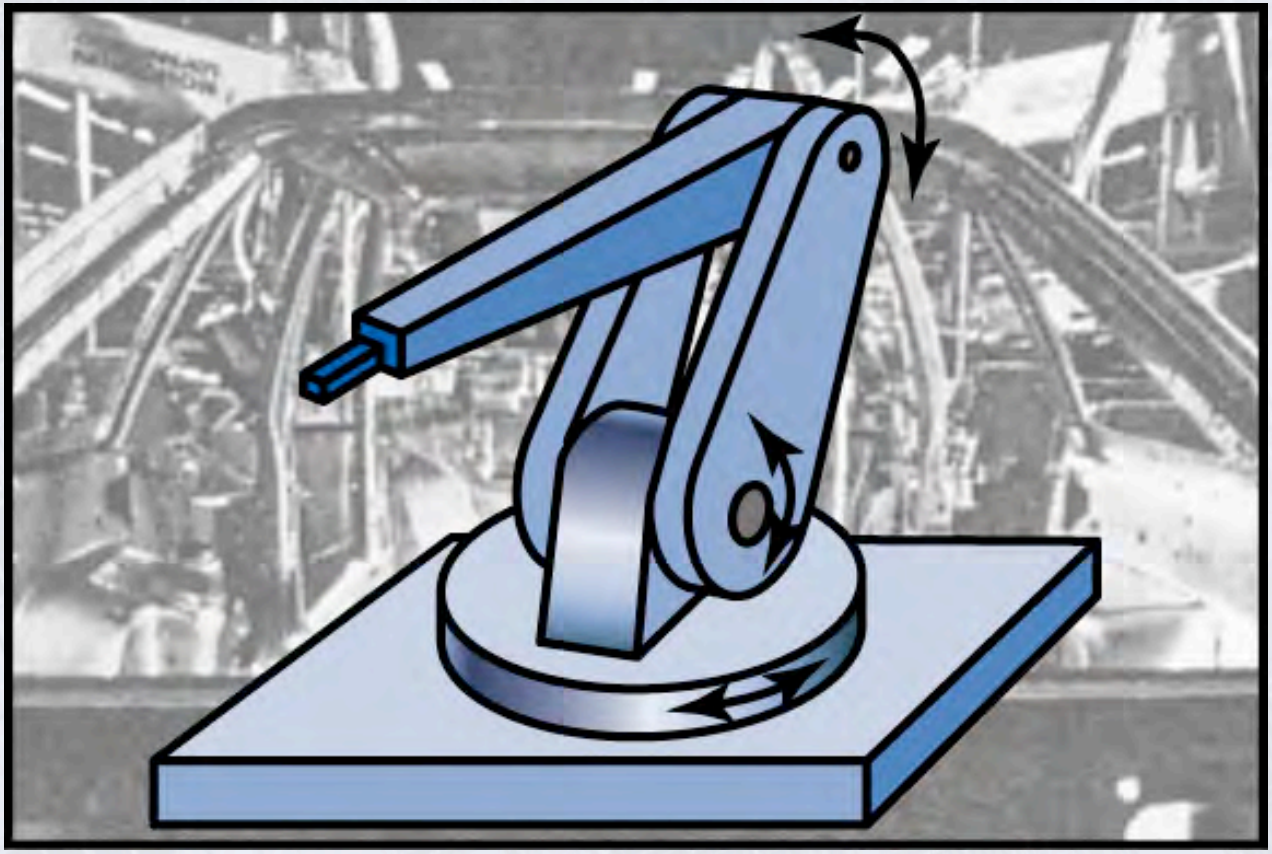
Chapter 37

Automation of Manufacturing Processes



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Chapter 37 Topics

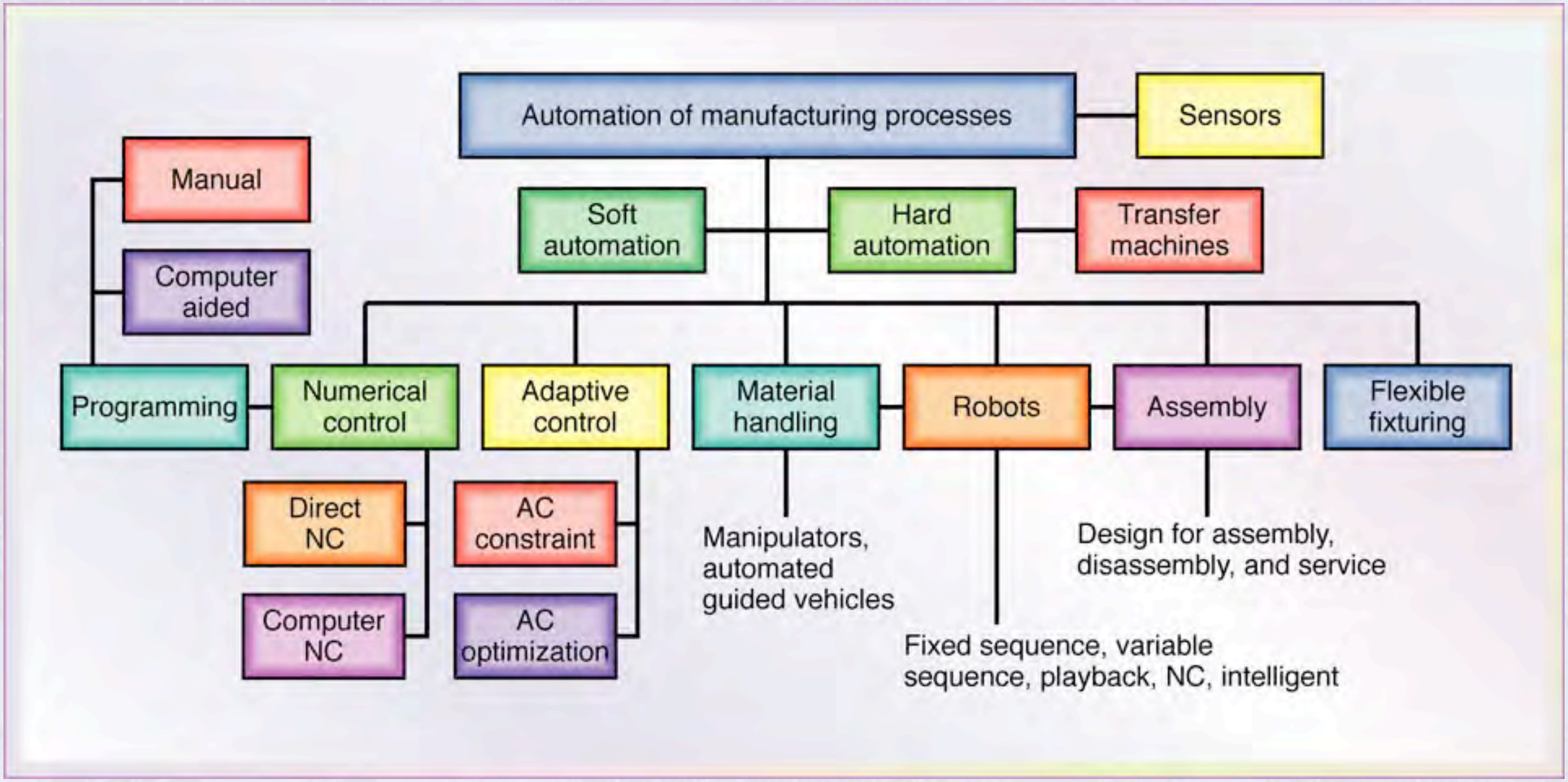

Figure 37.1 Outline of topics described in Chapter 37.

History of Automation of Manufacturing

TABLE 37.1

Development in the History of the Automation of Manufacturing Processes

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*
1960s	Industrial robots
1965	Large-scale integrated circuits
1968	Programmable logic controllers
1970	First integrated manufacturing system; spot welding of automobile bodies with robots
1970s	Microprocessors; minicomputer-controlled robot; flexible manufacturing systems; group technology
1980s	Artificial intelligence; intelligent robots; smart sensors; untended manufacturing cells
1990–2000	Integrated manufacturing systems; intelligent and sensor-based machines; telecommunications and global manufacturing networks; fuzzy-logic devices; artificial neural networks; internet tools

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Flexibility and Productivity of Manufacturing Systems

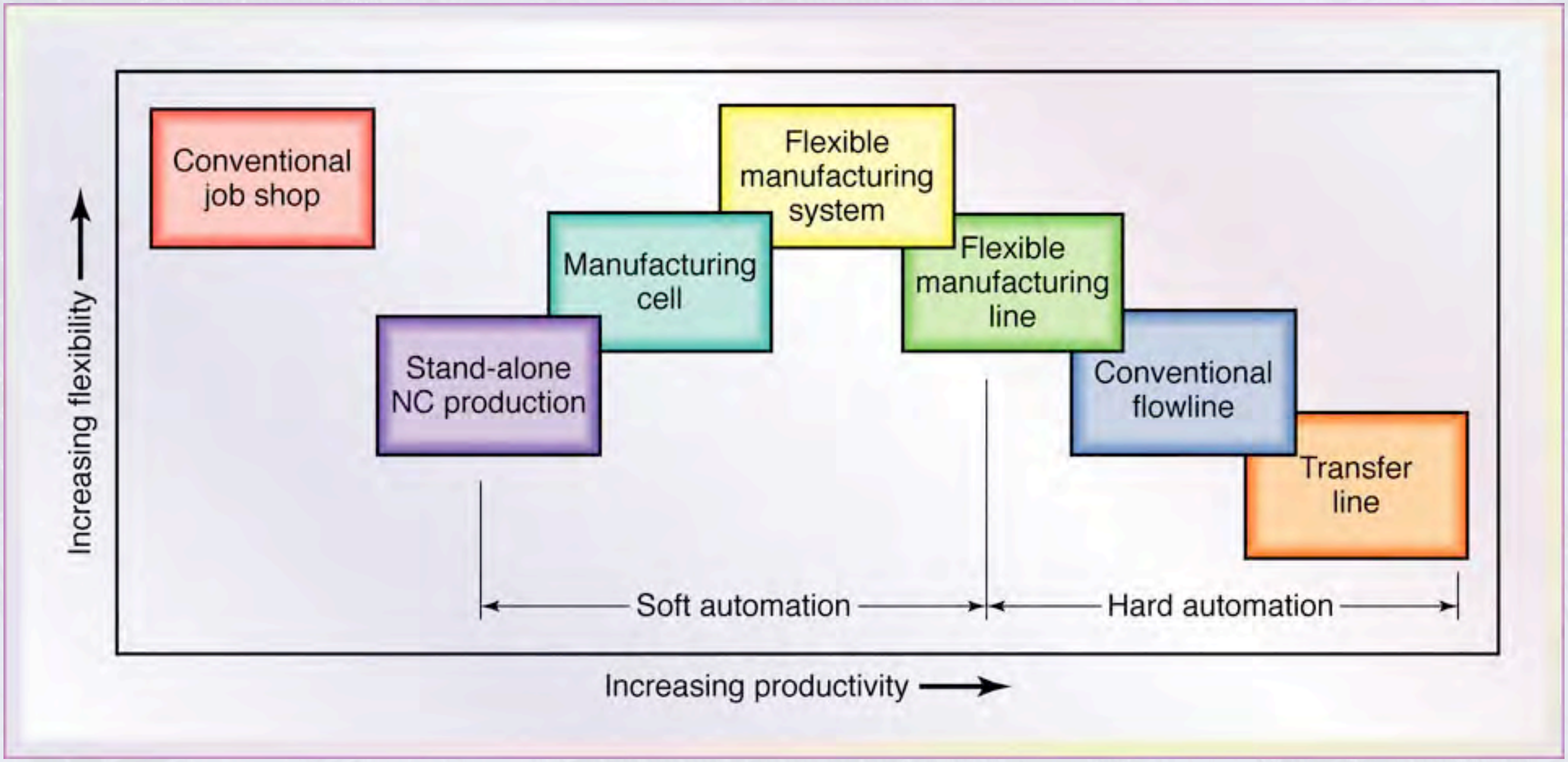

Figure 37.2 Flexibility and productivity of various manufacturing systems. Note the overlap between the systems; it is due to the various levels of automation and computer control that are possible in each group. See also Chapter 39 for details.

Approximate Annual Production Quantity

TABLE 37.2

Approximate Annual Production Quantity

Type of production	Number produced	Typical products
Experimental or prototype	1-10	All products
Piece or small-batch	10-5000	Aircraft, missiles, special machinery, dies, jewelry, and orthopedic implants
Batch or high-volume	5000-100,000	Trucks, agricultural machinery, jet engines, diesel engines, computer components, and sporting goods
Mass production	100,000 and over	Automobiles, appliances, fasteners, and food and beverage containers

Characteristics of Three Types of Production Methods

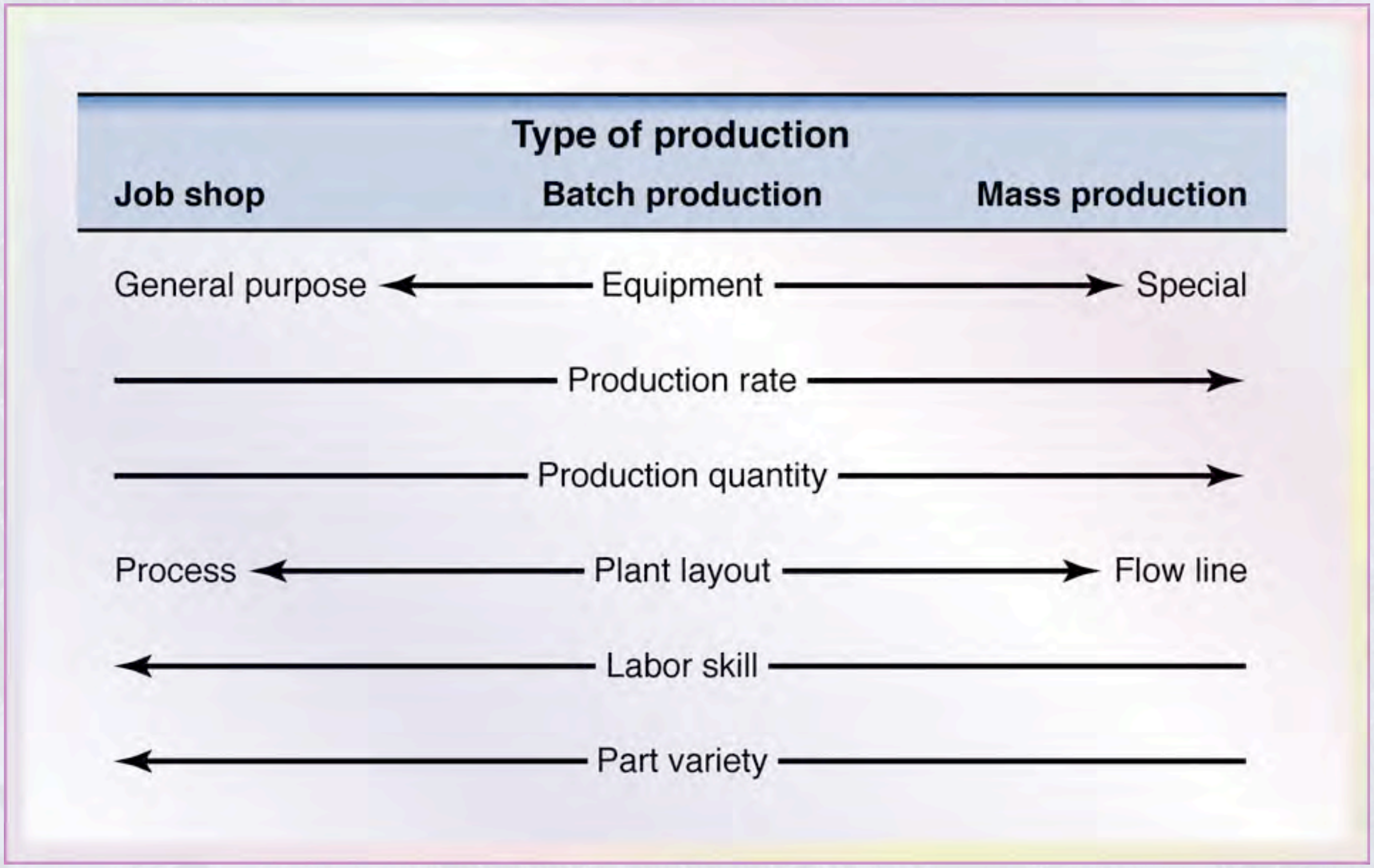

Figure 37.3 General characteristics of three types of production methods: job shop, batch, and mass production.

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Types of Transfer Mechanisms

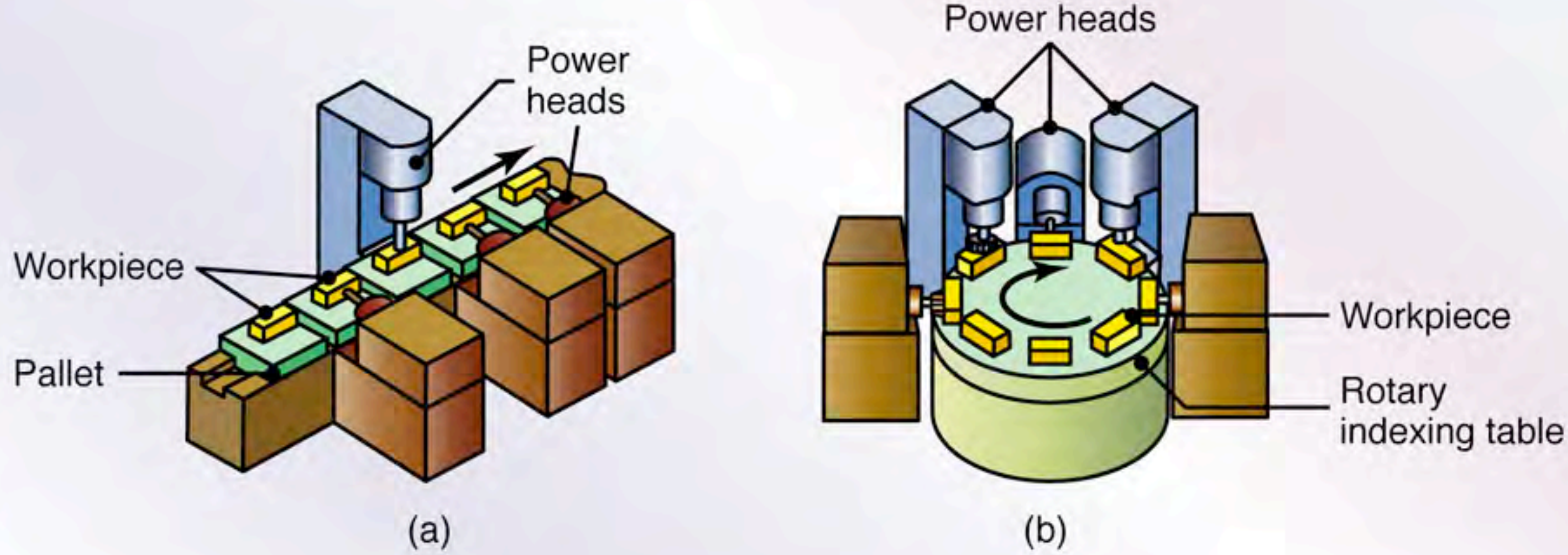


Figure 37.4 Two types of transfer mechanisms:
(a) straight rails and (b) circular or rotary patterns.

Transfer Line for Engine Blocks and Cylinder Heads

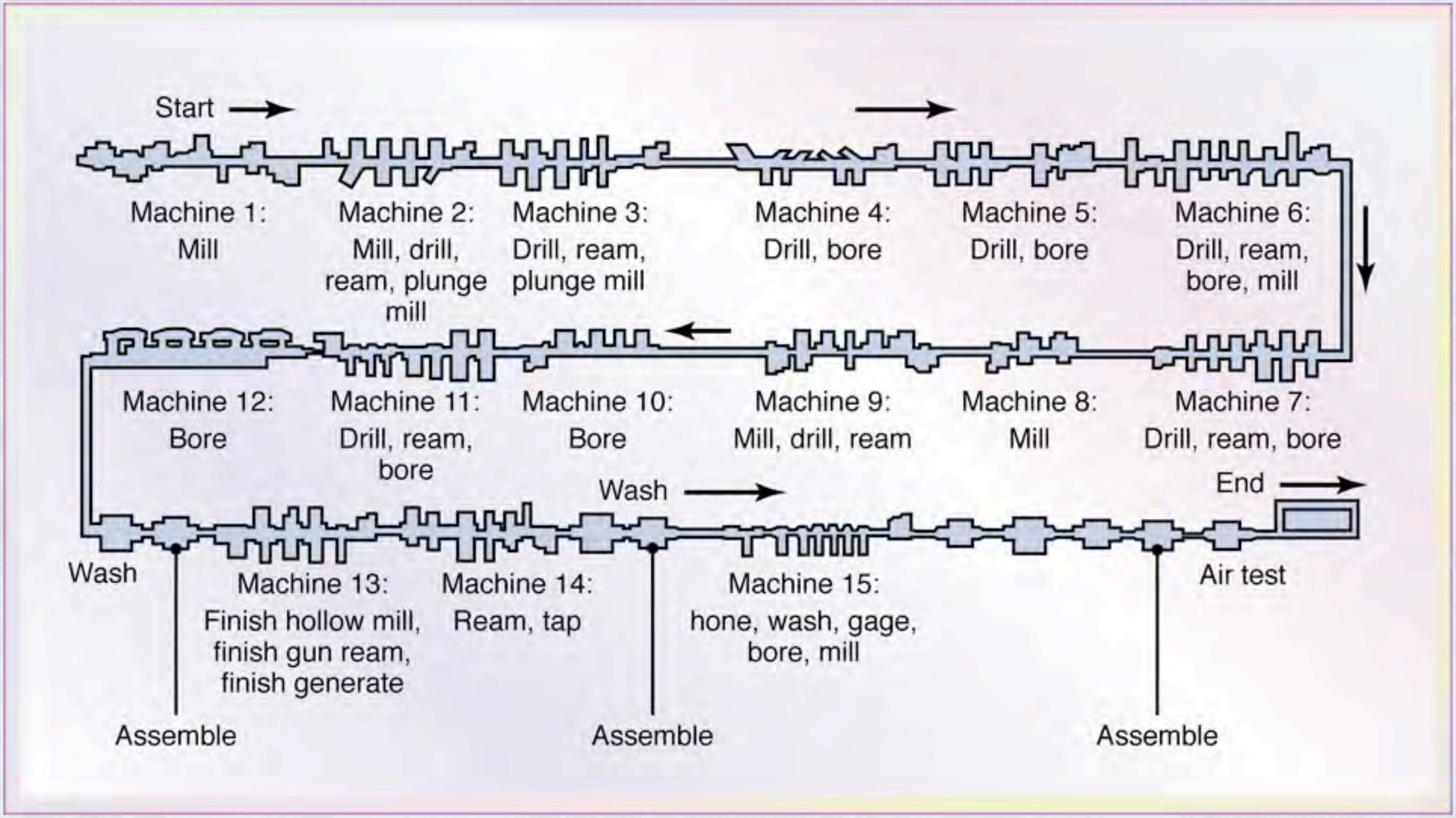


Figure 37.5 A large transfer line for producing engine blocks and cylinder heads. *Source*: Courtesy of Ford Motor Company.

Positions of Drilled Holes in Workpiece

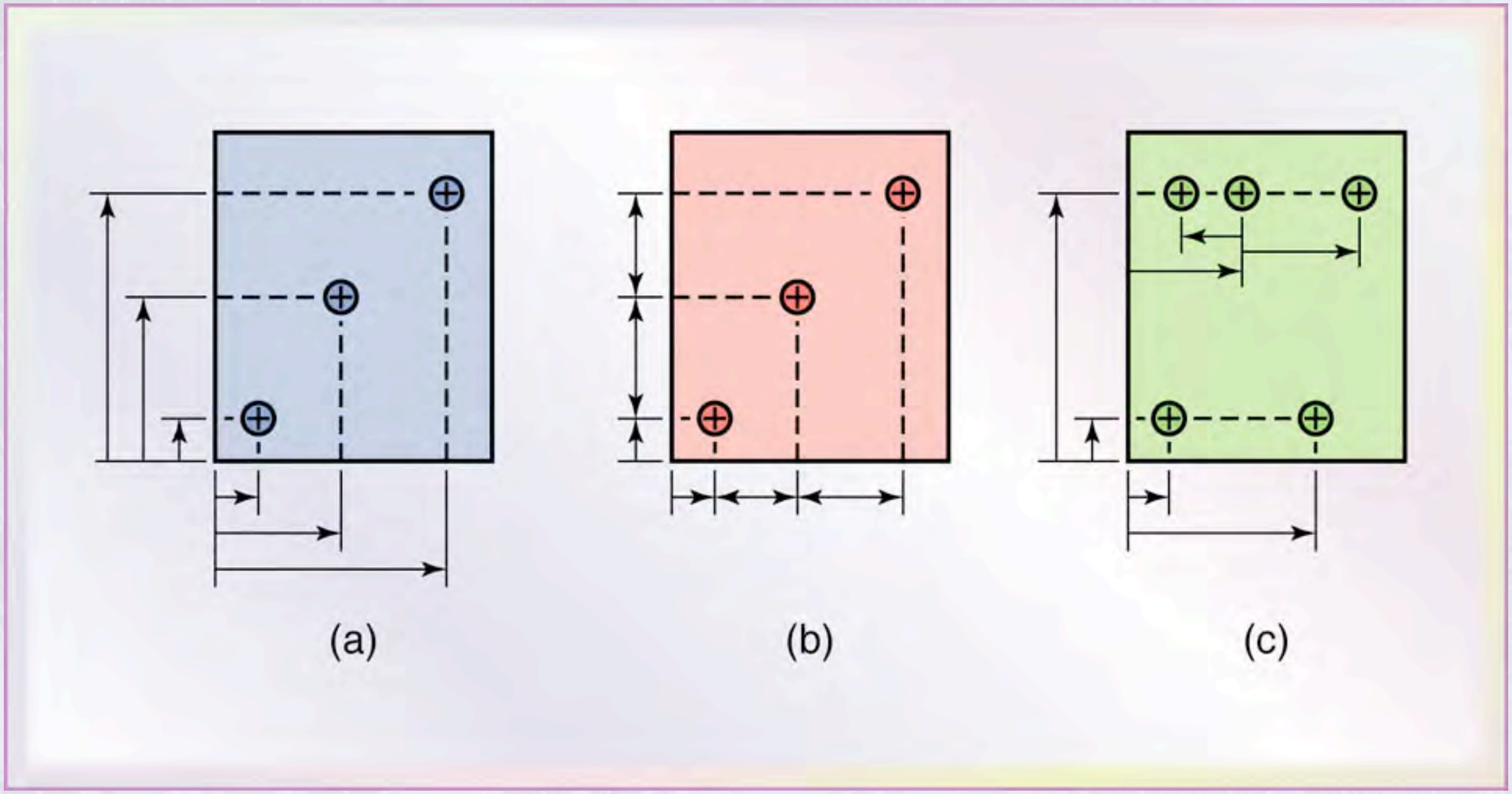
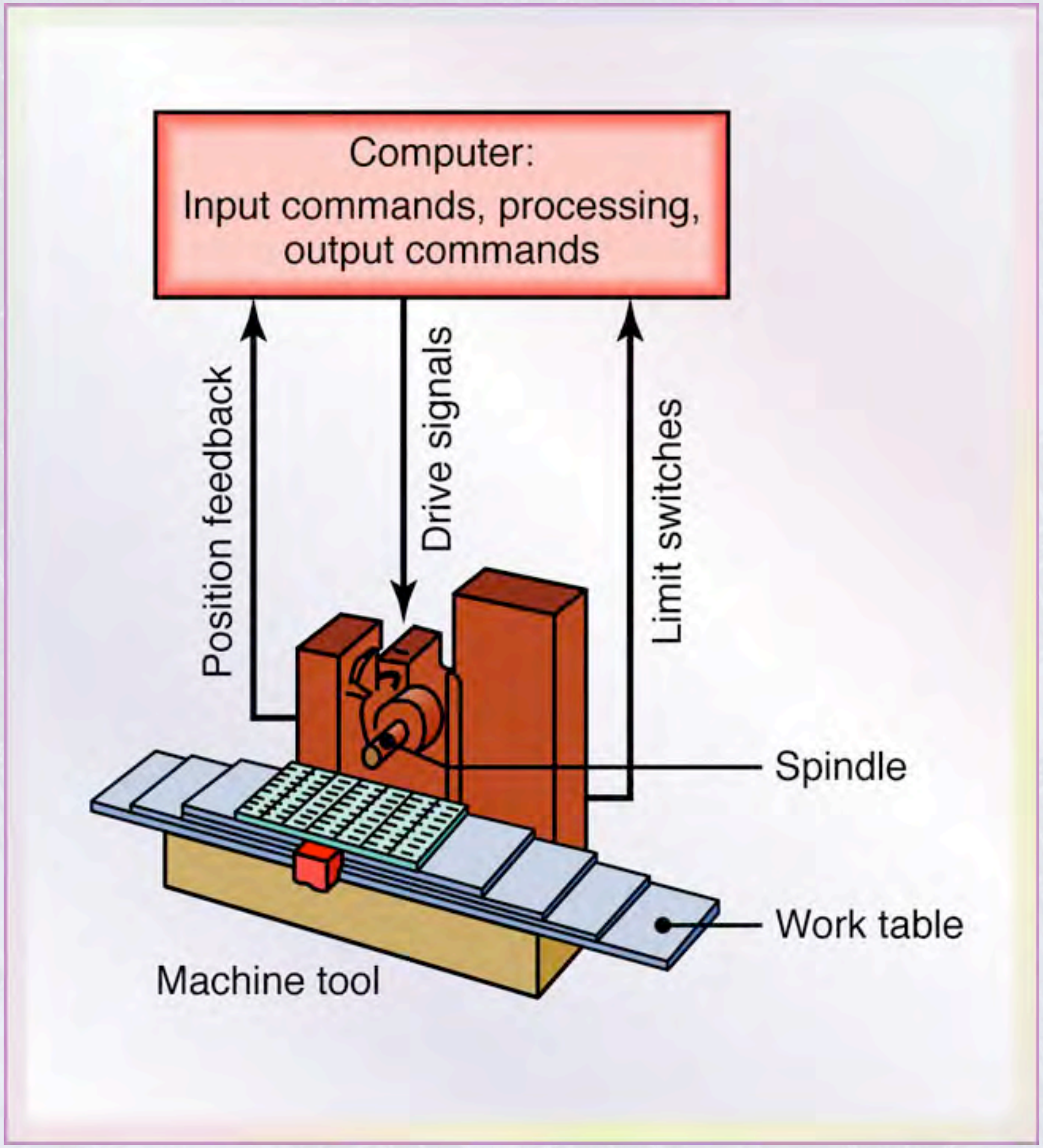


Figure 37.6 Positions of drilled holes in a workpiece. Three methods of measurements are shown: (a) absolute dimensioning referenced from one point at the lower left of the part; (b) incremental dimensioning made sequentially from one hole to another; and (c) mixed dimensioning – a combination of both methods.



Numerical-Control Machine Tool

Figure 37.7 Schematic illustration of the major components of a numerical-control machine tool.

Open-Loop and Closed-Loop Control Systems for Numerical-Control Machine

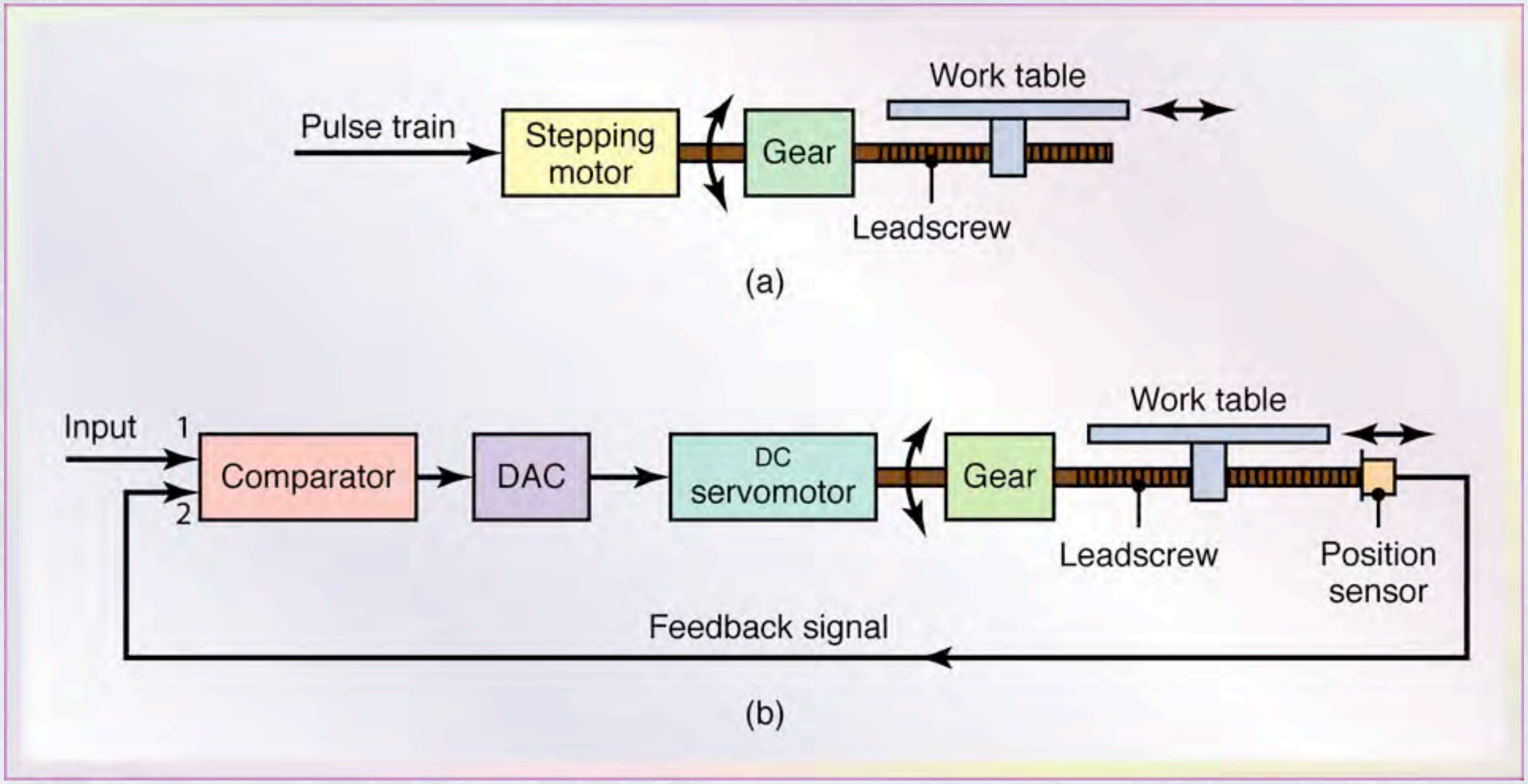


Figure 37.8 Schematic illustration of the components of (a) an open-loop and (b) a closed-loop control system for a numerical-control machine. DAC means “digital-to-analog converter.”

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Direct and Indirect Measurement of Machine-Tool Work Table

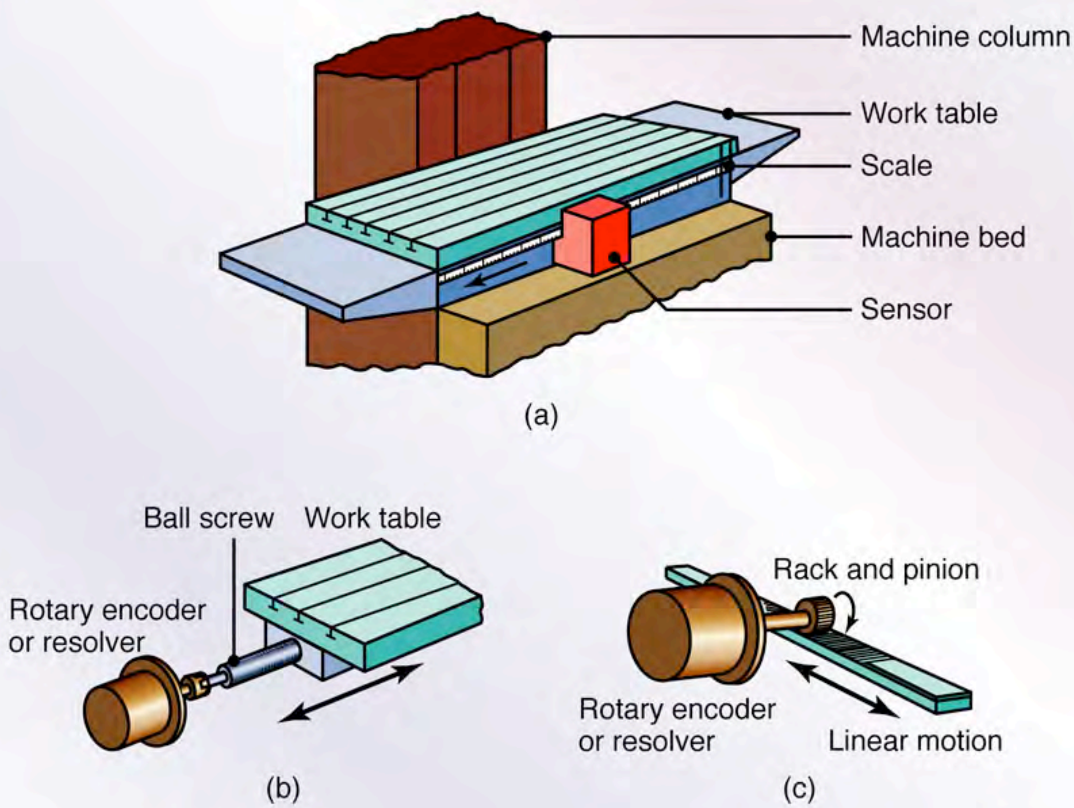

Figure 37.9 (a) Direct measurement of the linear displacement of a machine-tool work table. (b) and (c) Indirect measurement methods.

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Movement of Tools in Numerical-Control Machining

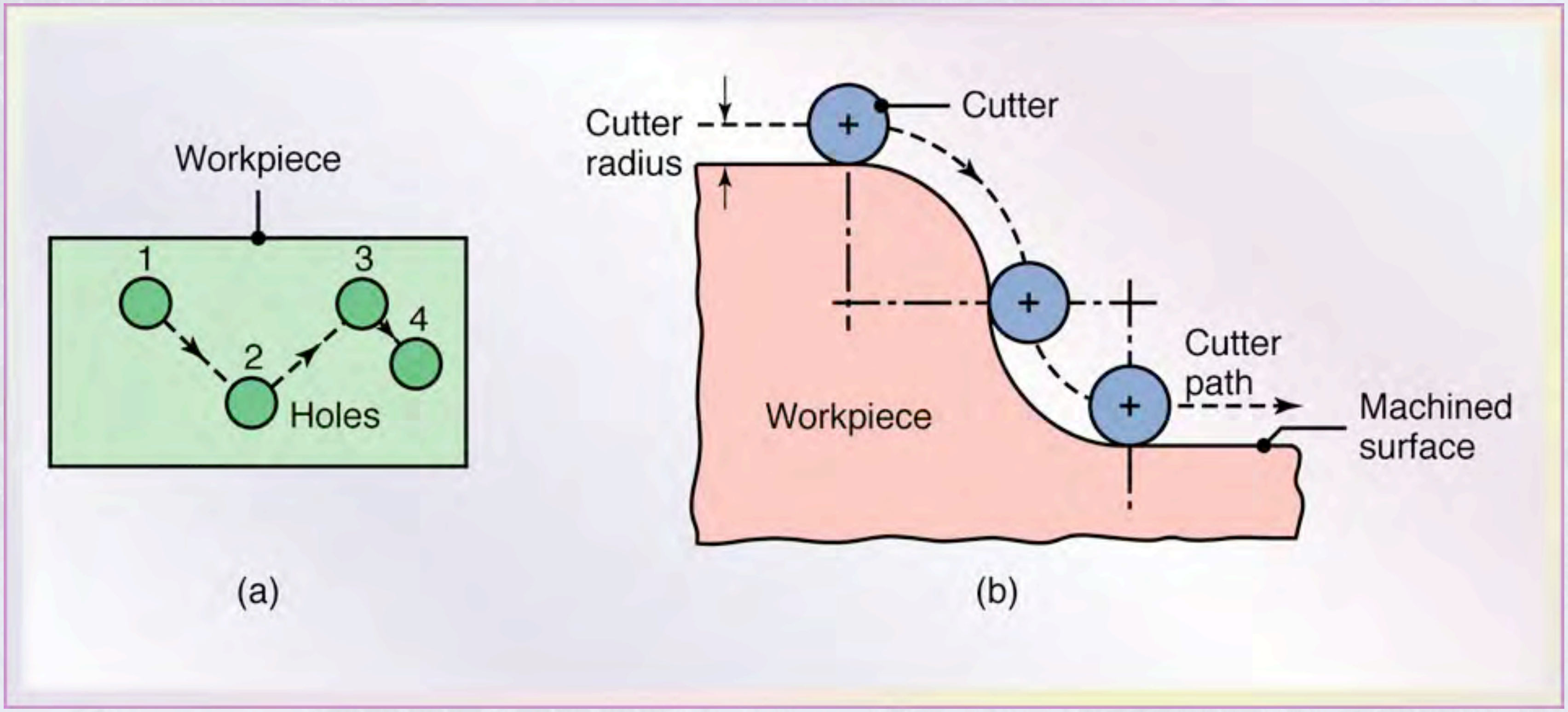


Figure 37.10 Movement of tools in numerical-control machining. (a) Point-to-point, in which the drill bit drills a hole at position 1, is retracted and moved to position 2 and so on. (b) Continuous path by a milling cutter. Note that the cutter path is compensated for by the cutter radius. This path also can be compensated for cutter wear.

Types of Interpolation in Numerical Control

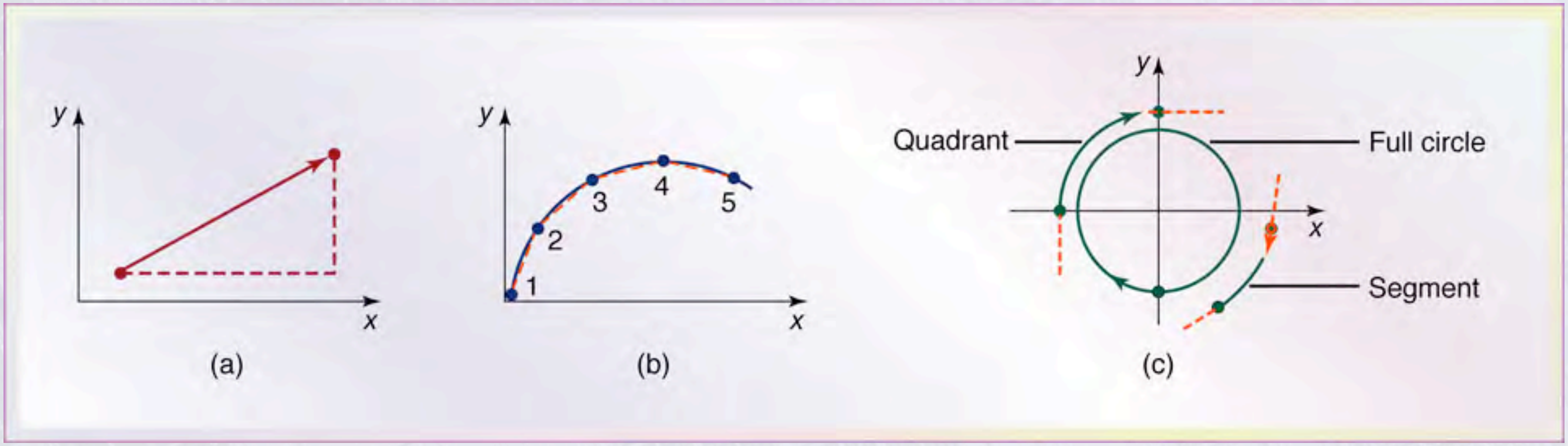
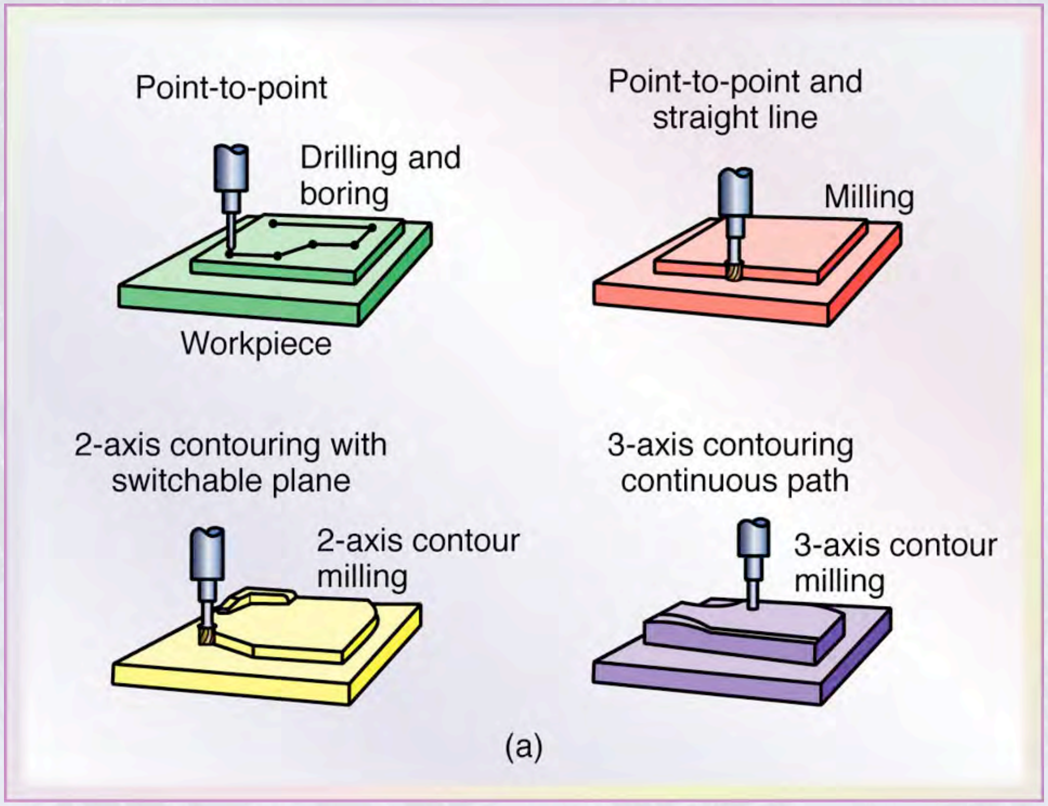


Figure 37.11 Types of interpolation in numerical control: (a) linear, (b) continuous path approximated by incremental straight lines, and (c) circular.

Interpolation Methods



(b)

Figure 37.12 (a) Schematic illustration of drilling, boring, and milling with various paths. (b) Machining a sculptured surface on a 5-axis numerical-control machine. *Source*: Courtesy of The Ingersoll Milling Machine Co.

Application of Adaptive Control (AC) for Turning Operation

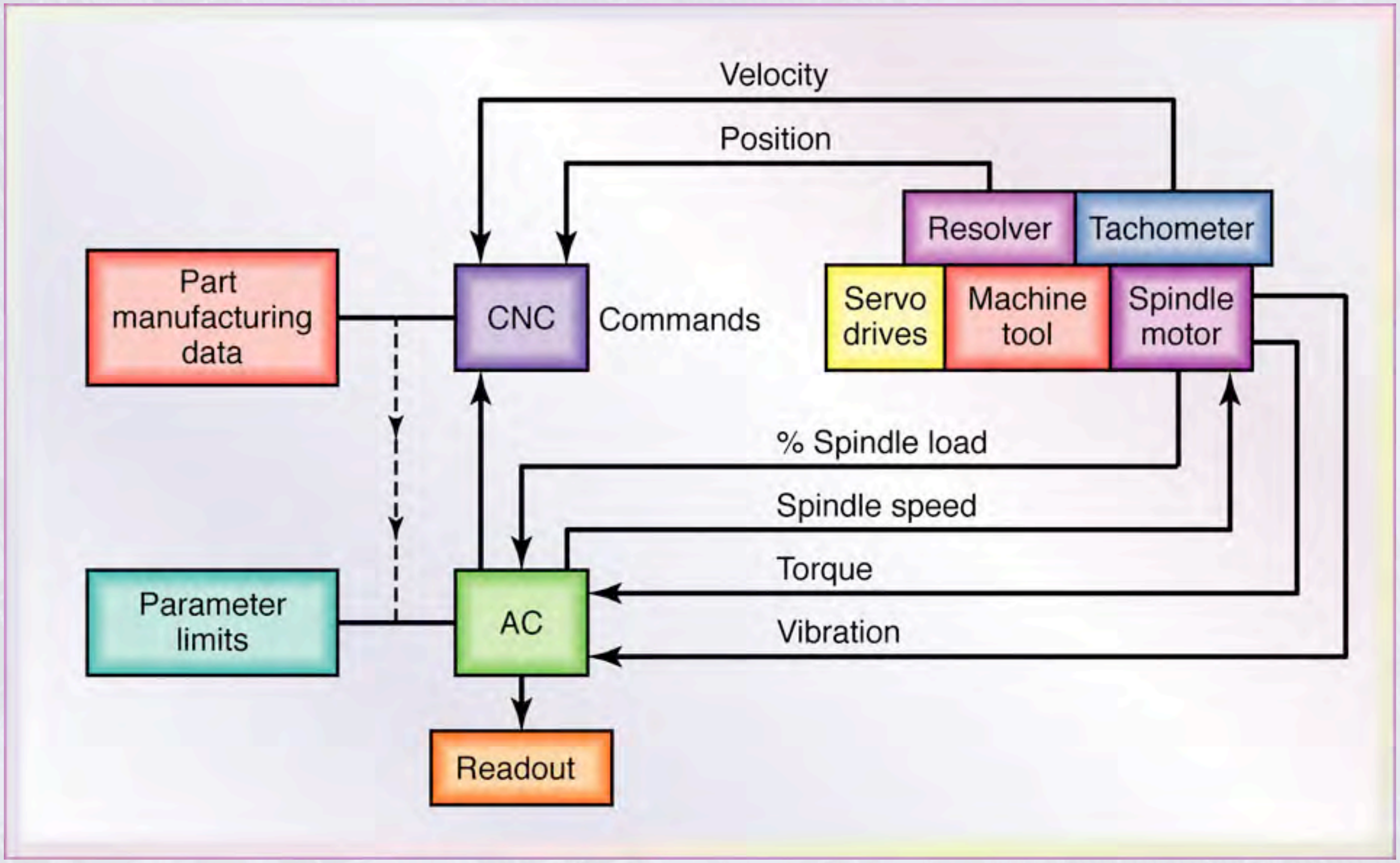


Figure 37.13 Schematic illustration of the application of adaptive control (AC) for a turning operation. The system monitors such parameters as cutting force, torque, and vibrations. If these parameters are excessive, it modifies process variables (such as feed and depth of cut) to bring them back to acceptable levels.

Adaptive Control in Milling

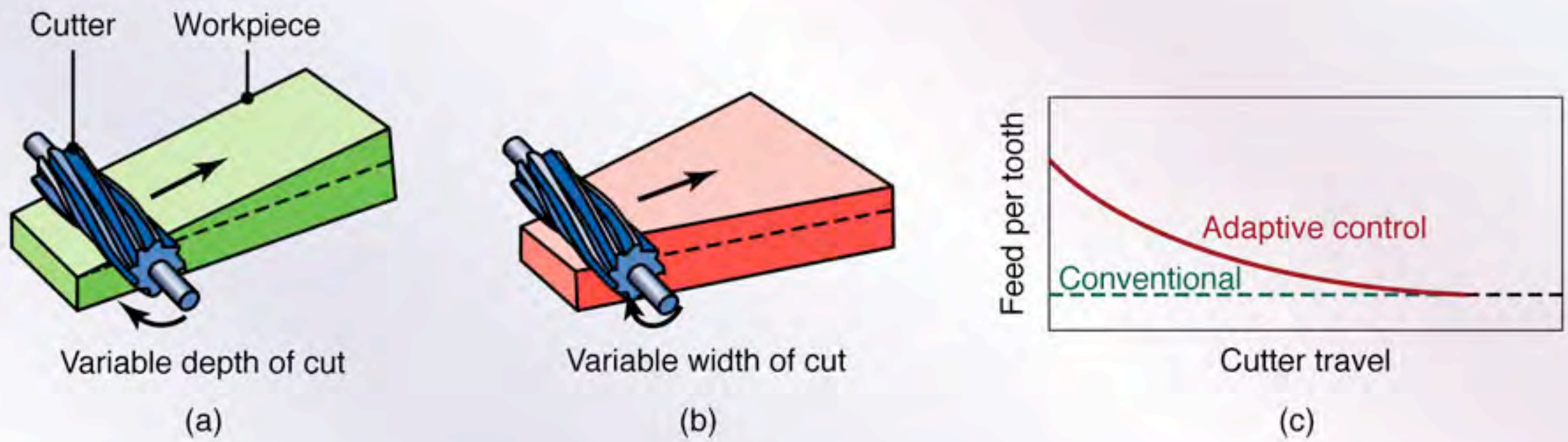


Figure 37.14 An examples of adaptive control in milling. As depth of cut (a) or the width of cut (b) increases, the cutting forces and the torque increase. The system senses this increase and automatically reduces the feed (c) to avoid excessive forces or tool breakage in order to maintain cutting efficiency. *Source*: After Y. Koren.

Inspection of Workpiece Diameter in Turning Operation

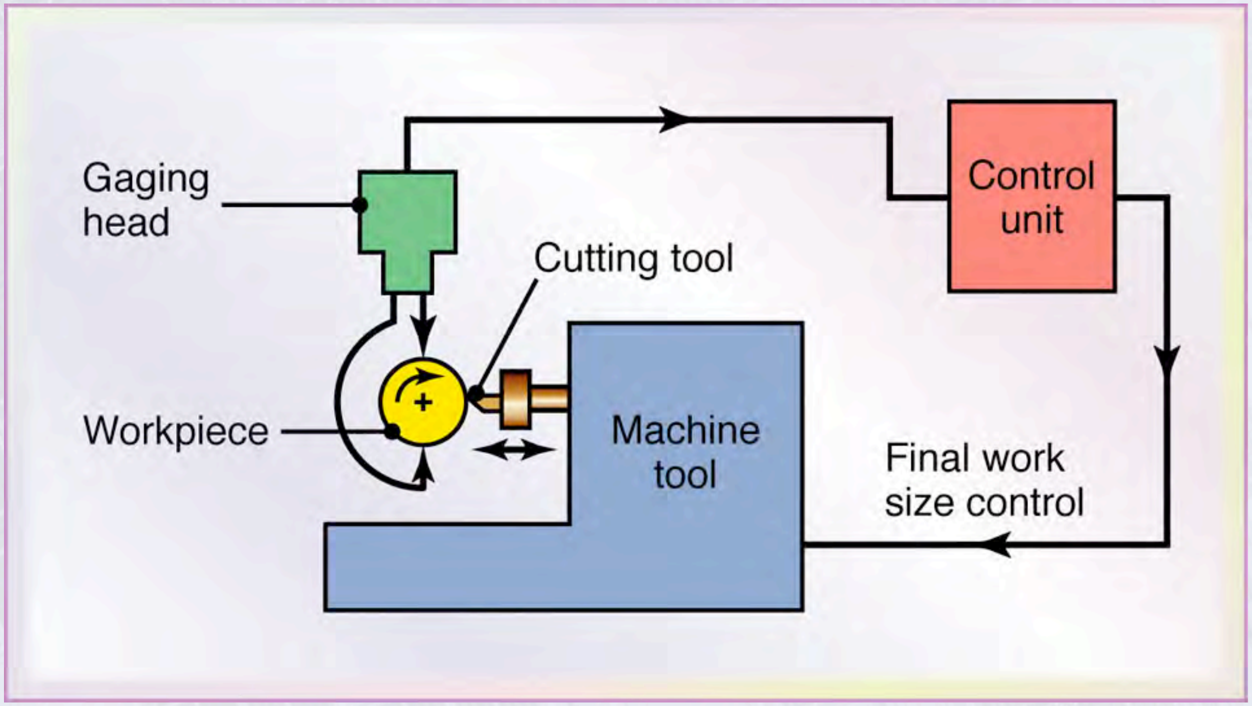
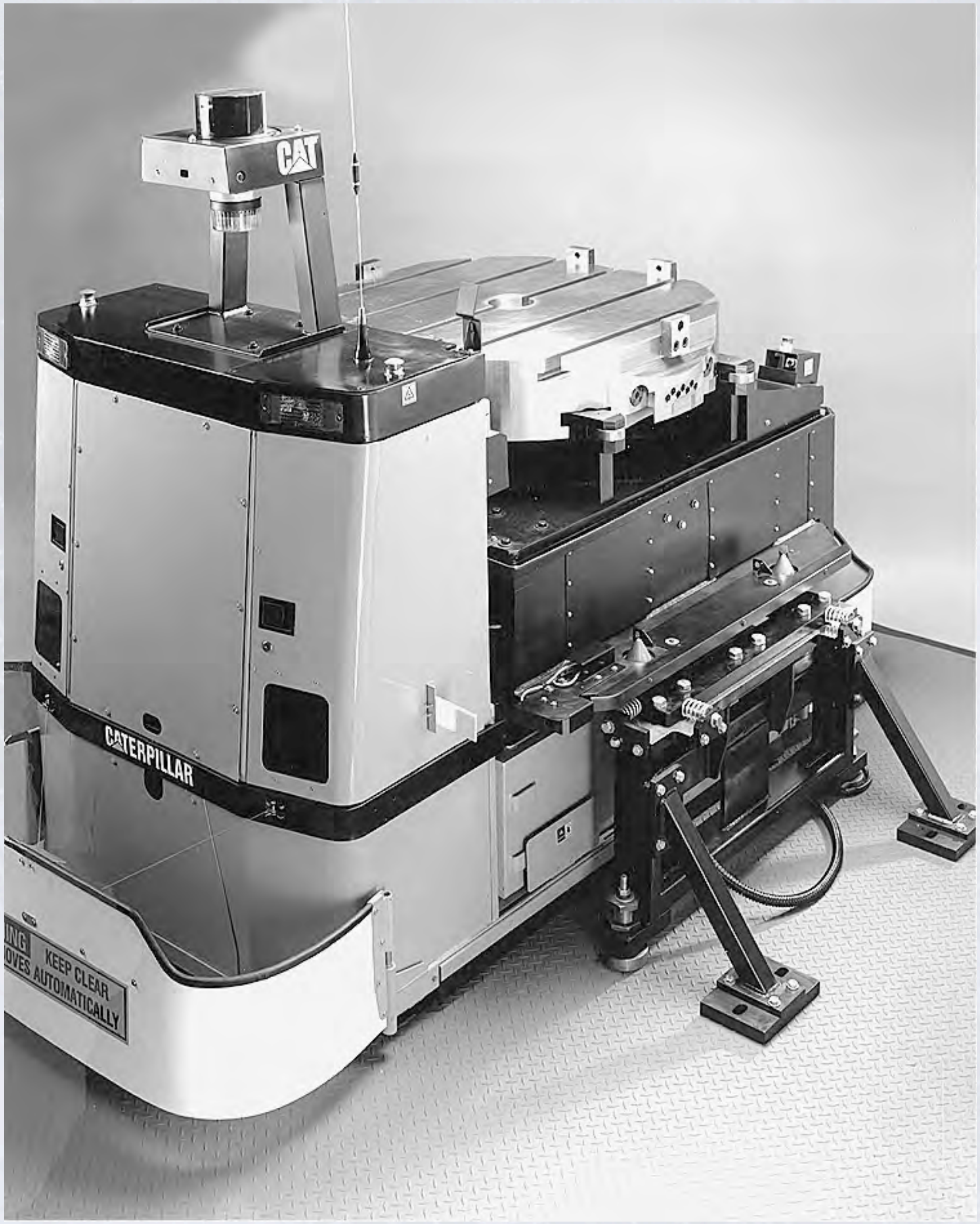


Figure 37.15 In-process inspection of workpiece diameter in a turning operation. The system automatically adjusts the radial position of the cutting tool in order to produce the correct diameter.



Automated Guided Vehicle (AGV)

Figure 37.16 A self-guided vehicle (Caterpillar Model SGC0M) carrying a machining pallet. The vehicle is aligned next to a stand on the floor. Instead of following a wire or stripe path on the factory floor, this vehicle calculates its own path and automatically corrects for any deviations. *Source*: Courtesy of Caterpillar Industrial, Inc.

6-Axis KR030 KUKA Robot

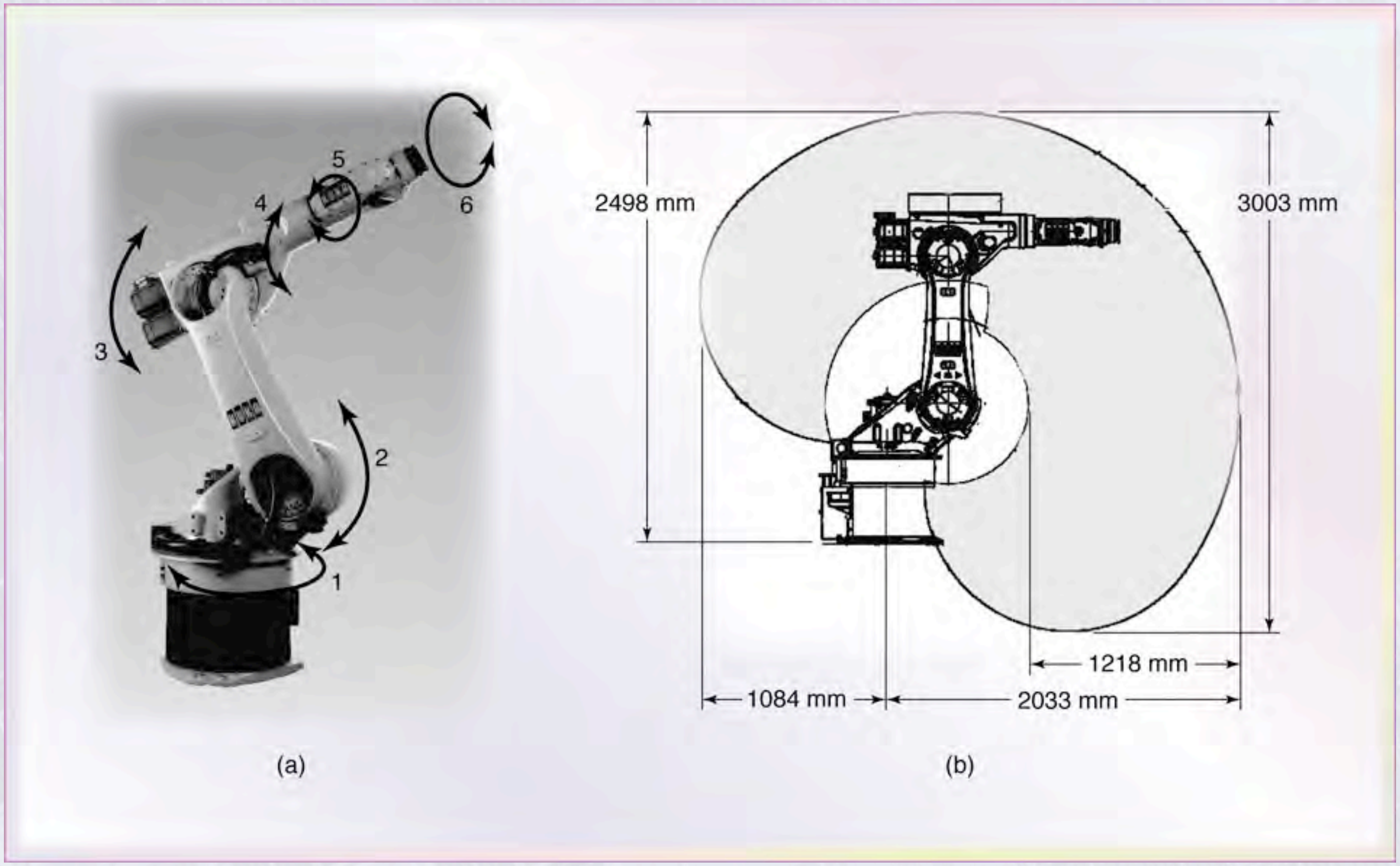


Figure 37.17 (a) Schematic illustration of a 6-axis KR030 KUKA robot. The payload at the wrist is 30 kg and repeatability is ±0.15mm (±0.006 in.). The robot has mechanical brakes on all of its axes, which are coupled directly. (b) The work envelope of the robot, as viewed from the side. *Source*: Courtesy of KUKA Robotics.

Devices Attached to End Effectors

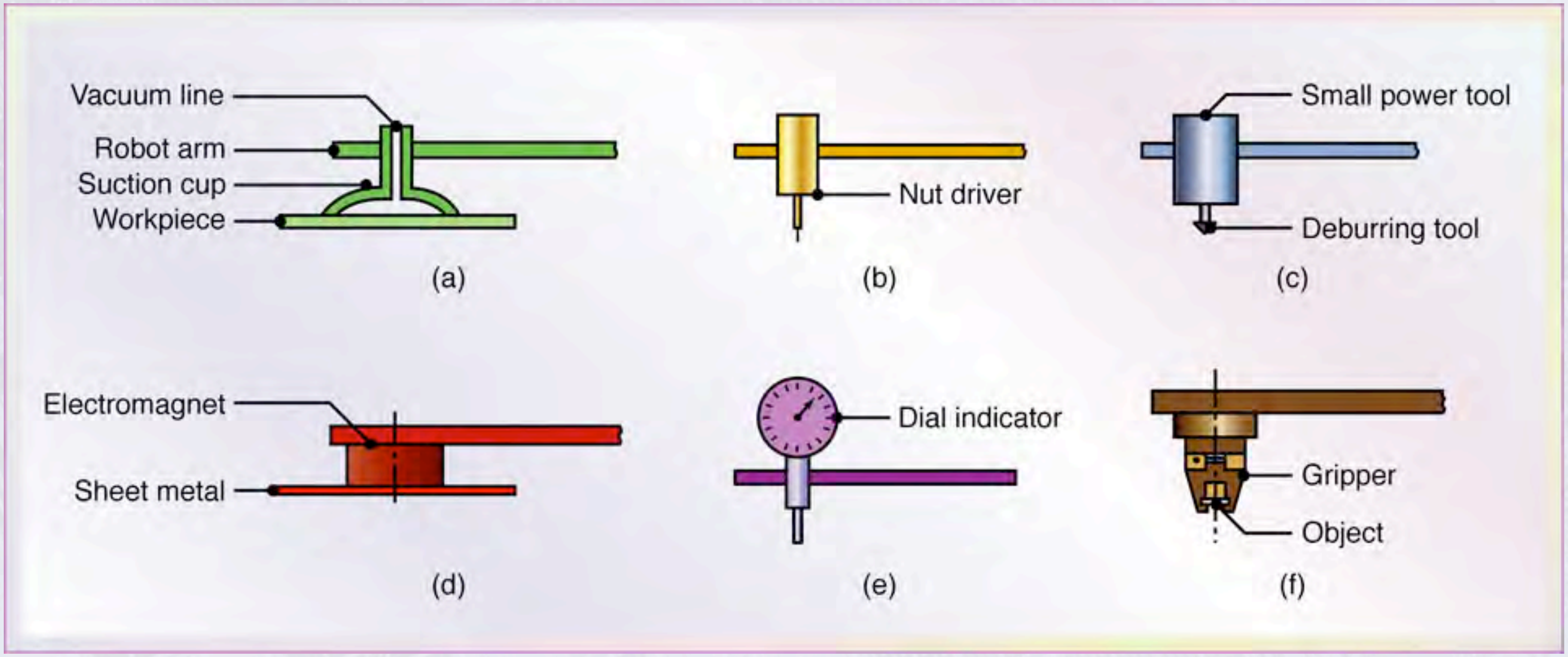


Figure 37.18 Types of devices and tools attached to end effectors to perform a variety of operations.

Types of Industrial Robots

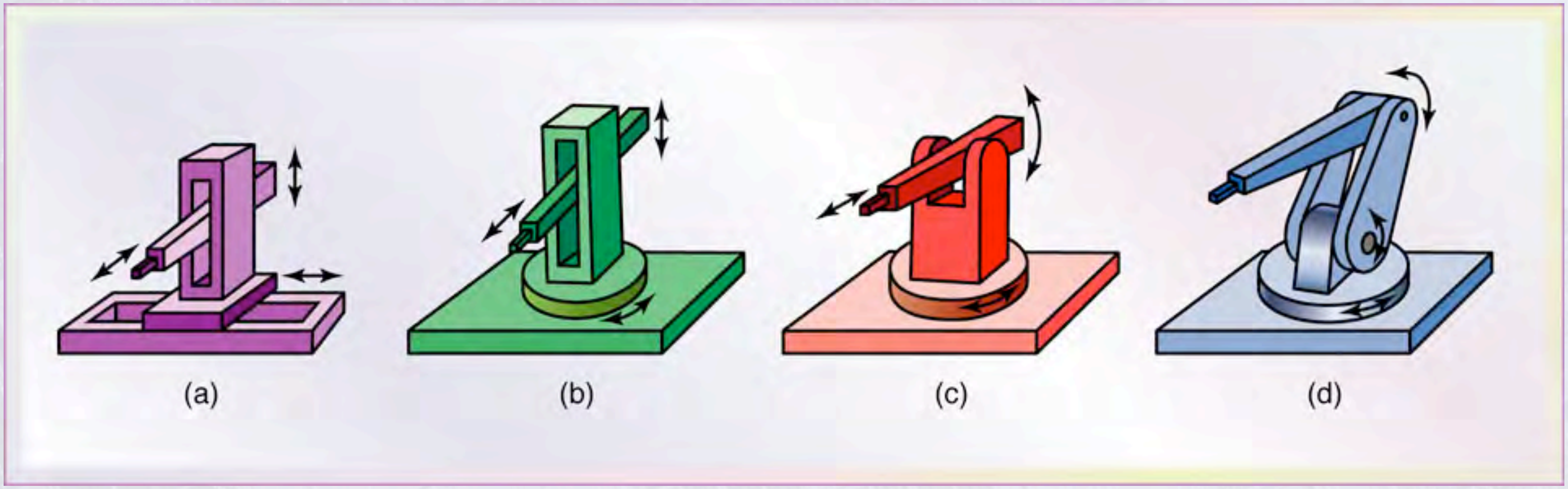


Figure 37.19 Four types of industrial robots: (a) cartesian (rectilinear), (b) cylindrical, (c) sperical (polar) and (d) articulated (revolute, jointed, or anthropomorphic)

Work Envelopes for Three Types of Robots

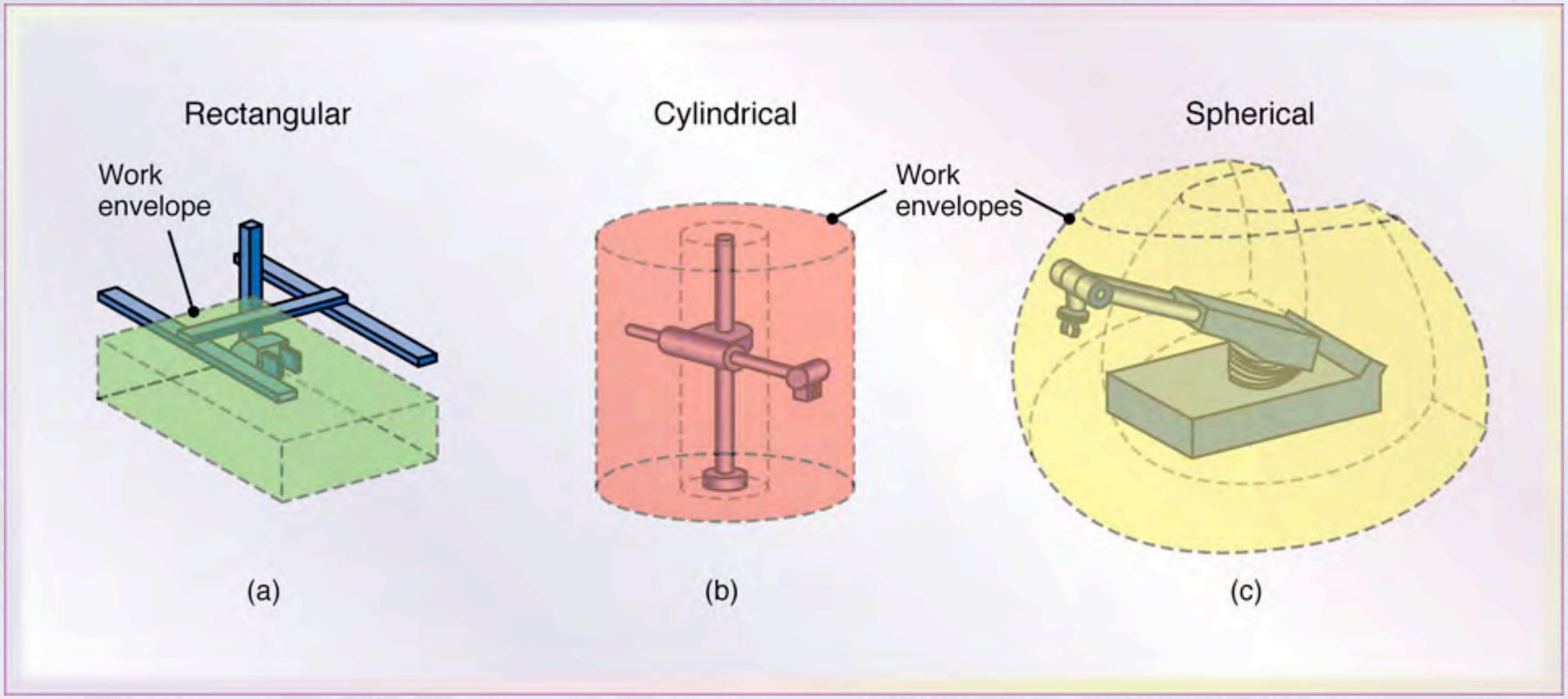
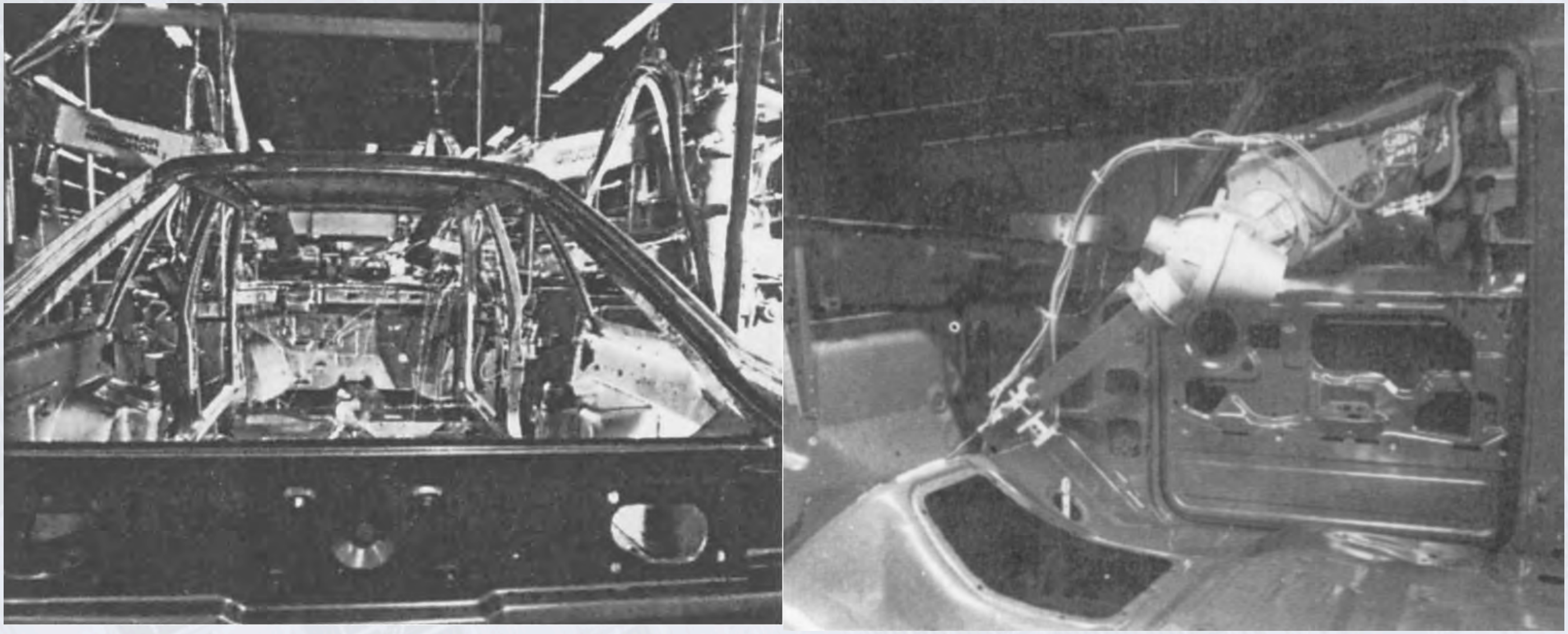


Figure 37.20 Work envelopes for three types of robots. The choice depends on the particular application. (See also Fig, 37.17b).

Industrial Robot Applications



(a) **(b)**

Figure 37.21 Examples of industrial robot applications. (a) Spot welding automobile bodies with industrial robots. (b) Sealing joints of an automobile body with an industrial robot. *Source*: Courtesy of Cincinnati Milacron, Inc.

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Automated Assembly Operations

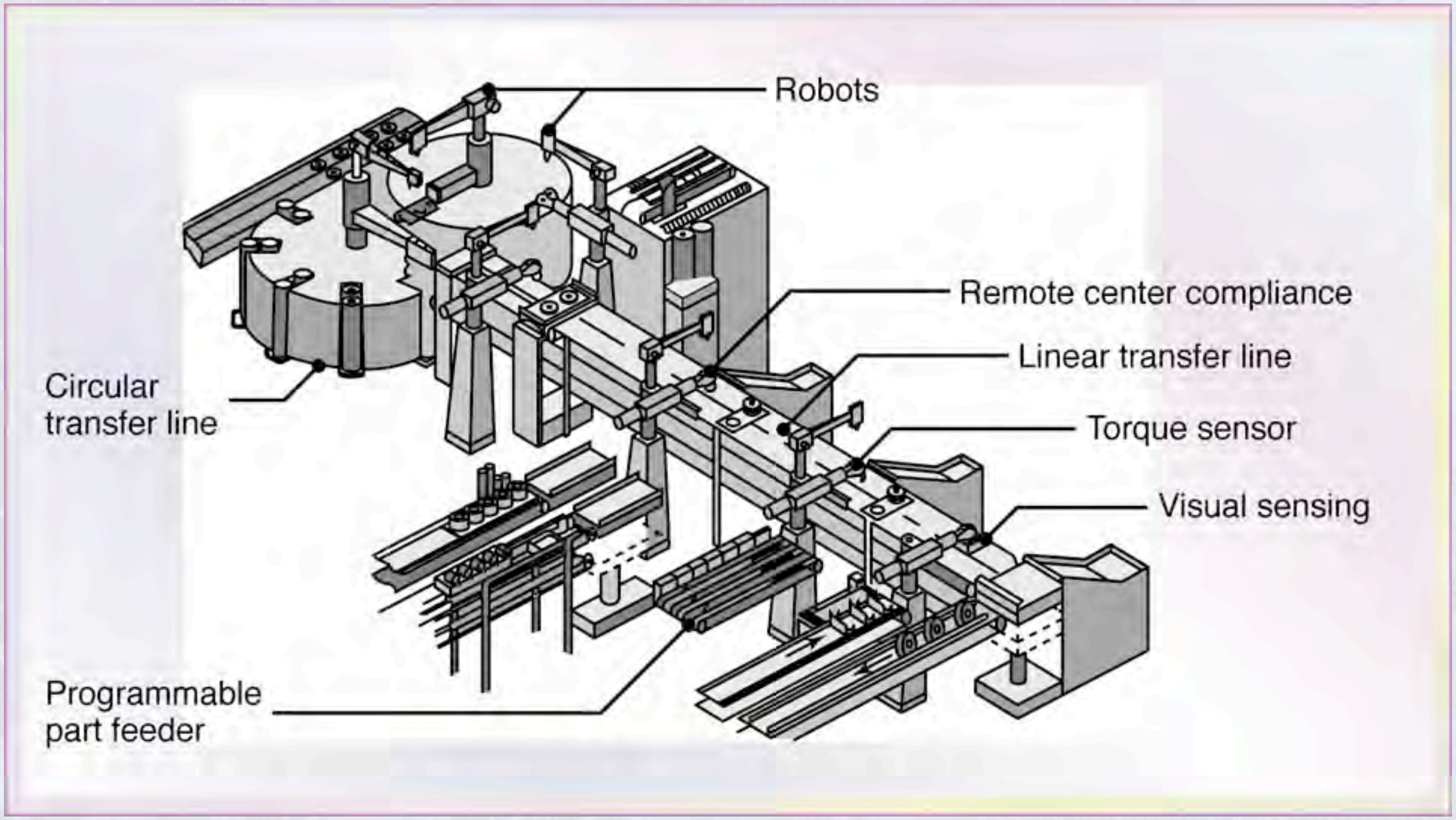

Figure 37.22 Automated assembly operations using industrial robots and circular and linear transfer lines.

Smart Toolholder

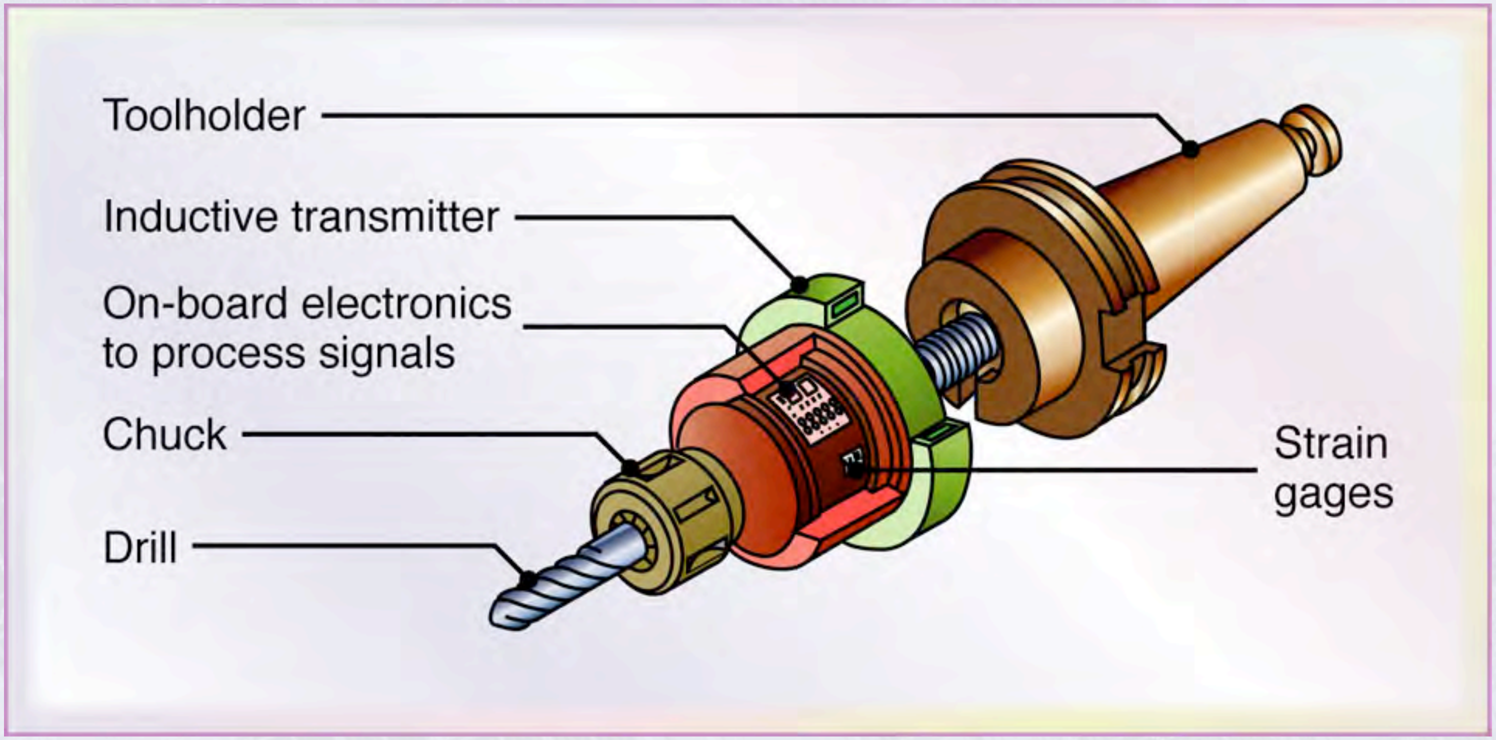

Figure 37.23 A toolholder equipped with thrust-force and torque sensors (smart toolholder), capable of continuously monitoring the cutting operation. Such toolholders are necessary for the adaptive control of manufacturing operations. *Source*: Courtesy of Cincinnati Milacron, Inc.

Robot Gripper

Figure 37.24 A robot gripper with tactile sensors. In spite of their capabilities, tactile sensors are used less frequently because of their high cost and their low durability in industrial environments. *Source*: Courtesy of Lord Corporation.

Machine-Vision Applications

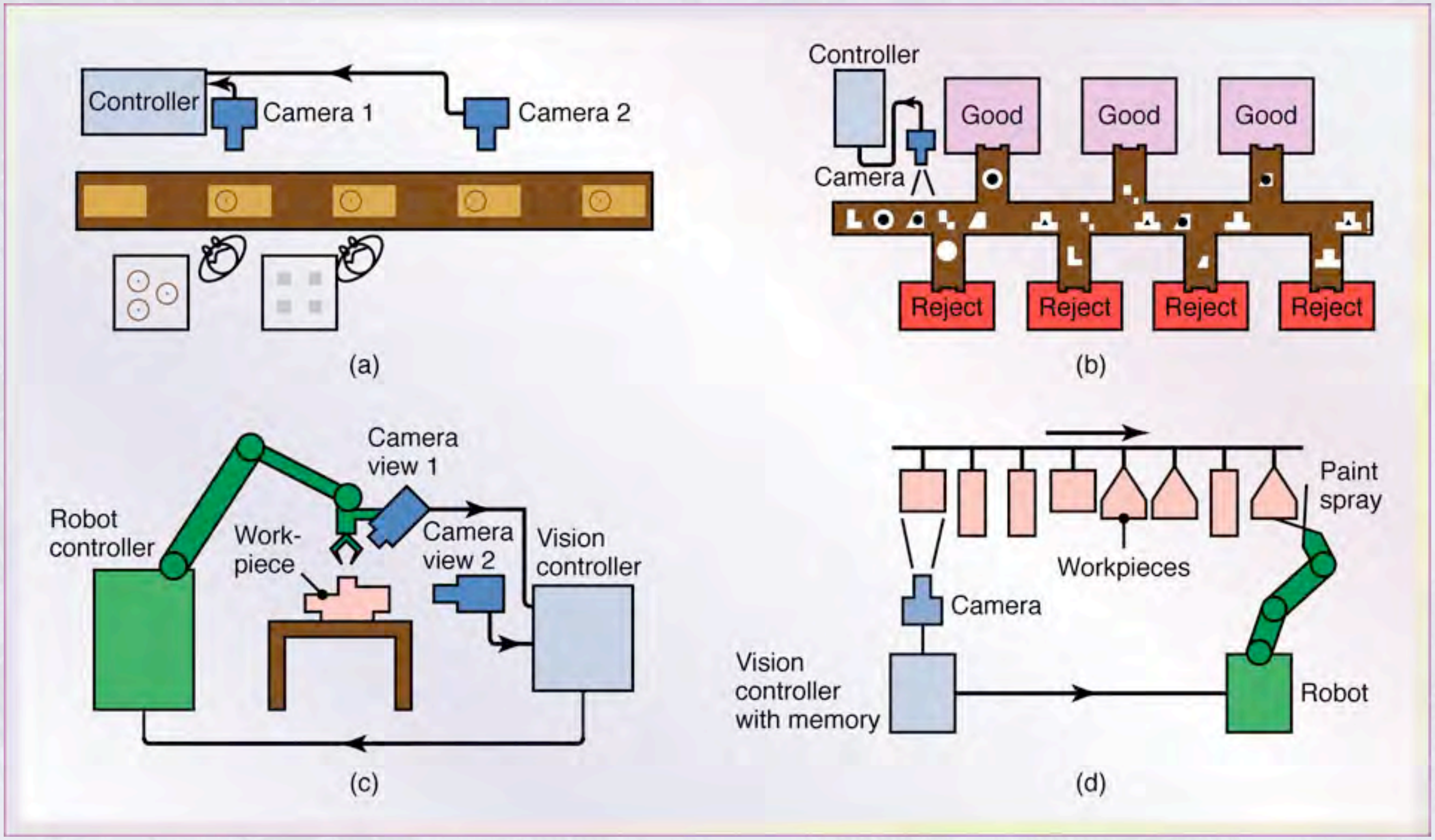

Figure 37.25 Examples of machine-vision applications. (a) In-line inspection of parts. (b) Identification of parts with various shapes and inspection and rejection of defective parts. (c) Use of camera to provide positional input to a robot relative to the workpiece. (d) Painting parts having different 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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Adjustable-Force Clamping System

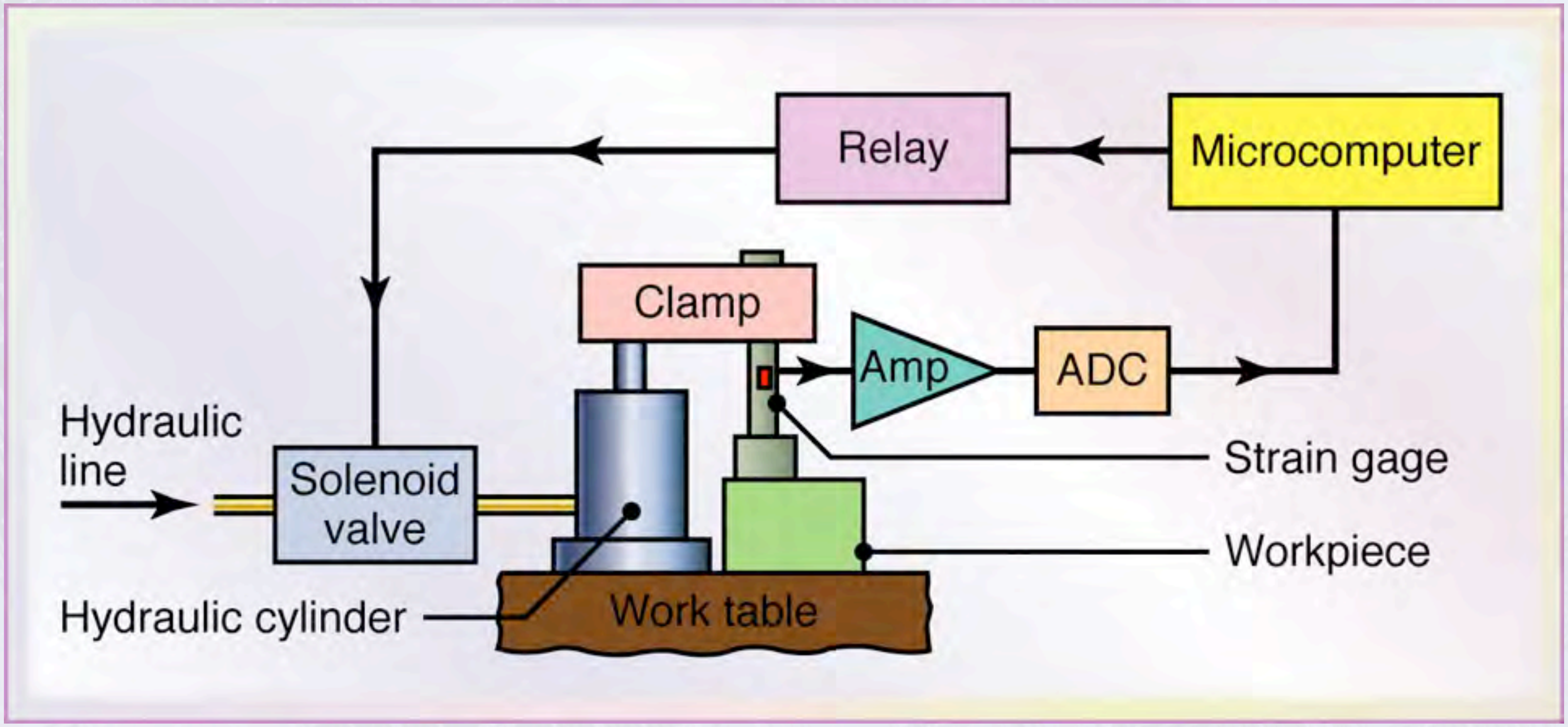

Figure 37.26 Schematic illustration of an adjustable-force clamping system. The clamping force is sensed by the strain gage, and the system automatically adjusts this force. *Source*: After P.K. Wright.

Case Study: Modular Fixture Design

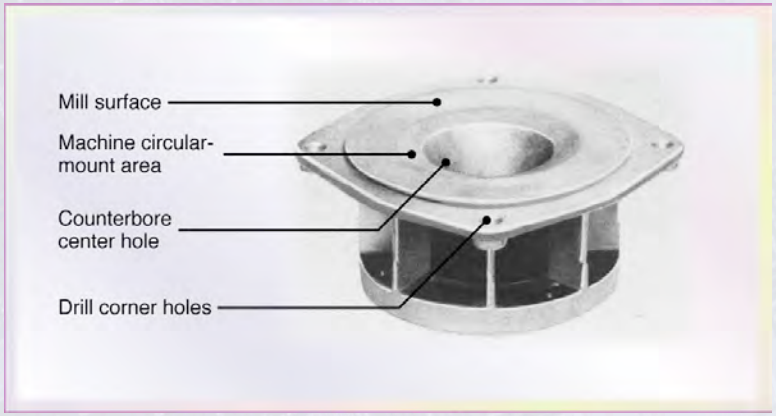

Figure 37.27 Cast-iron housing and the machining operations required.

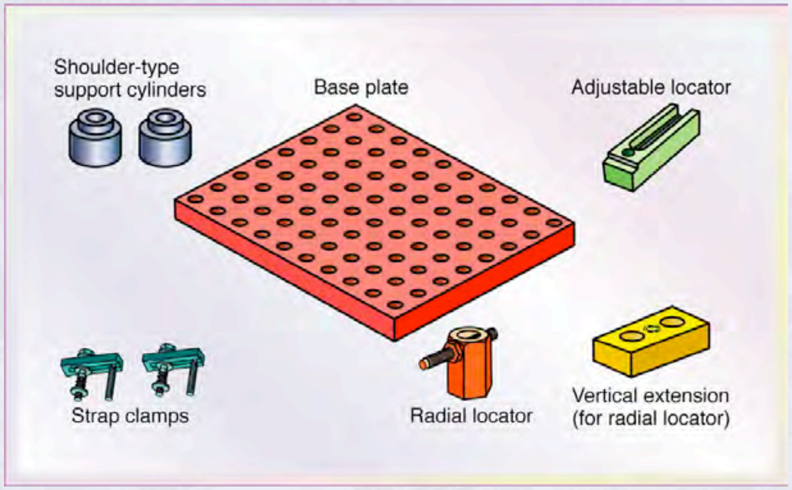

Figure 37.28 Modular components used to construct the fixture for CNC machining of the cast-iron housing depicted in Fig. 37.27.

Figure 37.29 Completed modular fixture with cast-iron housing in place, as would be assembled for use in a machining center or CNC milling machine. *Source*: Courtesy of Carr Lane Manufacturing Company.

Design-For-Assembly Analysis

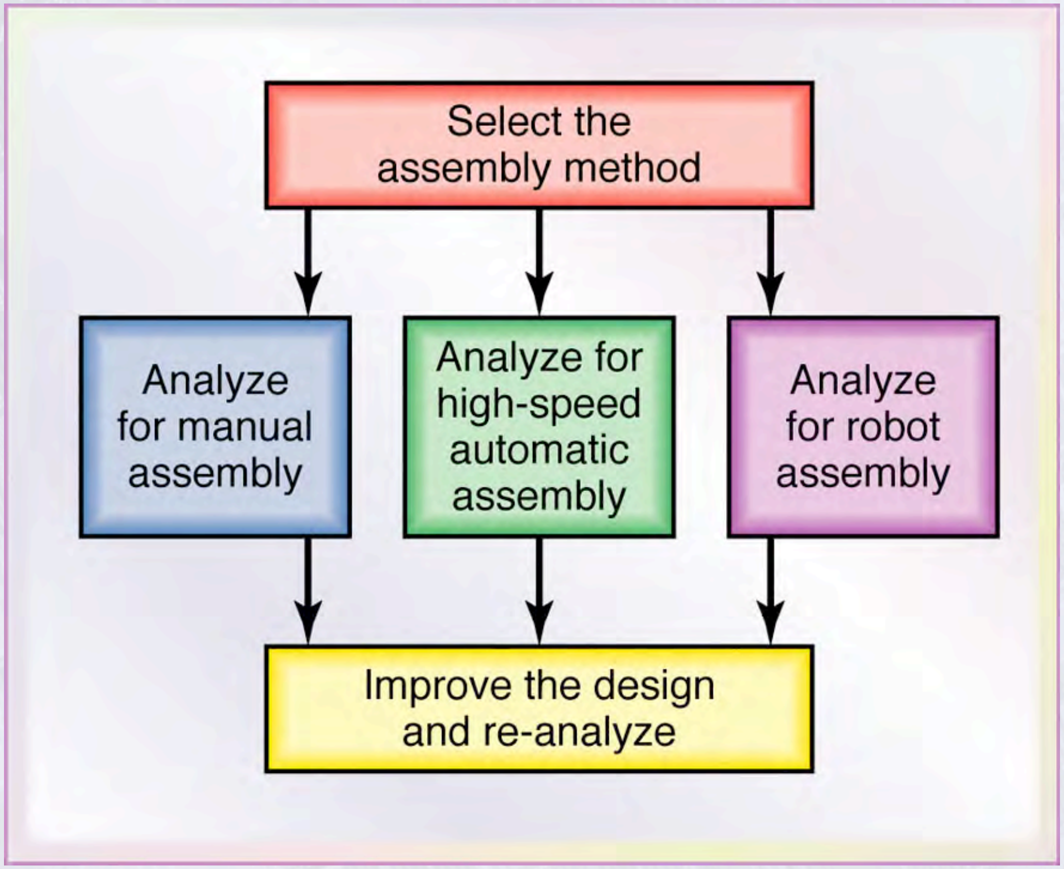

Figure 37.30 Stages in the design-for-assembly analysis. *Source:* After G. Boothroyd and P. Dewhurst.

Transfer Systems for Automated Asembly

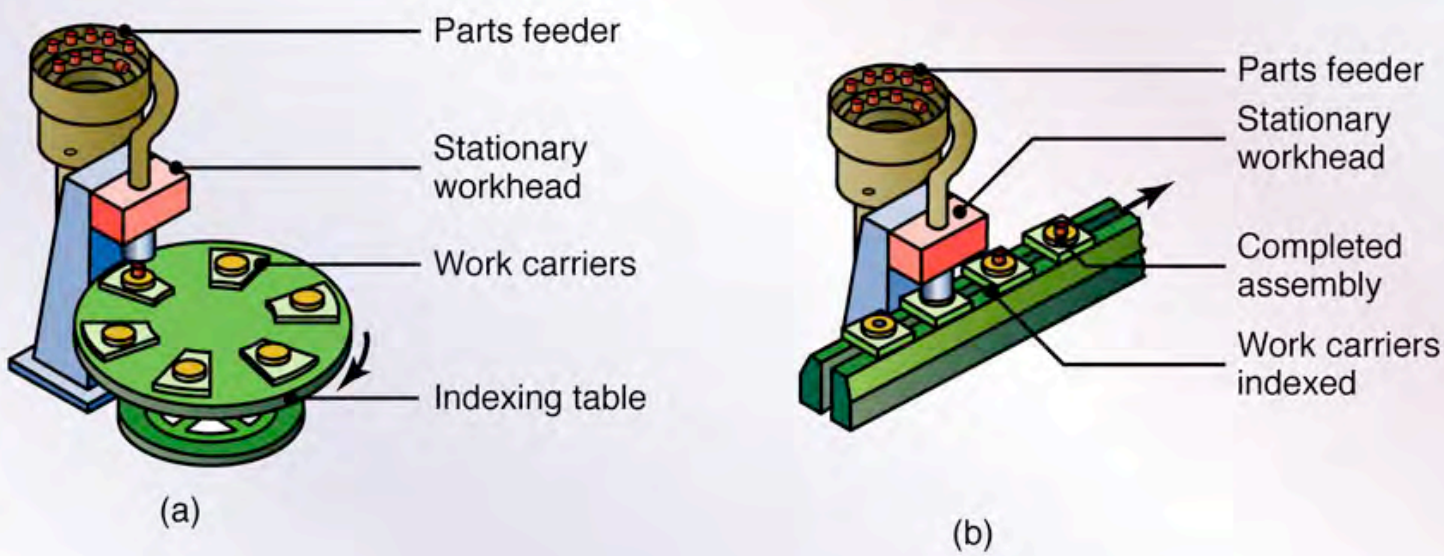

Figure 37.31 Transfer systems for automated assembly: (a) rotary indexing machine and (b) in-line indexing machine. *Source:* After G. Boothroyd.

Two-Arm Robot Assembly Station

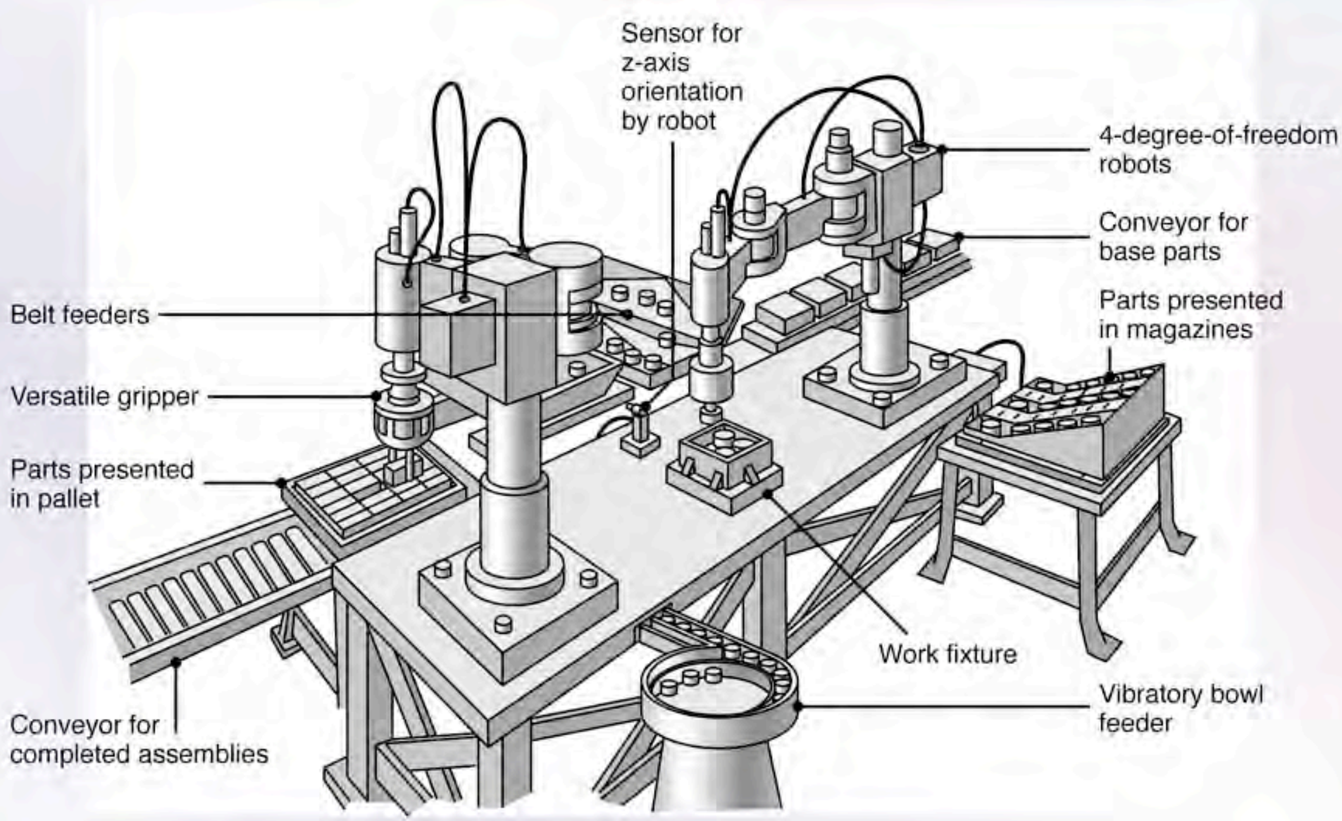

Figure 37.32 A two-arm robot assembly station. *Source: Product Design for Assembly*, 1989 edition, by G. Boothroyd and P. Dewhurst. Reproduced with permission.

Part Feeders

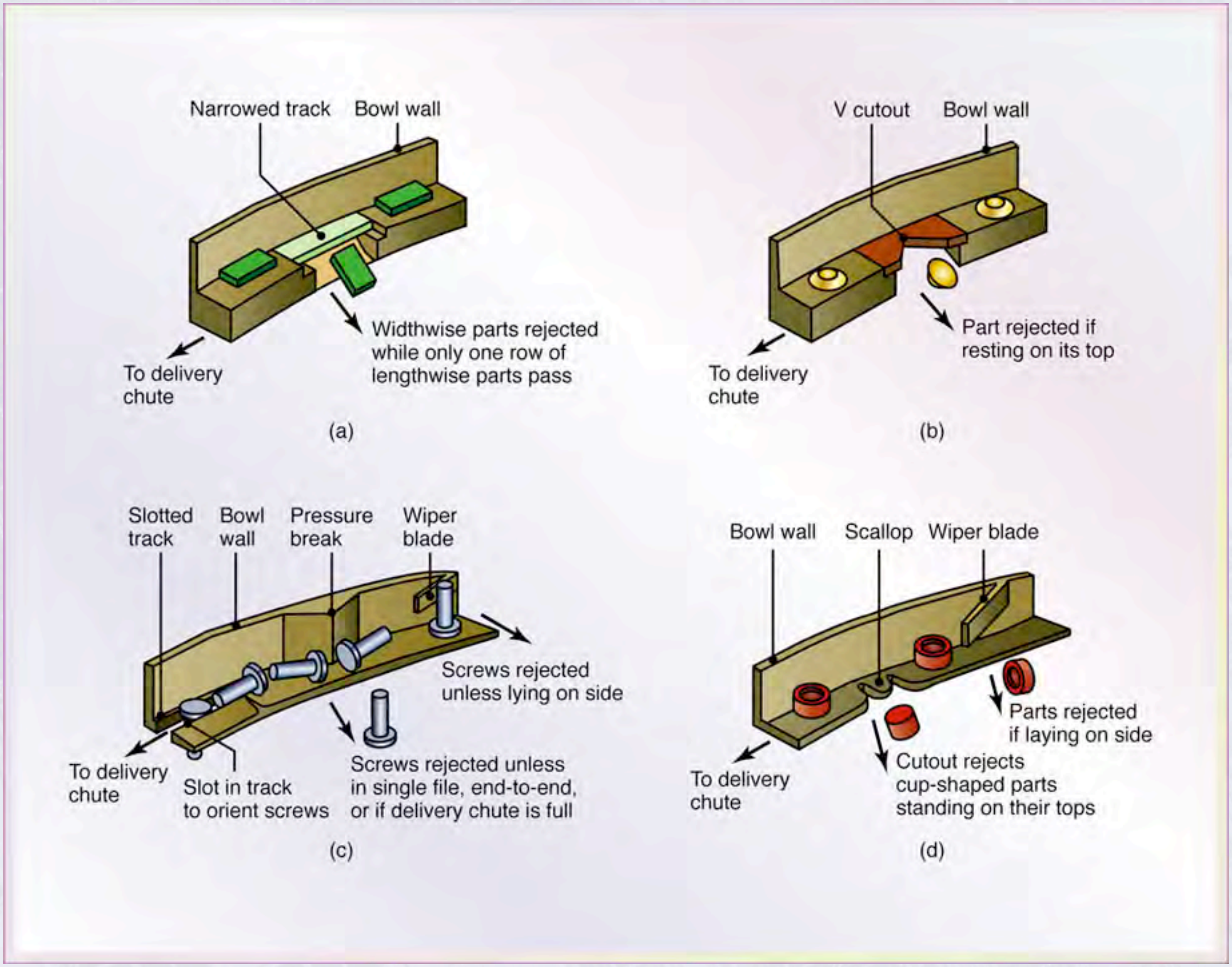

Figure 37.33 Examples of guides to ensure that parts are properly oriented for automated assembly. *Source*: After G. Boothroyd.