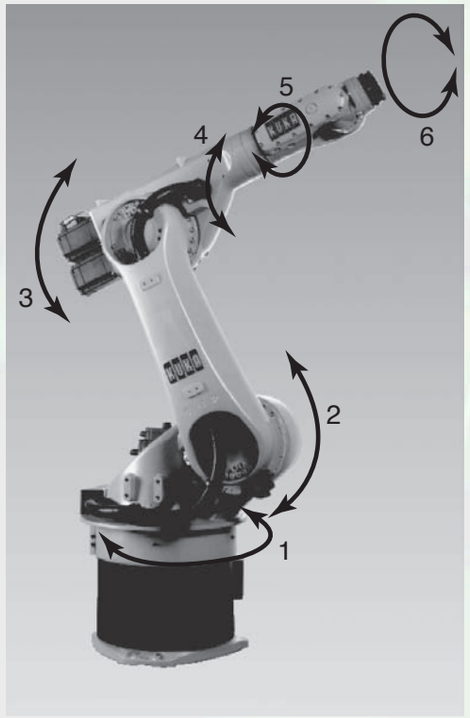
# Industrial Robots

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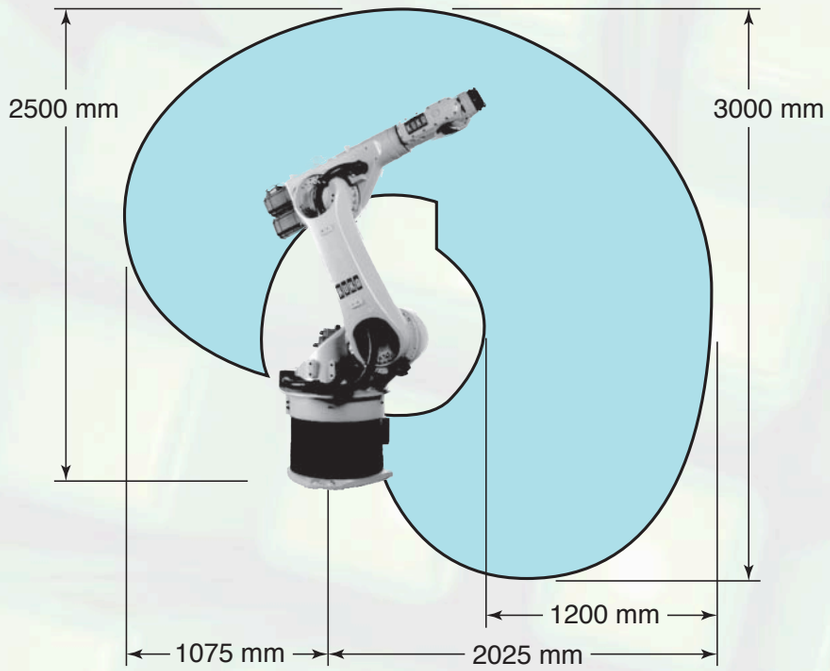
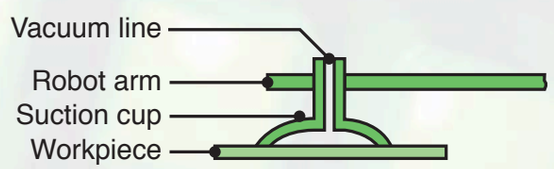


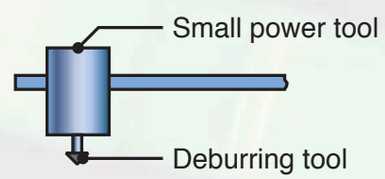

(b)

FIGURE 14.17 (a) Schematic of a six-axis KR-30 KUKA robot; the payload at the wrist is 30 kg and repeatability is ±0.15 mm (±0.006 in.). The robot has mechanical brakes on all of its axes. (b) The work envelope of the KUKA robot, as viewed from the side. *Source:* Courtesy of KUKA Robotics.



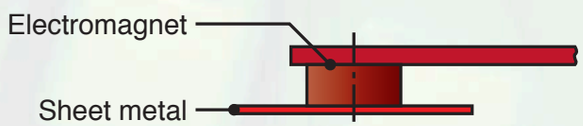

(a)

(b)




(c)

FIGURE 14.18 Various devices and tools that can be attached to end effectors to perform a variety of operations.

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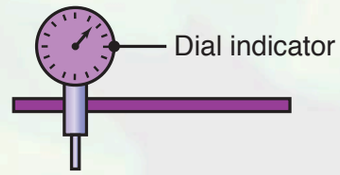


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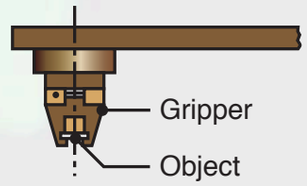


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# Robot Types & Workspaces

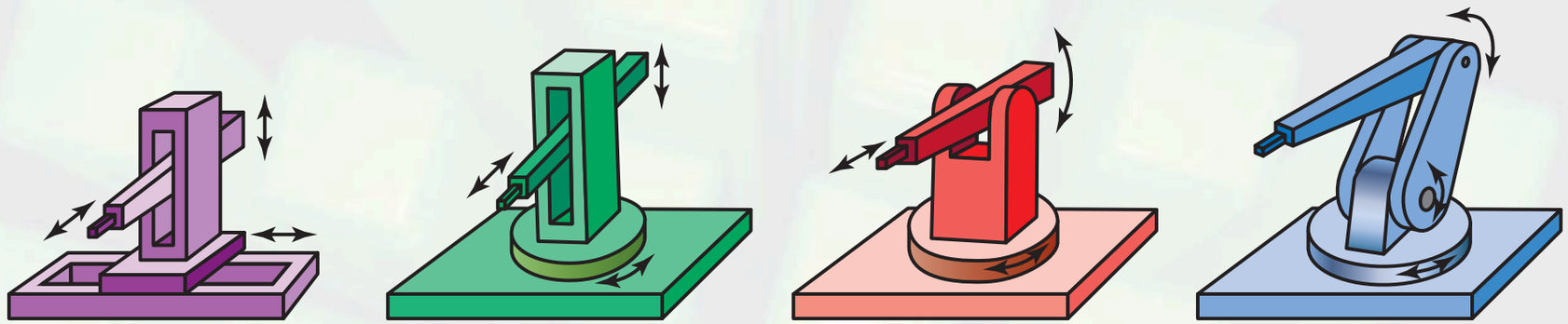



FIGURE 14.19 Four types of industrial robots: (a) Cartesian (rectilinear); (b) cylindrical; (c) spherical (polar); and (d) articulated, (revolute, jointed, or anthropomorphic). Some modern robots are *anthropomorphic*, meaning that they resemble humans in shape and in movement. These complex mechanisms are made possible by powerful computer processors and fast motors that can maintain a robot's balance and accurate movement control.

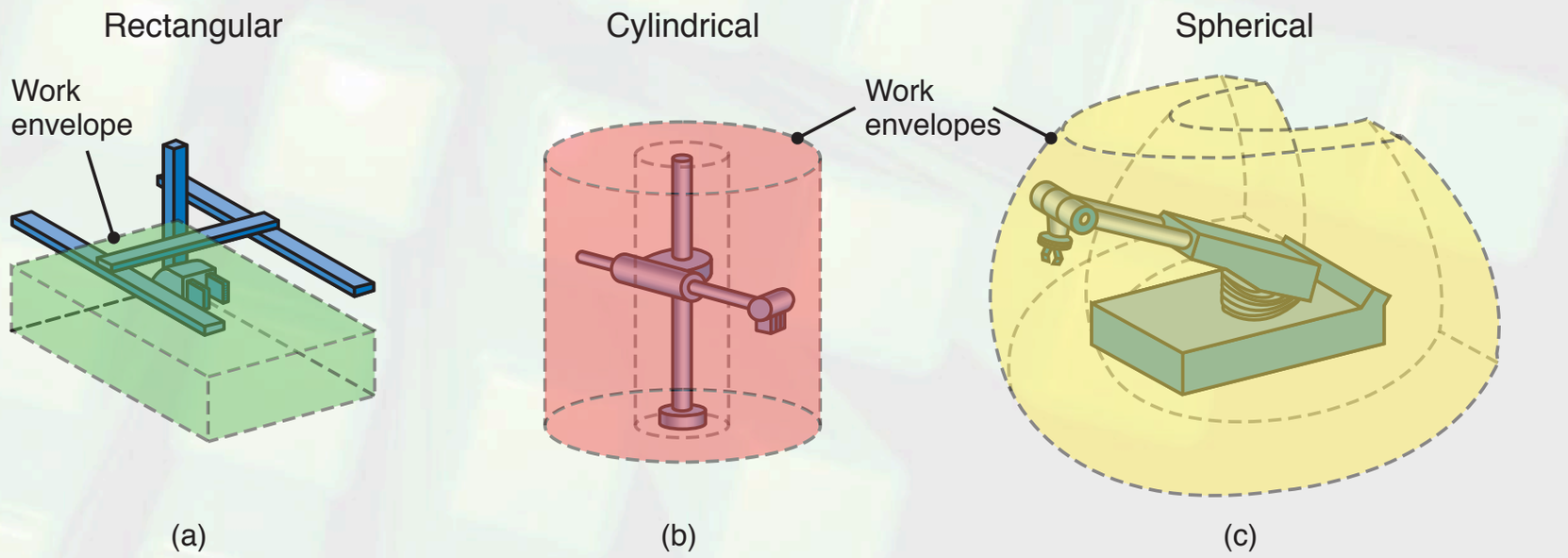
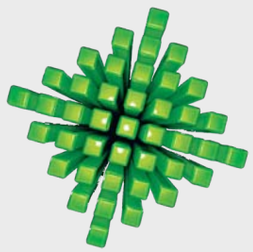



FIGURE 14.20 Work envelopes for three types of robots. The selection depends on the particular application (See also Fig. 14.17b.)



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# Robot Applications

FIGURE 14.21 Spot welding automobile bodies with industrial robots. *Source:* Courtesy of Ford Motor Co.

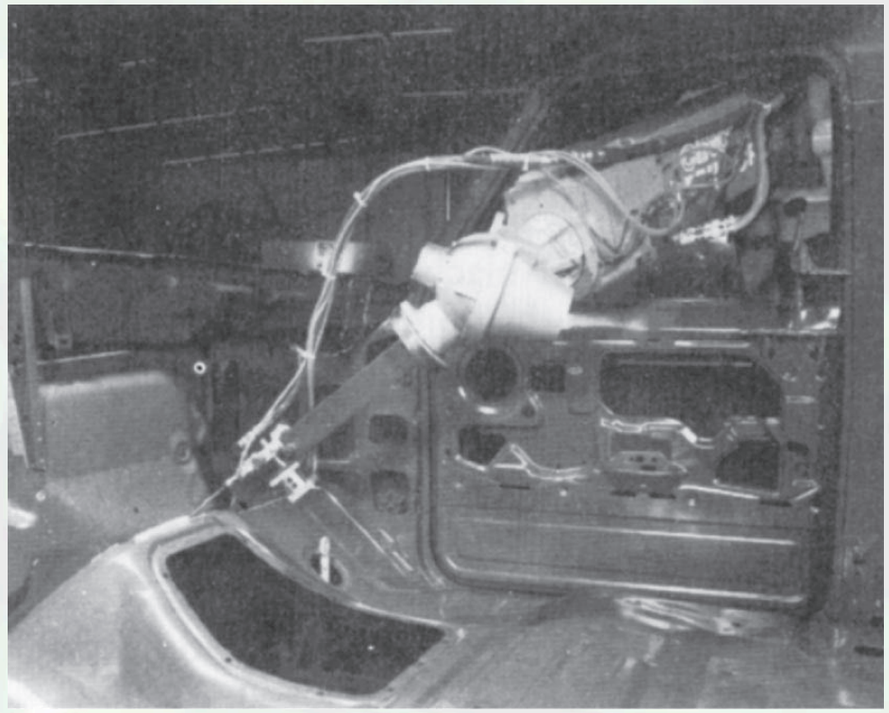

FIGURE 14.22 Sealing joints of an automobile body with an industrial robot. *Source:* Cincinnati Milacron, Inc.

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# Robots and Transfer Lines

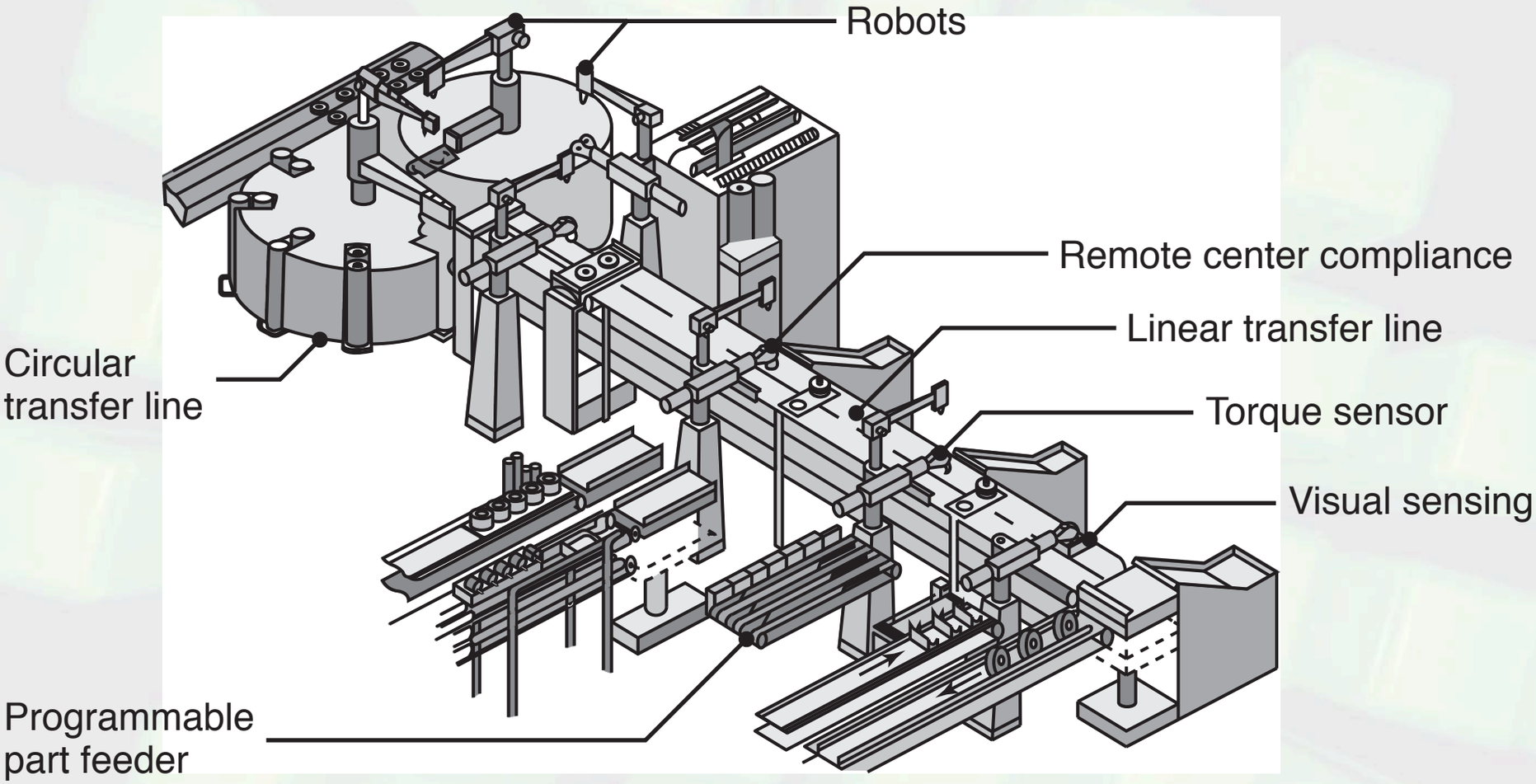


FIGURE 14.23 An example of automated assembly operations using industrial robots and circular and linear transfer lines.

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# Advanced End Effectors

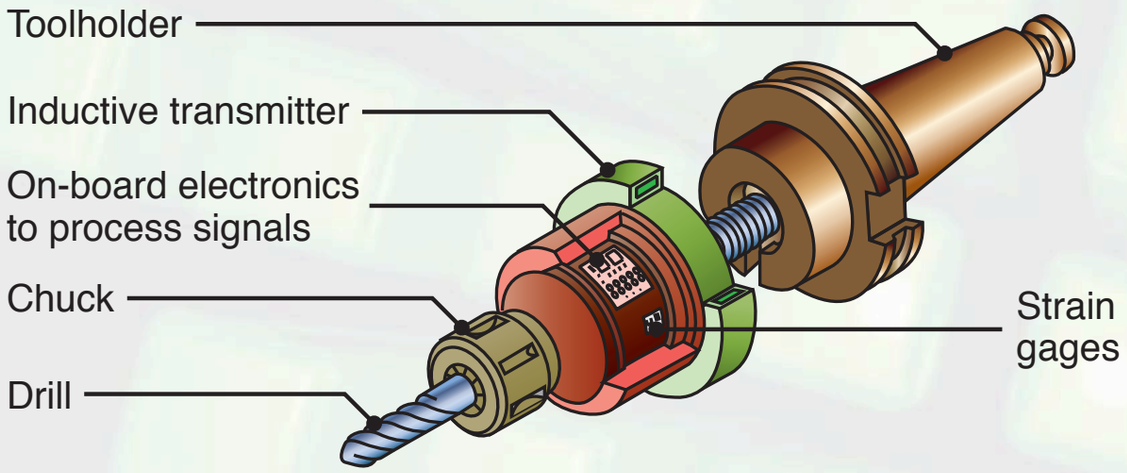



FIGURE 14.24 A toolholder equipped with thrust-force and torque sensors (\it smart tool holder), capable of continuously monitoring the machining operation. (See Section 14.5). *Source:* Cincinnati Milacron, Inc.

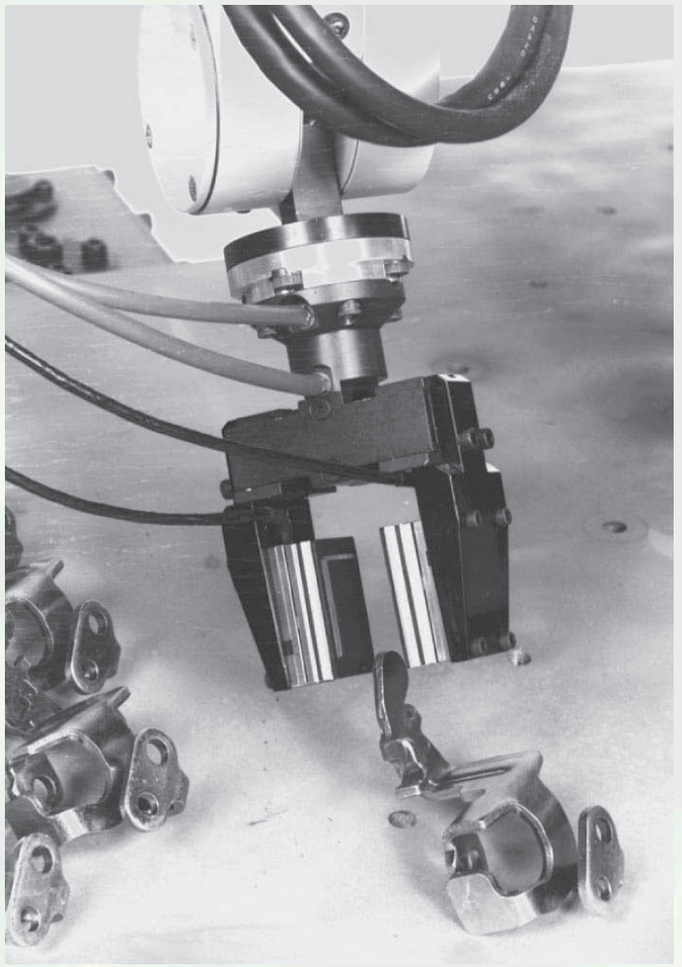
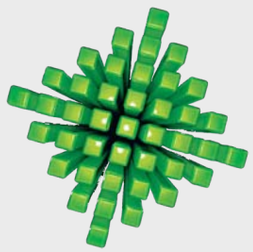


FIGURE 14.25 A robot gripper with tactile sensors. In spite of their capabilities, tactile sensors are now being used less frequently, because of their high cost and low durability (lack of robustness) in industrial applications. *Source:* Courtesy of Lord Corporation.



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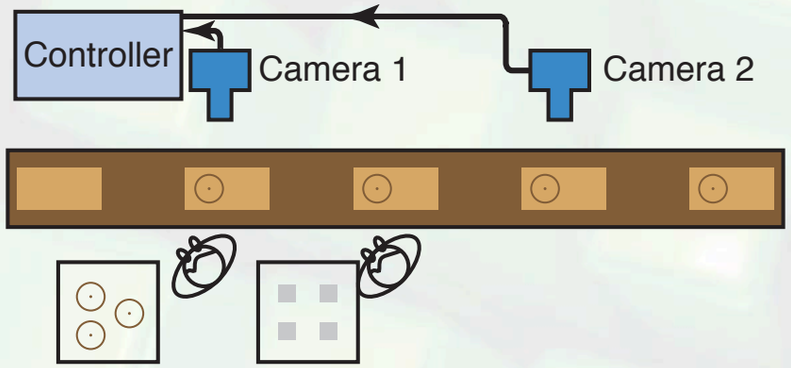
# Applications of Machine Vision

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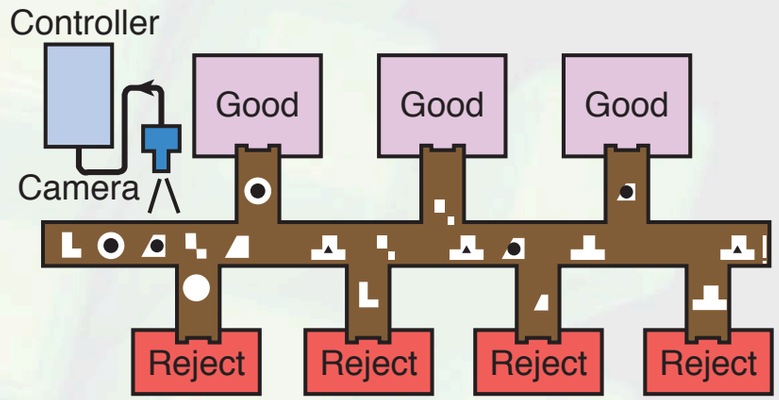


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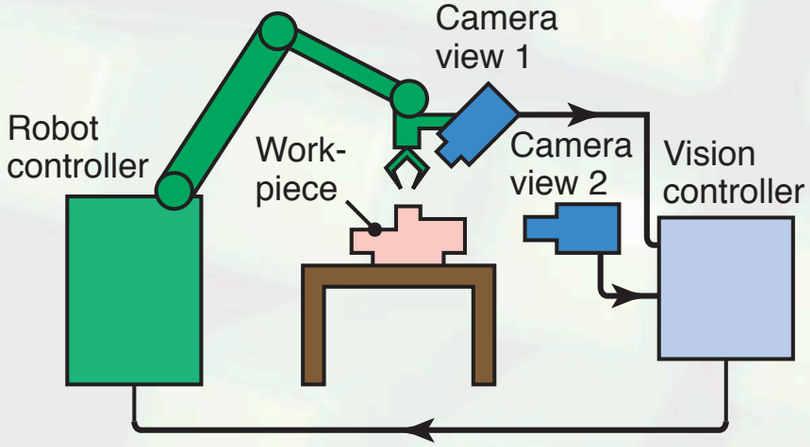


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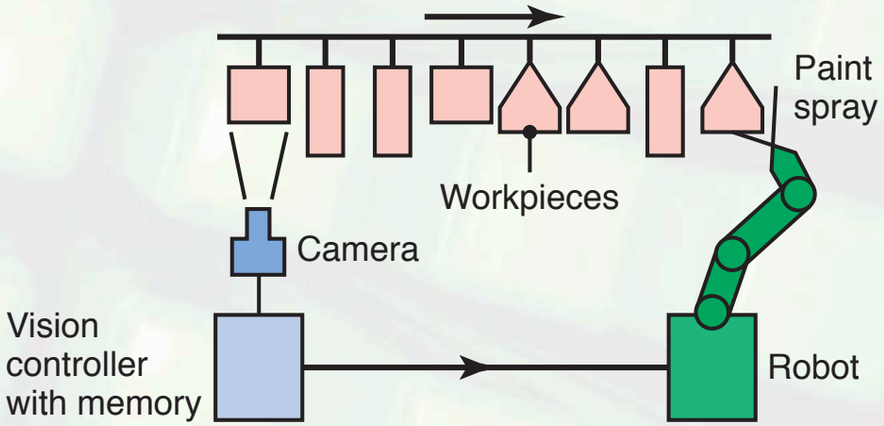
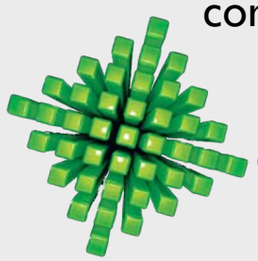



(d)

FIGURE 14.26 Examples of machine vision applications. (a) In-line inspection of parts. (b) Identifying parts with various shapes, and inspection and rejection of defective parts. (c) Use of cameras to provide positional input to a robot relative to the workpiece. (d) Painting of parts with different shapes by means of input from a camera; the system's memory allows the robot to identify the particular shape to be painted and to proceed with the correct movements of a paint spray attached to the end effector.



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# Fixturing

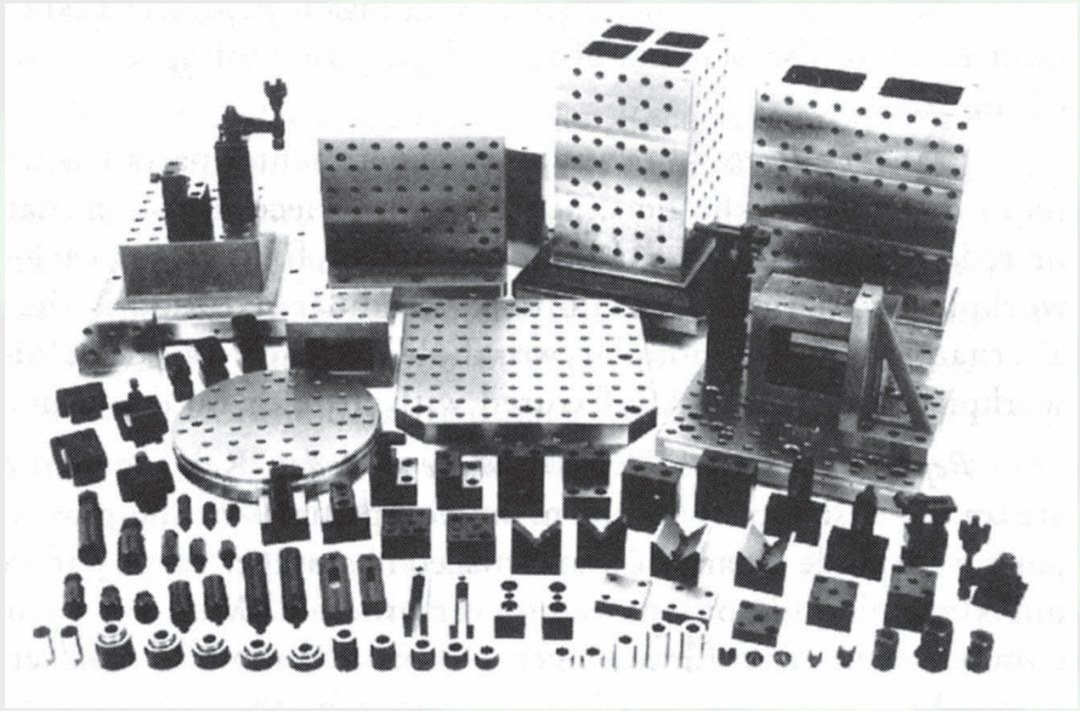


FIGURE 14.27 Components of a modular workholding system. *Source:* Carr Lane Manufacturing Co.

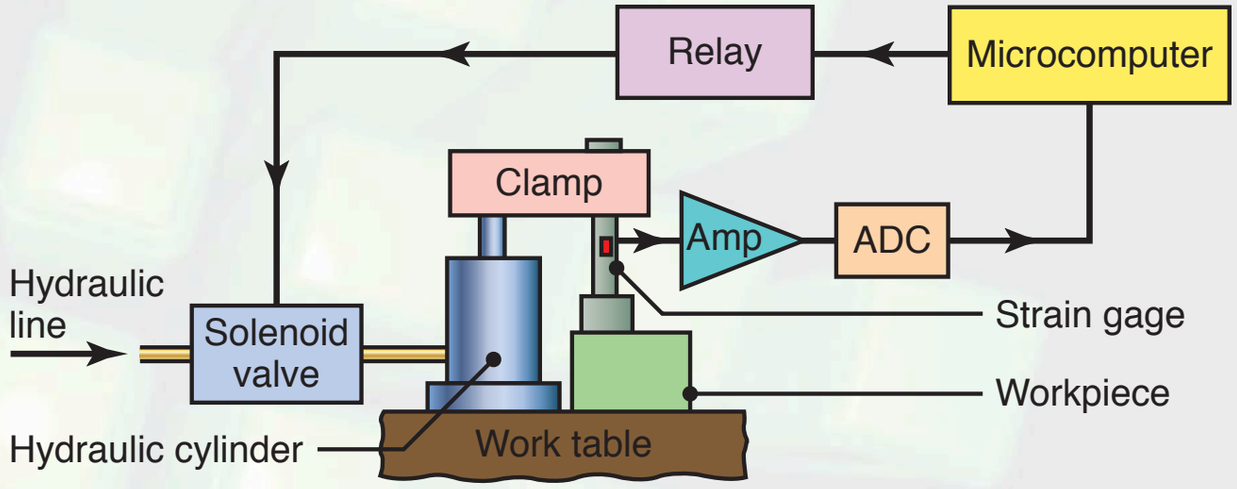
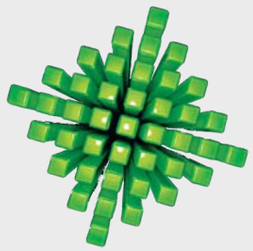



FIGURE 14.28 Schematic illustration of an adjustable-force clamping system. The clamping force is sensed by the strain gage, and the system automatically adjusts this force. *Source:* After P.K. Wright and D.A. Bourne.



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# Design for Assembly

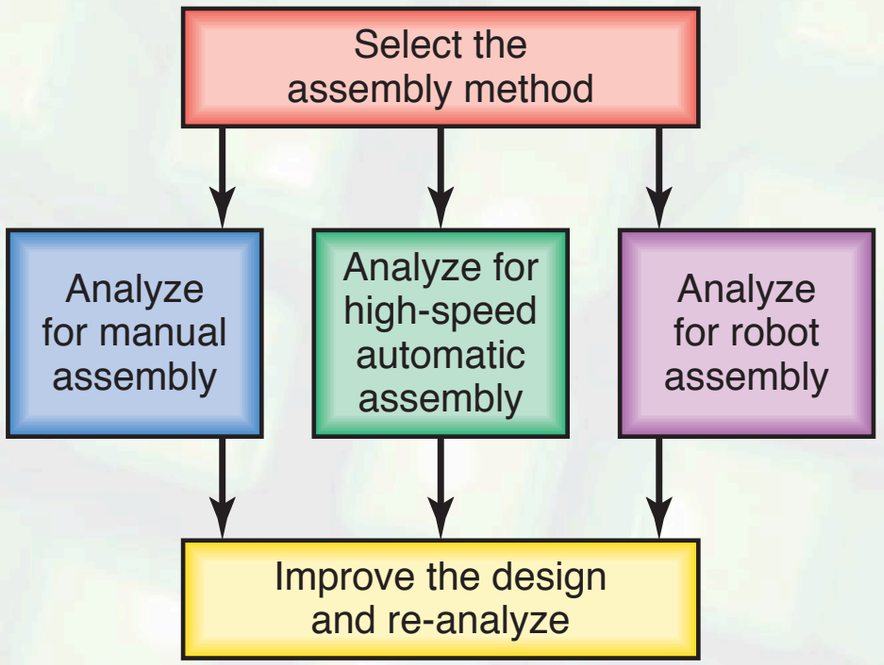
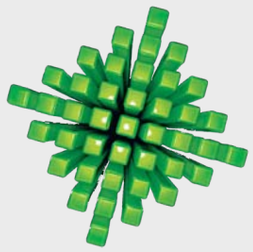



FIGURE 14.29 Stages in the design-for-assembly analysis. *Source:* After G. Boothroyd and P. Dewhurst.



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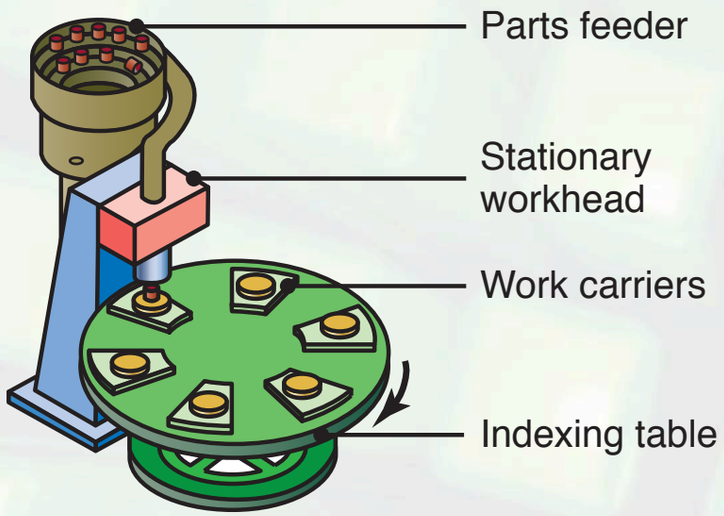
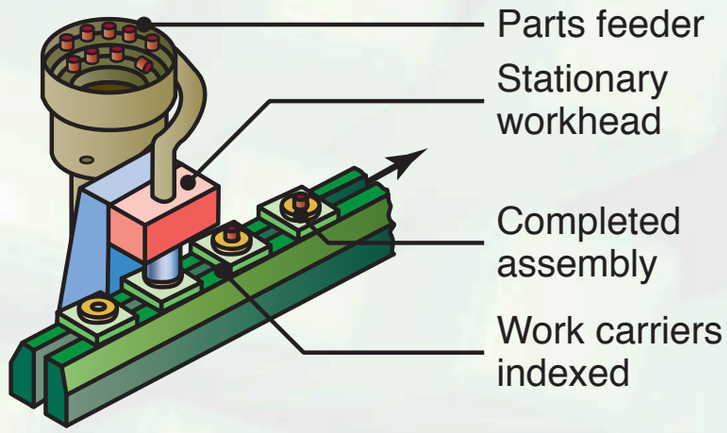
# Indexing Machines

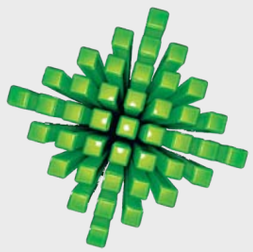



(a)




(b)

FIGURE 14.30 Transfer systems for automated assembly: (a) rotary indexing machine, and (b) in-line indexing machine. *Source:* After G. Boothroyd.



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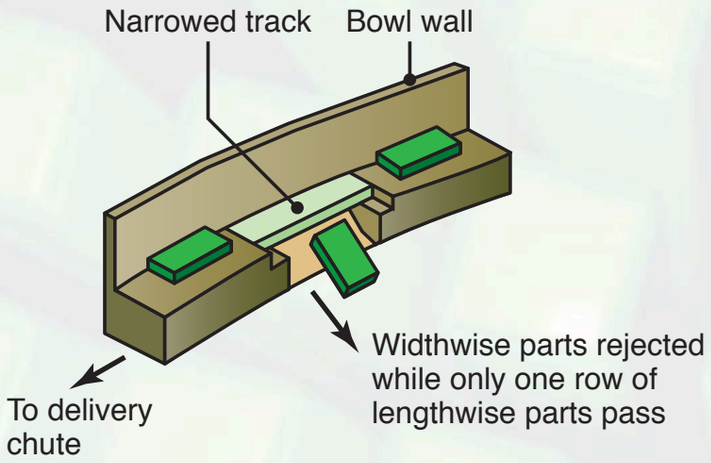
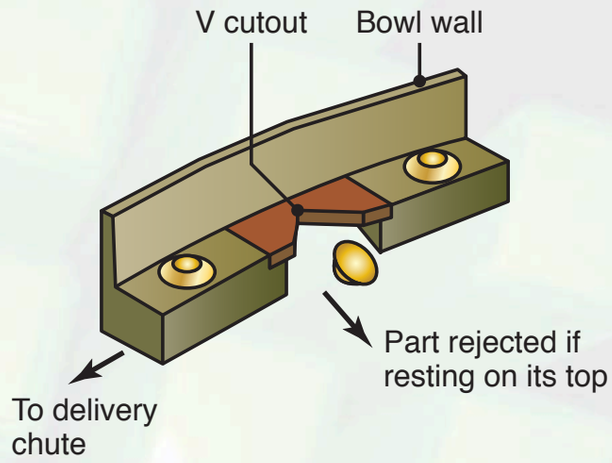
# Vibratory Feeder Guides




(a)

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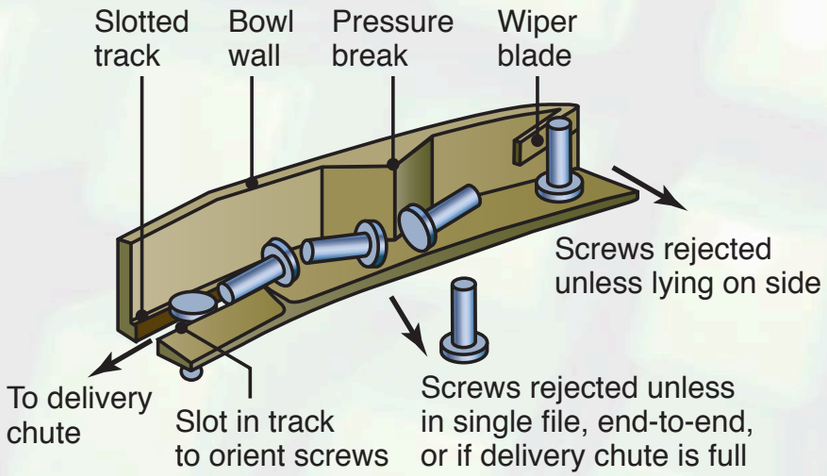


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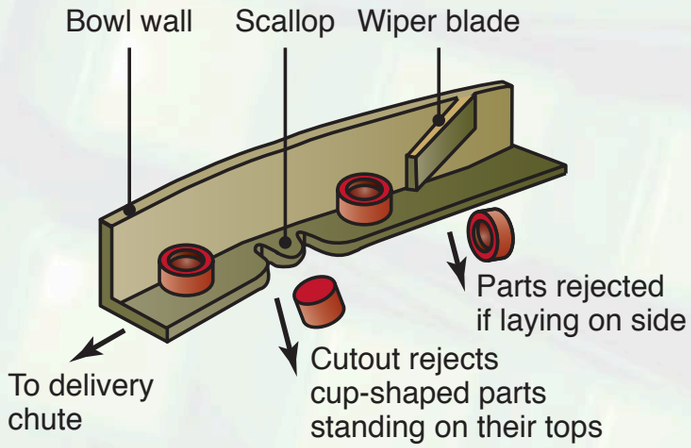
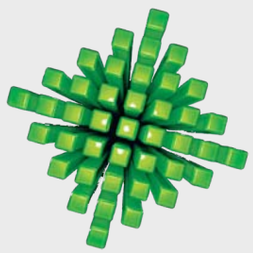



(d)

FIGURE 14.31 Examples of guides to ensure that parts are properly oriented for automated assembly. *Source:* After G. Boothroyd.



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# Robotics Example: Toboggan Deburring

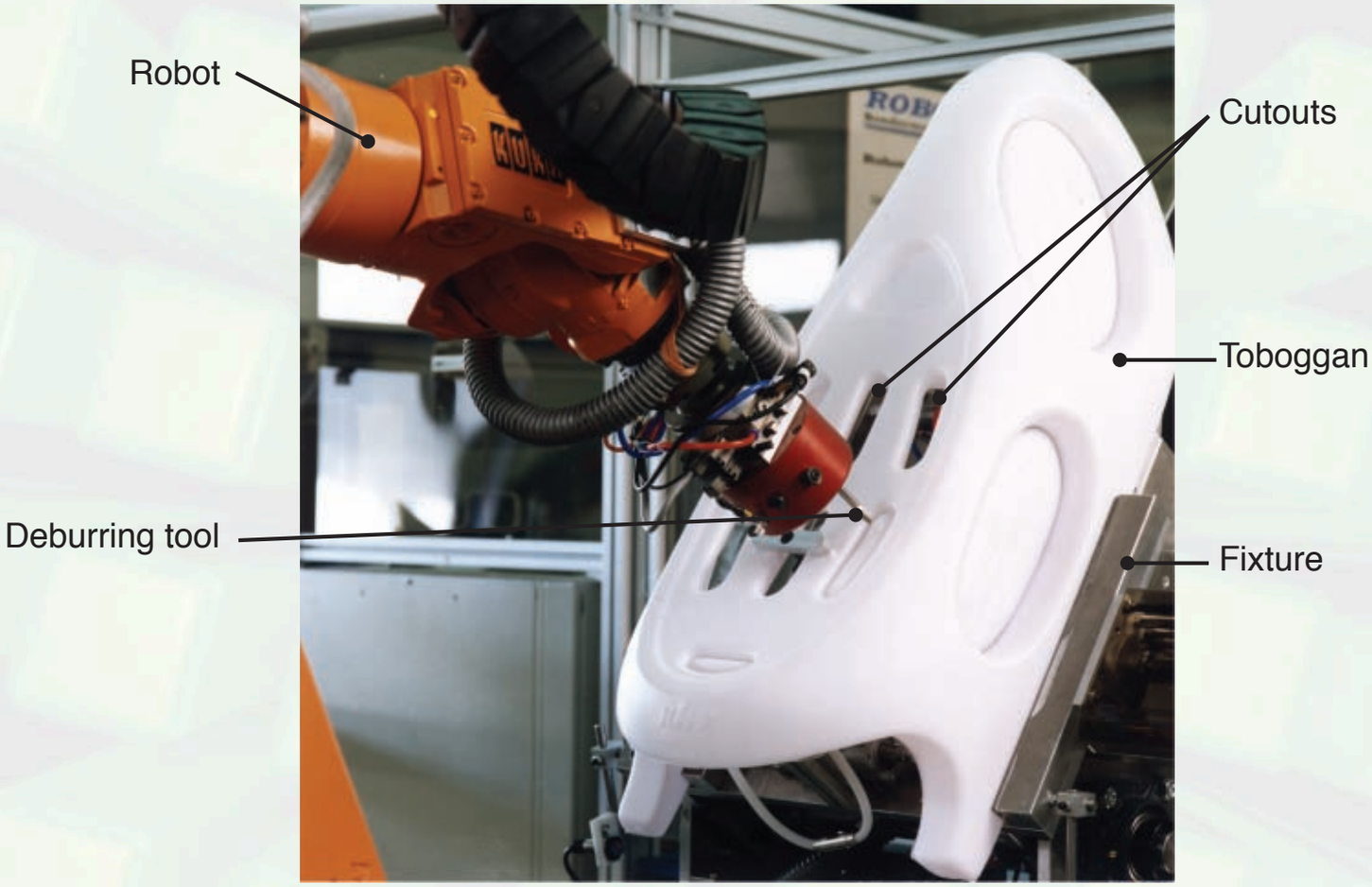


FIGURE 14.32 Robotic deburring of a blow-molded toboggan. *Source:* Courtesy of Kuka Robotics, Inc. and Roboter Technologie, GmbH.

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