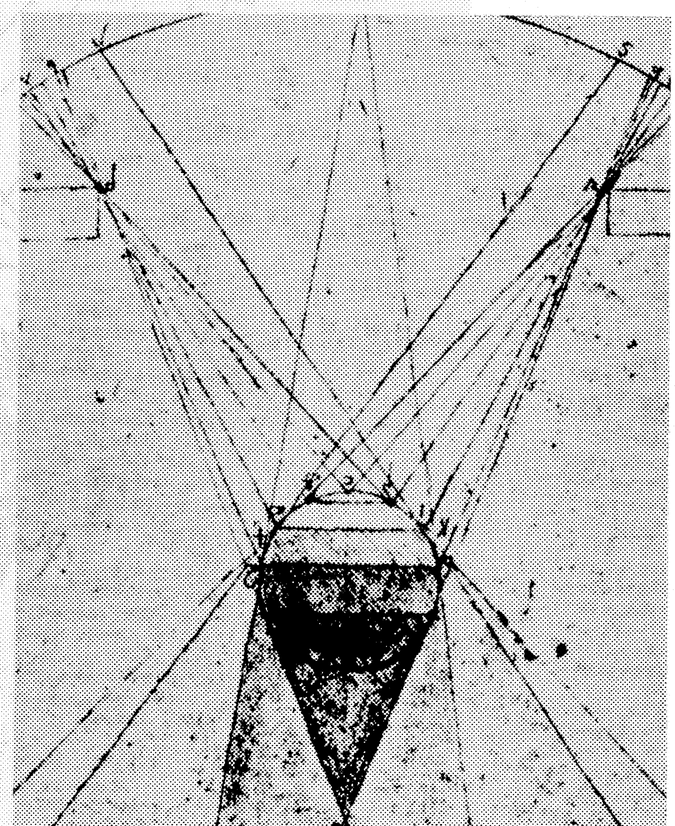
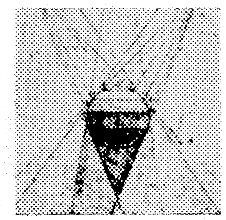
PROCESSES AND DOCUMENTATION



MANUFACTURING PROCESSES

Chapter 14



LEARNING OBJECTIVES

Upon completion of this chapter you will be able to:

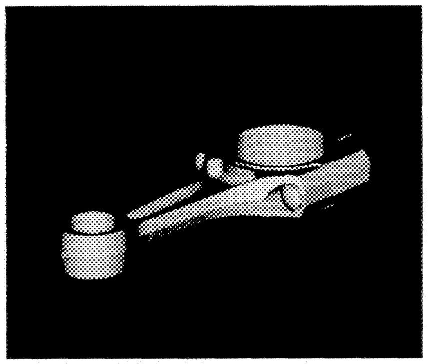
1. Identify specific stages in the manufacturing process.
2. Demonstrate an understanding of materials used in the manufacturing process.
3. Develop an understanding of design-for-manufacturability (DFM) concepts.
4. Identify the basic types of machine tool operations.
5. Describe the processes involved in materials forming.
6. Understand the differences among finishing techniques.
7. Describe the process of automated and computer-aided manufacturing.
8. Define robotics and describe its role in the manufacturing process.

14.1 INTRODUCTION

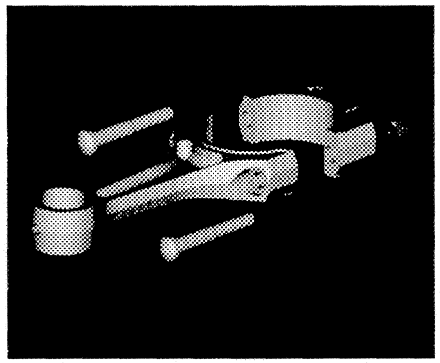
The purpose of any engineering drawing or design database is to provide the information necessary to manufacture a part or system. To design and manufacture a part properly, engineers and designers must understand manufacturing. This chapter describes basic manufacturing and production processes.

When a 3D CAD/CAM system is being employed, the part design might be completely described in the database. When this is the case, the need for engineering drawings may be lessened or entirely eliminated. Regardless of the method of manufacture, the part must be produced from the information provided to the manufacturing facility by the engineering/design department. Figure 14.1 shows a series of steps in the design and manufacture of a connecting rod. Of course, the last step is the actual machining of the part, but the manufacturing methods for producing the part must be known and understood at the beginning of the project, not after the part has been designed and documented. Because the manufacturing process will influence and determine many aspects of the design's configuration, the aspiring designer or engineer must be familiar with the traditional machine tool capabilities and the advanced automated processes and methods.

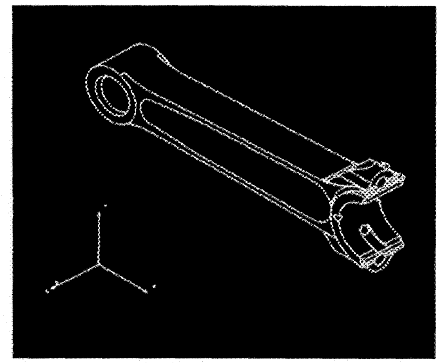
The engineering drawing shows the specific size and geometric shape of the part. It also provides related information about material specifications, finish requirements, and required treatments, along with the revisions and releases made to the document. The drawing in Figure 14.2 shows the revisions in the upper right-hand corner. The notes, in the lower left-hand corner, provide manufacturing with information about the part. Here, the corners are to be ground to **BREAK ALL SHARP CORNERS,** and the finish (surface texture) is established for the part.



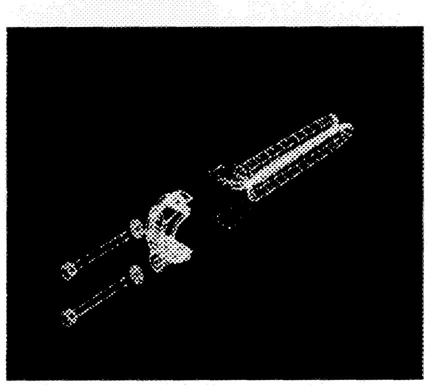
(a) Via interactive commands, the ICEM Solid Modeler assists the design engineer in creating a connecting rod. The engineer constructs shaded, color images in true 3D perspective by combining fourteen geometric primitives



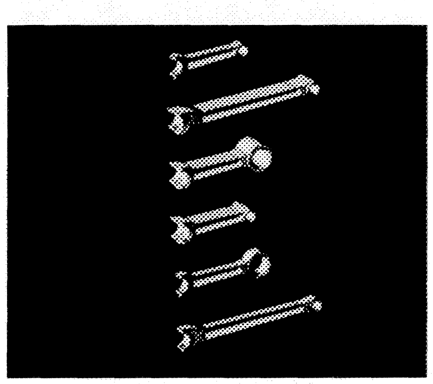
(b) Once the geometric model is created, the ICEM Solid Modeler can "explode" the connecting rod into its component parts, rotate them for viewing at different angles, create cross sections, and check for interference fits



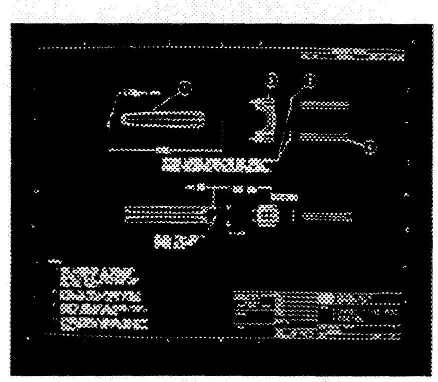
(c) The ICEM Solid Modeler creates a wireframe model automatically from the solid geometry. Hidden lines are also removed automatically



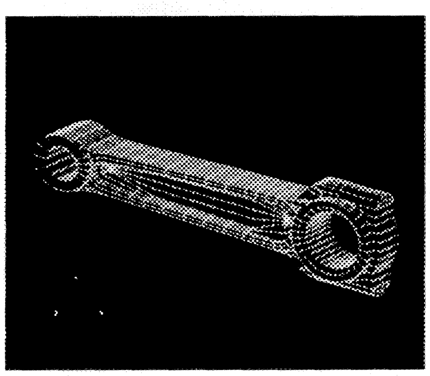
(d) The ICEM Solid Modeler can create an "exploded"-view wireframe model. Weights, volumes, surface areas, moments of intertia, and radii of gyration can also be calculated automatically



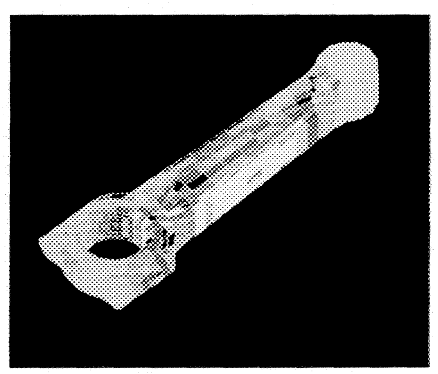
(e) The ICEM Solid Modeler gives the design engineer parametric modeling capability. This allows automatic generation of families of parts



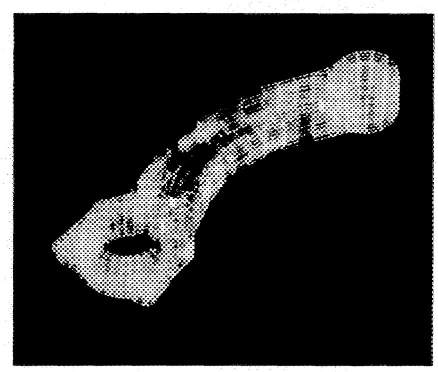
(f) The ICEM Engineering Data Library provides the design engineer with comprehensive, automatic, and security-controlled progression of product documentation



(g) The ICEM utilizes Control Data's UNISTRUC II system or Patran-G for automatic mesh generation for finite-element models



(h) ICEM provides a wide variety of mesh controls. Color schemes depict stress levels at the centroids of each element



(i) Magnified deformation of connecting rod also shows stress data

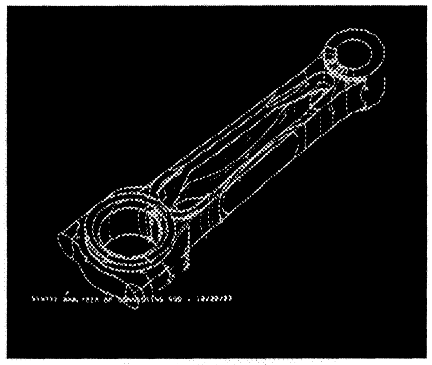
(Continues)

FIGURE 14.1 CAD/CAM Design and Manufacture of a Part

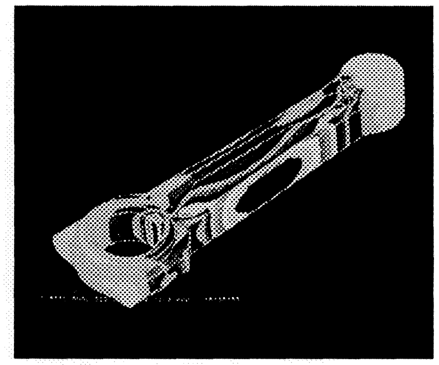
14.2 MANUFACTURING

Manufacturing is the process of coordinating workers, machines, tools, and materials to create a product. The primary purpose of manufacturing is to produce quality parts from raw materials and to assemble related parts in creating assemblies. Manufacturing steps include:

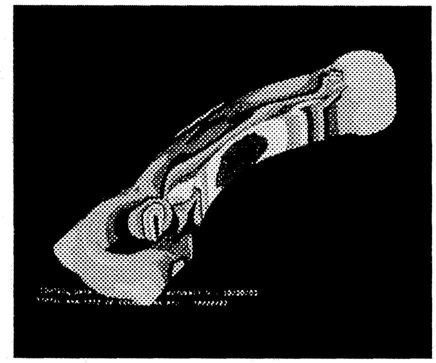
1. Selecting materials and manufacturing methods



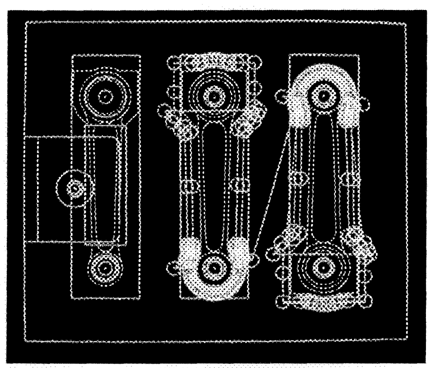
(j) Colored lines depict uniform stress lines in the connecting rod



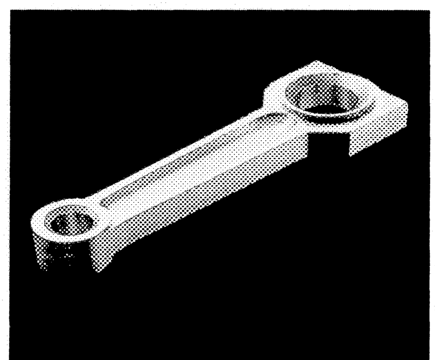
(k) Colored regions indicate ranges of stress or deformations



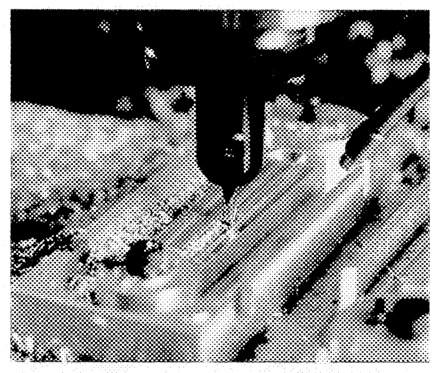
(l) Colored regions are contoured to display accurately stress of connecting rod in motion



(m) Design engineers can preview cutter paths for CNC machining of the part. Changes can be input before machining so that time to part is reduced



(n) The ICEM NC capability generates control tapes directly from design geometry. The NC output is used for machining the actual part



(o) The ICEM assists design engineers in creating CNC machining codes for complex surfaces of dies, molds, and finished parts

FIGURE 14.1 CAD/CAM Design and Manufacture of a Part—*Continued*

2. Determining assembly requirements
3. Production control
4. Determining planning and tooling requirements
5. Production and manufacture of the product
6. Inspection and quality control

Many companies have separate areas for product development, tooling and manufacturing, and facilities. **Product development** is where the conceptual work is done in the development of a product. Producing and manufacturing a product requires new machines, tools, dies, jigs, and fixtures. Thus, **tool design** is very important for a successful product. *Facility design* covers building and plant upgrading, maintenance design, and new additions.

If you understand the cost, mechanical capabilities, and limitations of basic processes, you can design the part with the manufacturing process in mind. This increases **manufacturability** and reduces the cost of the item. The final product is what is manufactured and produced for sale. The drawing or the CAD database is the starting point for the design-through-manufacture sequence.

14.2.1 Manufacturing Processes and Manufacturability

The primary goal of all manufacturing is to produce a product cost-effectively, quickly, and at the required level of accuracy. Although manufacturing engineers decide the way to produce the part, designers have major input.

Once the engineering drawing has been received by manufacturing, it is reviewed to ensure that all information necessary to make the part is provided. During this review, manufacturing engineers decide on tooling, machines, inspection, and time to produce the part. New concepts, including the integration of manufacturing decisions into the beginning stages of design, are being implemented throughout industry today. This is called **design for manufacturability** (DFM). DFM is a company design philosophy. Since the way a product is designed determines 70–90% of the total ongoing cost of the product, it makes sense to design for quality and manufacturability. **Concurrent engineering** is the effort to get design, engineering, manufacturing, and production to work in parallel rather than in sequence. The following considerations are important for a successful product, but they *must* be considered during design, when changes can be implemented most readily:

1. Material specification
2. Size and configuration
3. Production run (how many parts are needed), which greatly influences the production method
4. Tolerances specified for the part
5. Machine and tooling operations

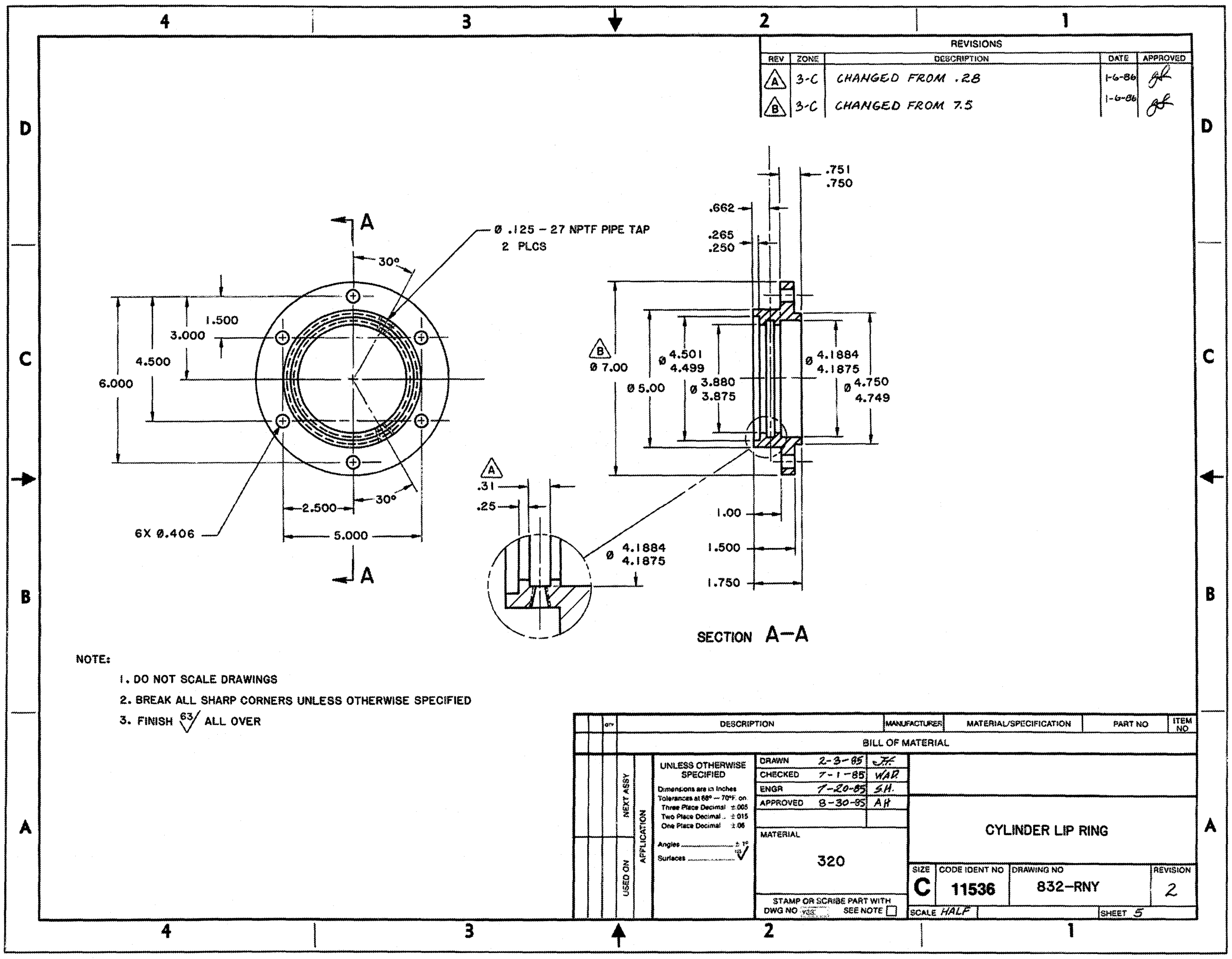


FIGURE 14.2 Cylinder Lap Ring Detail Drawing

The part (Fig. 14.3) is manufactured from a **stock piece** or other raw material. A variety of standard **stock forms** are available. **Bar stock** comes in square, round, and hexagonal shapes (Fig. 14.4). Figure 14.5 shows the available types of **structural shapes.** If a stock form is not used, then the part must be cast, extruded, or formed through other processes.

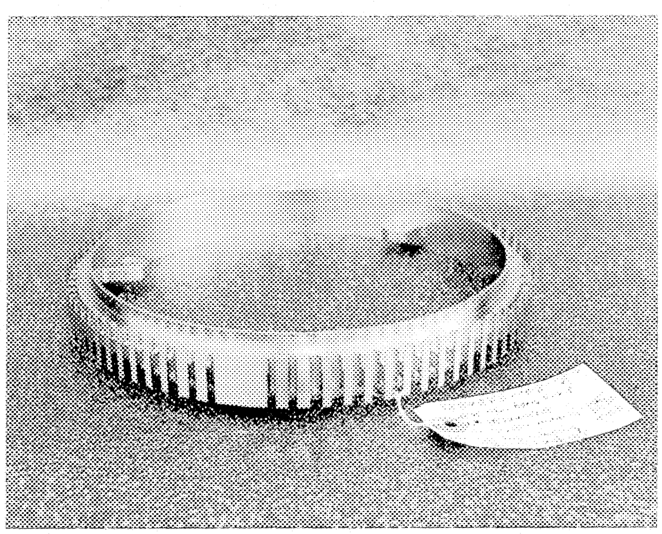


FIGURE 14.3 6061 Aluminum Outer Support Ring for Electronic Control Cables

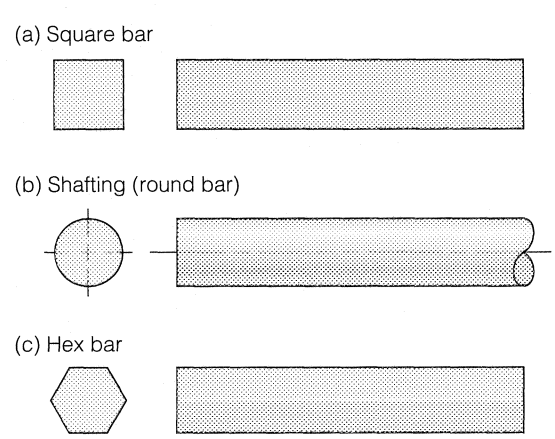


FIGURE 14.4 Stock Forms

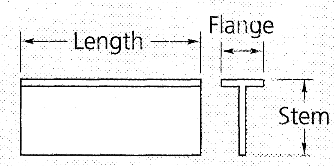
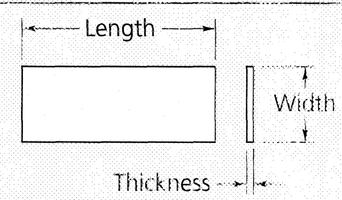
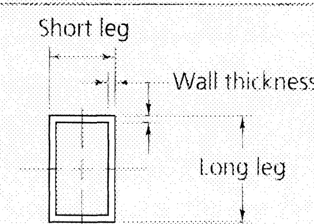
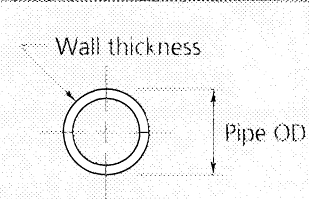
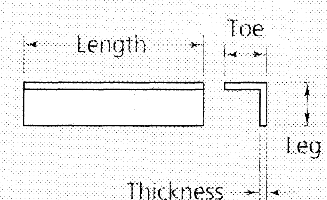
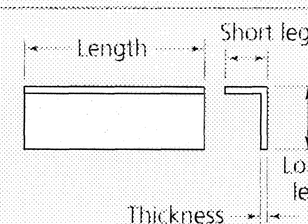
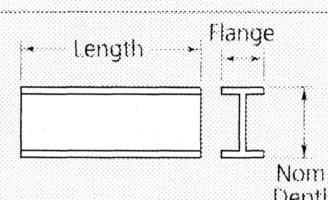
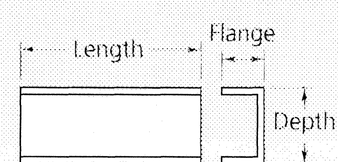
Type of component	Graphic representation
Tees WT 4 X 6.5 X 3'-9" LG Member length Weight per foot in pounds Nominal depth in inches W Tee symbol	
Plate PL 1/2 X 6 X 14" Member length Width in inches Thickness in inches Plate symbol	
Rectangular structural tubing TS 6 X 4 X .375 X 3'-9" LG Member length Wall thickness Short leg in inches Long leg in inches Structural tubing symbol	
Pipe Pipe 6 Std. X 3'-6" LG Pipe 6 Sch. 40 X 3'-9" LG Member length Wall thickness index Nominal pipe diameter in inches	
Equal leg angle L 3 X 3 X 3/8 X 3'-9" LG Member length Thickness in inches Leg width in inches Leg width in inches Angle symbol	
Unequal leg angle L 6 X 4 X 3/8 X 3'-9" LG Member length Thickness in inches Short leg in inches Long leg in inches Angle symbol	
Wide flange beam W6 X 20 X 3'-9" LG Member length Weight per foot in pounds Nominal depth in inches Wide flange symbol	
Standard channels C4 X 5.4 X 3'-9" LG Member length Weight per foot in pounds Depth in inches Channel symbol	

FIGURE 14.5 Structural Stock Forms

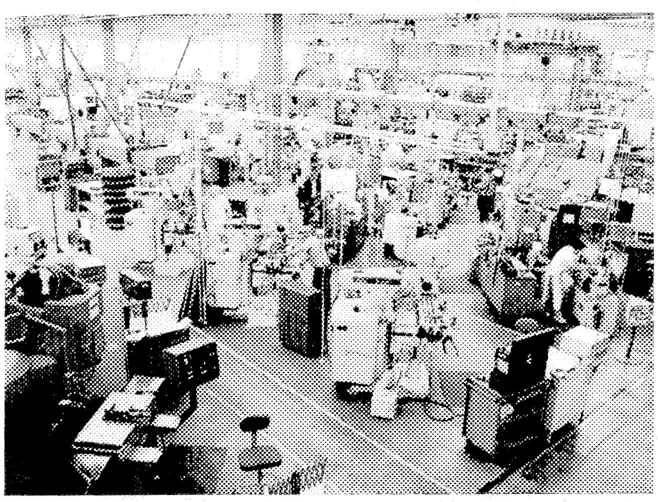
There are five basic families of processes:

1. **Molding** or **casting** into the proper configuration
2. Forming by **bending** into the required shape
3. **Cutting** or **sawing** into the proper size and shape
4. Pounding or **forging** into shape
5. **Fabrication** via a fastening method: *welding, riveting, bolting, screwing, adhering,* or *nailing* parts formed by any of the preceding processes

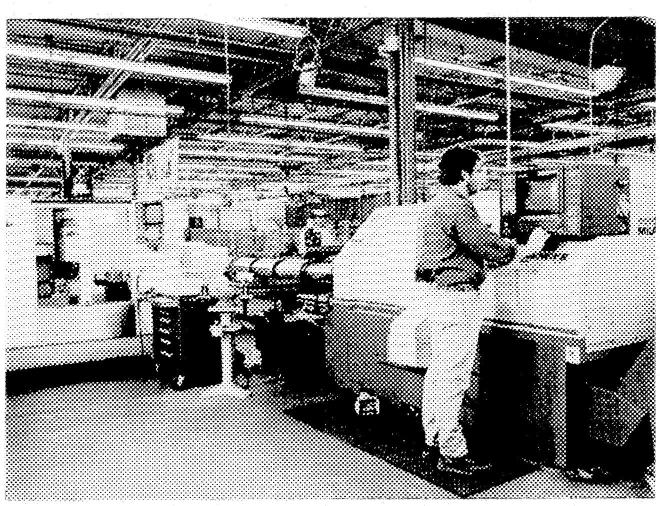
14.3 MACHINE TOOL OPERATIONS

Machine tools are machines that cut metal or form new material. Some machines are dedicated to one operation; others can perform many types of cutting or drilling operations. Figure 14.6 shows manufacturing plants equipped with a wide variety of traditional and computer-controlled machine tools. Five basic processes are performed on machine tools:

- **Drilling** (drilling, reaming, counterboring, countersinking, spotfacing)
- **Turning** (lathe work)
- **Planing** and **shaping**
- **Milling**
- **Grinding**



(a) Aerospace manufacturing facility



(b) CNC machine on factory floor

FIGURE 14.6 Manufacturing Facilities

14.3.1 Drilling

Drilling is one of the most common of the basic machine tool operations. It includes drilling holes from under $\frac{1}{64}$ in. (0.4 mm) to more than 2 in. (50 mm). Machined holes include: counterboring, countersinking, spotfacing, spot or center drilling, and reaming (Fig. 14.7). In industrial drilling, the **drill bit** [Fig. 14.7(a)] is a cutting tool held by a chuck and rotated by a large motor. The rotating tool is fed into the part at a controlled rate. The **turning speed** and **feed rate** of the drill are determined by the material and by the size of the hole.

Almost every machined part has drilled holes (Fig. 14.8). The type of process required is determined by the tolerance of the hole. Drilling [Fig. 14.7(a)] is also used to create rough holes before the boring, reaming, counterboring, countersinking, or tapping operations are performed. **Reamers** [Fig. 14.7(c)], **counterbores** [Fig. 14.7(d)], **center drills** and **countersinks** [Fig. 14.7(f)] are used after a hole has been drilled.

A tap drill is used when the hole will have a **thread** applied to it with a tapping tool. The tap drill must be the proper size to produce the minor diameter of the internal thread. (Threads are covered in Chapter 17.)

14.3.2 Reamers

When a hole must be precise, a **reamer** is used [Fig. 14.7(c)]. Reamers are required because twist drills make holes that are not accurately sized, are not precisely round, and have poor finishes. An undersized drill removes most of the material, then the reamer finishes the hole. Reamers are made of tungsten carbide (tool) steel. Many types of reamers are available.

14.3.3 Counterboring

A drilled hole must be made before any **counterboring** [Fig. 14.7(d)]. A counterbored hole is deeper than a spotfaced hole and has a specific dimension to its recessed depth. Counterboring enables socket-head and fillister screws to be seated with their heads flush or below the surface of the part.

14.3.4 Spotfacing

Spotfacing [Fig. 14.7(e)] is basically the same as counterboring, but it is done to no more than $\frac{1}{8}$ inch (3 mm) deep.

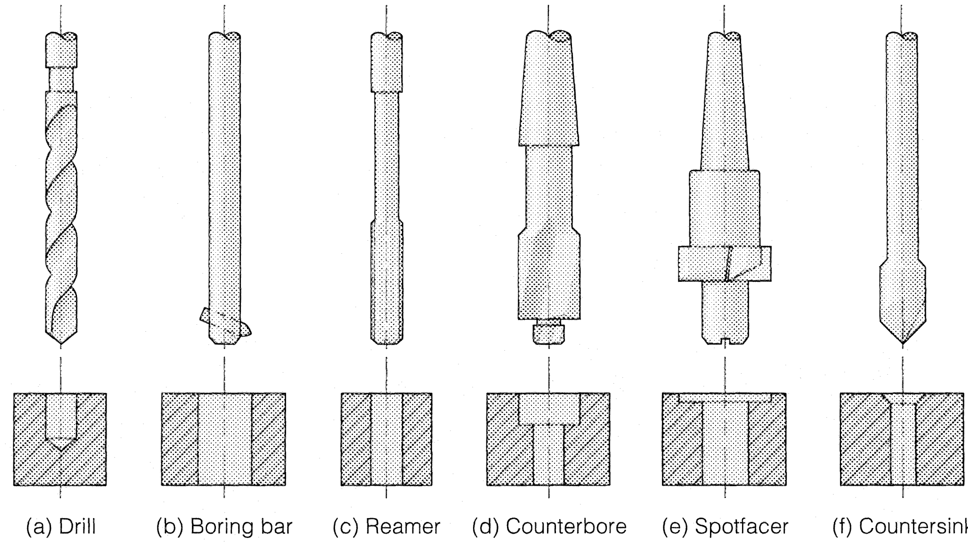


FIGURE 14.7 Machined Holes

This process is good for cleaning up the area around the hole, especially if the part is made of a cast material. The spotface provides a smooth bearing surface for **fasteners** (nuts, bolts, screws, rivets).

14.3.5 Countersinking

Countersinking creates a small **chamfer,** or bevel, at the edge of a hole [Fig. 14.7(f)]. A hole is drilled before countersinking. Countersinking makes it easier to insert dowel pins, bolts, taps, and reamers into the hole. For flathead bolts, chamfers are usually 82°.

14.3.6 Center Drilling

Center drilling is required when the part is to be held between centers for machining on a lathe. Center drilling also can create an accurately located starting hole for a twist drill.

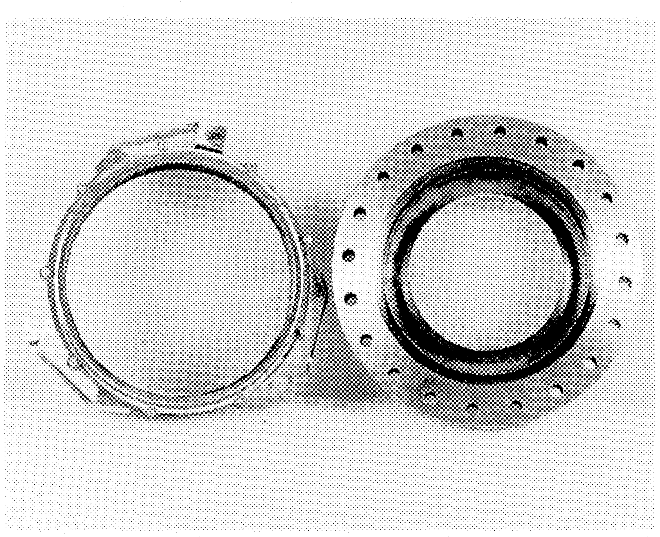


FIGURE 14.8 Inside and Outside Windows on Gravity Probe Telescope

14.3.7 Taps and Dies

Taps and **dies** are employed to machine internal and external threads. External threads on shafts are cut by a die; internal threads are cut by a tapping tool.

14.3.8 Broaching

Broaches are used to create odd-shaped holes or openings. A broaching machine can cut special features like keyseats and can form square, hexagonal, or odd-shaped holes after a drilled hole has been created. A *broach* is a long tool with a series of teeth or cutting edges that increase in size progressively so that each tooth removes only a small portion of the material as it is pulled or pushed through the part.

14.3.9 Boring

Boring is a machining process for producing a wide range of precise-tolerance holes, and it requires a milling machine, a lathe, or a special boring machine by which accuracy can be closely controlled. Boring can create a wide range of hole diameters that require precise tolerances or geometry [Fig. 14.7(b)].

The part in Figure 14.9 is an example of an industrial part that required multiple holes, counterbores, and slots. Study each of the "callouts" on the drawing. Notice that each hole is dimensioned to the center point, and the notes call out the required hole diameters and, where appropriate, the depths. A number of drilled holes, counterbored holes, and taps are required for the part. Note that *the process required for a particular hole is not specified in the note, only the size and type.* Manufacturing determines the proper tool and machine needed to manufacture the part economically.

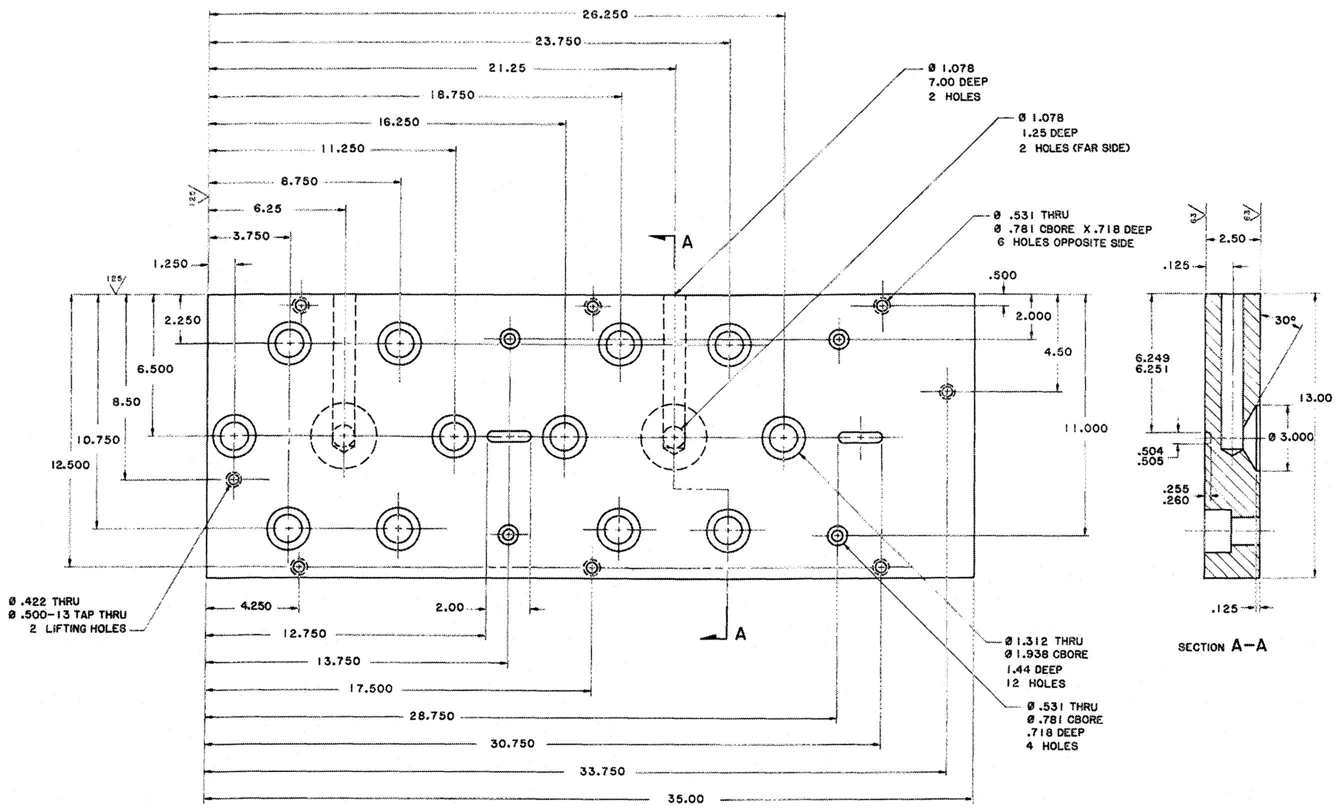


FIGURE 14.9 Detail Drawing

14.3.10 Turning Operations

Turning operations use the **CNC turning center** (Fig. 14.10), the **engine lathe** (Fig. 14.11), the **turret lathe**, and a variety of **boring machines.** A *lathe* is a machine that rotates the part rapidly while a stationary cutting tool performs the operation. The **vertical boring mill** is employed for turning large parts that need round cuts and for facing and contouring. Figure 14.12 shows an industrial detail of a pivot pin. This part was turned on a lathe.

The most common and versatile type of machine tool (found in every machine tool area) is the engine lathe. The engine lathe handles cylindrical part operations that include: cutting threads, facing, tapering, parting, turning, and knurling (Fig. 14.13). A part is usually held in a lathe by a

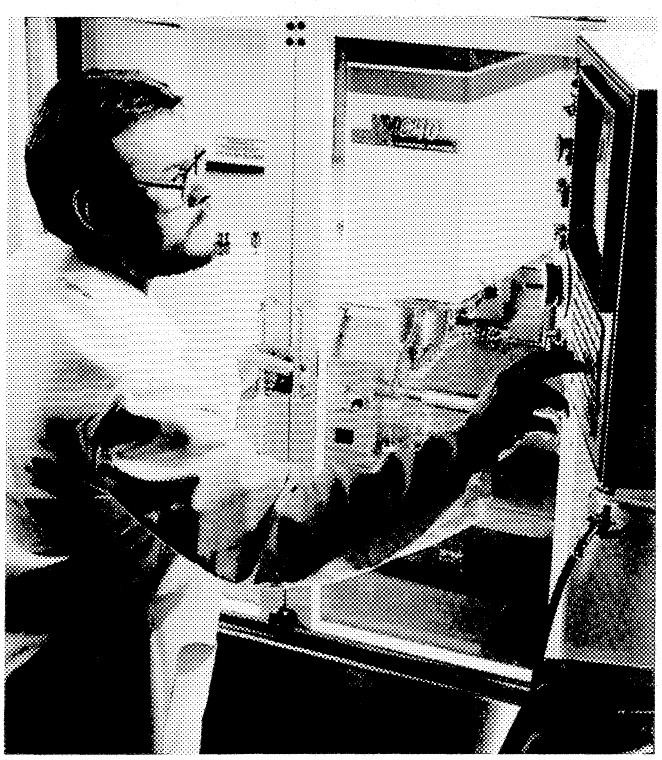


FIGURE 14.10 CNC Turning Center

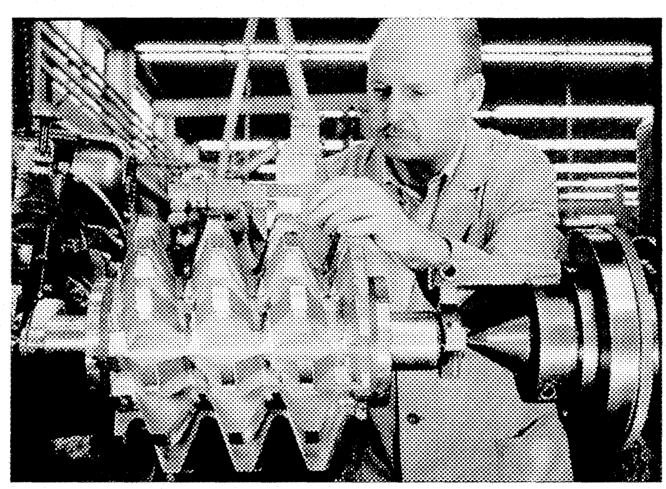


FIGURE 14.11 Lathe Machining

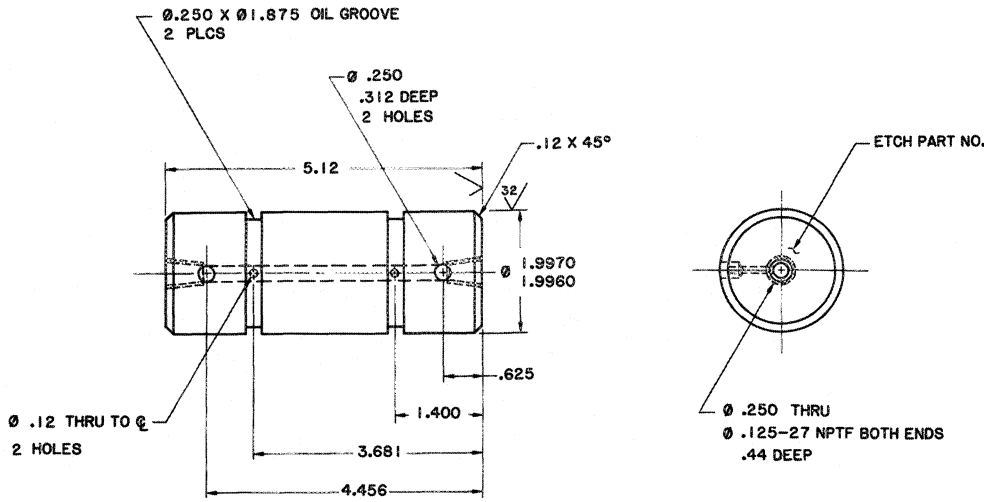


FIGURE 14.12 Pivot Pin Detail Drawing

chuck. The chuck is connected to the powered end of the machine (Fig. 14.11). Collets, face plates, drive plates, and other devices can also hold and drive the workpiece in the lathe.

A lathe can be used for drilling, reaming, boring, counterboring, facing, threading, knurling, and polishing. Drilling, reaming, boring, and counterboring are done on the face of the part as it turns. Boring and reaming on a lathe can be accomplished along the **Z** axis, in line with the center of the tail stock. The **tail stock** supports the part on one end, and the **tool post** fastens the tool holder securely. The tool post can be moved to the right or the left and rotated at an angle.

Computer numerically controlled (CNC) engine lathes are also available. All of the functions are controlled by a computer (and program). Therefore, manual controls are limited on this type of machine. The **turret lathe** has a rotating multisided turret on which a variety of cutting tools can be mounted. This allows the rapid changing of tools for low-volume vs. high-volume production. CNC turning centers help to perform turning operations on small, highly toleranced parts (Fig. 14.14).

Turning uses a lathe to reduce the outside diameter of a part. In this situation, the tool bit will travel parallel to the **Z** axis. **Facing** decreases the length of the part or flange and creates a flat surface (Fig. 14.13). **Threading** is done on an engine lathe with a single-point tool (a slow process). Drilling and reaming can be done on a lathe, but the hole location is limited to the center of the lathe's **Z** axis, in line with the tailstock center. **Knurling** (Fig. 14.13) is a pattern formed into the surface of a part, either for appearance or to provide a gripping surface. The pattern is either straight or diamond shaped.

The cylinder rod in Figure 14.15 is an example of a part produced on a lathe. Dimensions A, B, and C are given in three different sizes. This part is made from 1420 cold roll steel (CRS) and requires a tapped hole in the large end. Chamfering, facing, parting, drilling, and threading are required to complete the part.

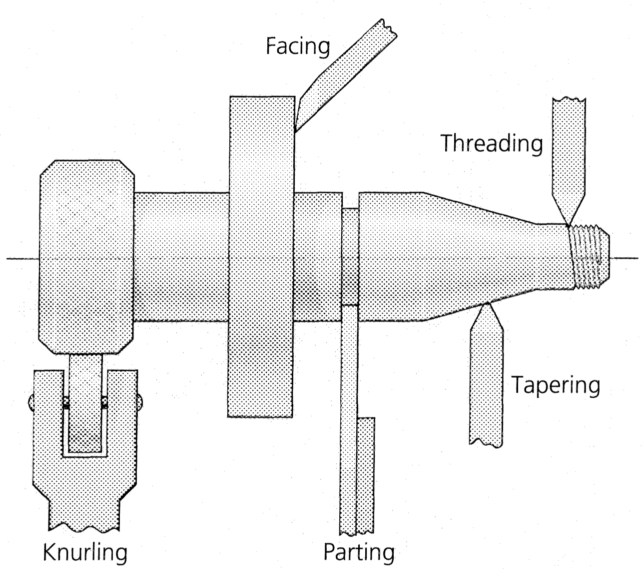


FIGURE 14.13 Lathe Processes

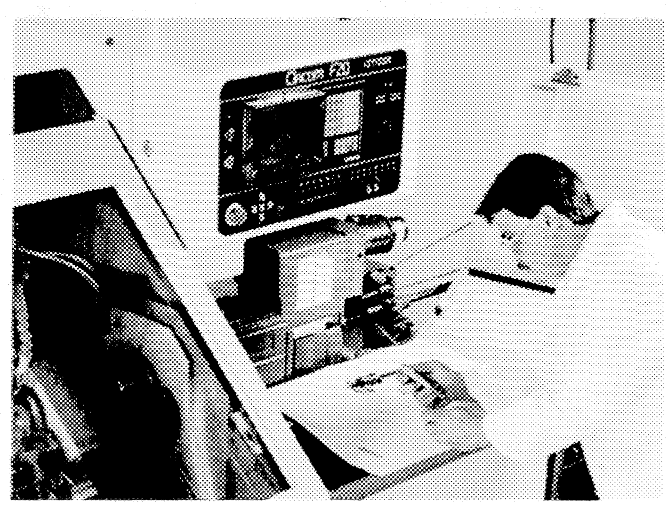


FIGURE 14.14 CNC Machine

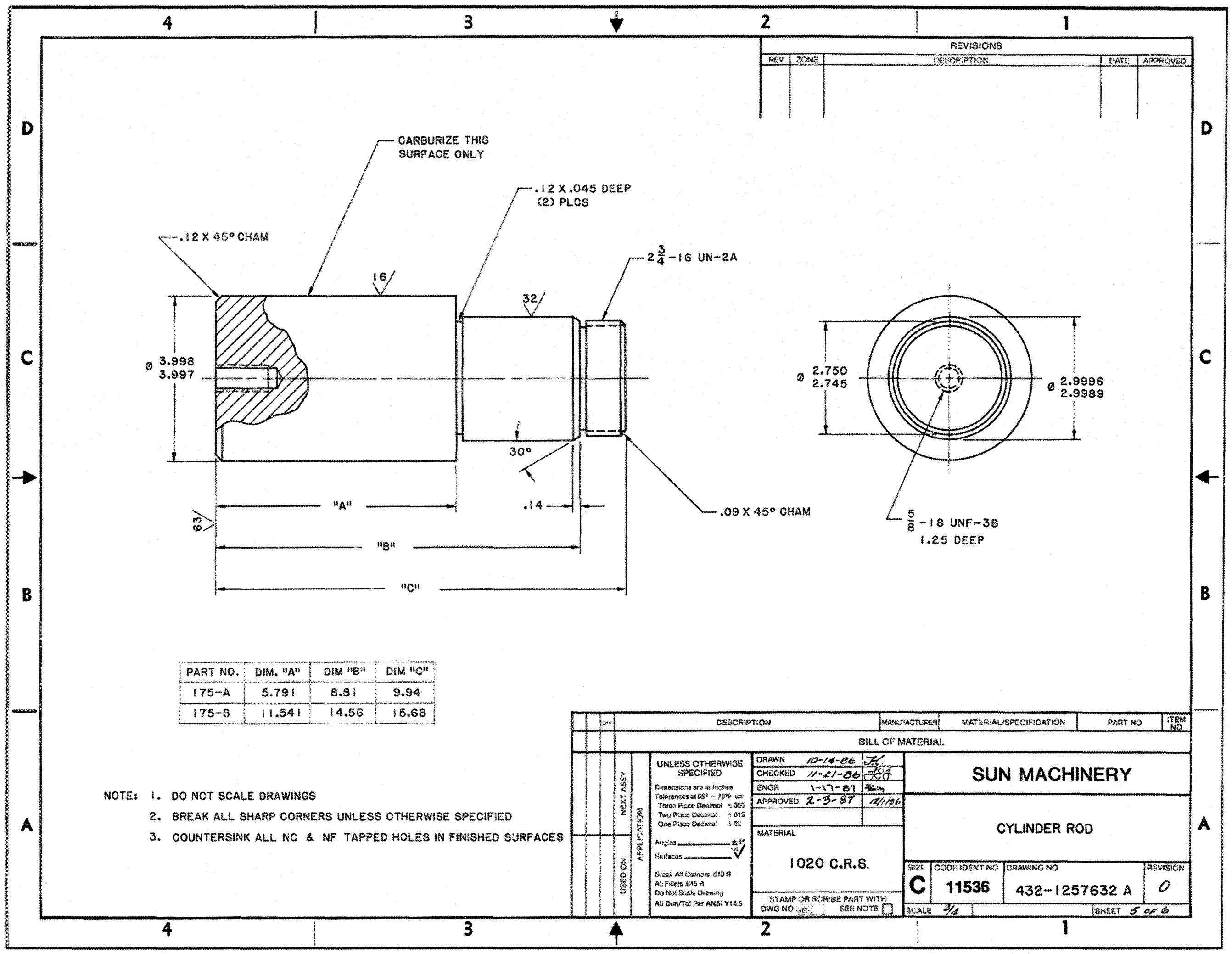


FIGURE 14.15 Cylinder Rod

14.3.11 Milling Machines and Milling Cutters

A **milling machine** is one of the most important and accurate machines in manufacturing. The typical milling machine has a table on which the part is securely fastened. Cutting is done by a rotary milling cutter with single or multiple cutting edges. One or more cutters are on each machine. Drilling, boring, reaming, slotting, facing, pocketing, and other types of cuts are made with this machine.

Milling machines are divided into two categories: vertical and horizontal. The classification depends on the orientation of the **spindle.** Figure 14.16 shows a vertical milling machine. The table is a flat surface with a variety of tee slots to insert clamping mechanisms that hold the part in place. Milling machines can also cut irregular surfaces, gears, slots, and keyways. Figure 14.17 shows a horizontal-spindle milling machine. This is also referred to as a **slitting saw.** Cutters are held in place by **collet adapters, arbors,** and quick-change **holders.**

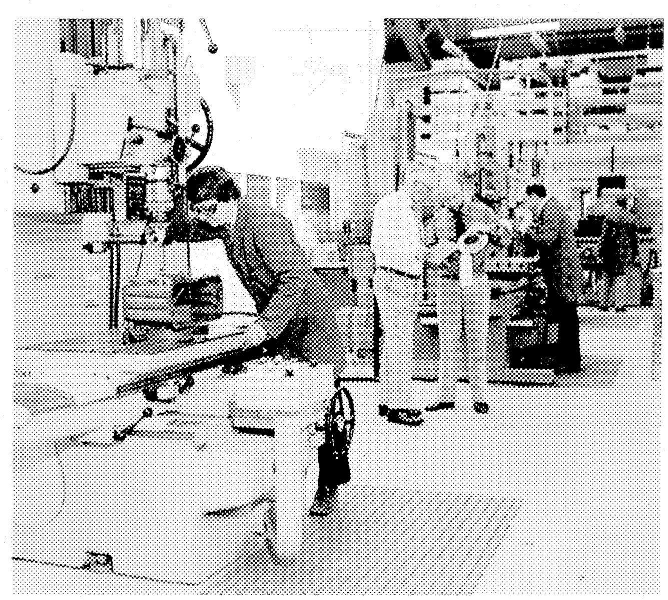


FIGURE 14.16 Vertical Mill

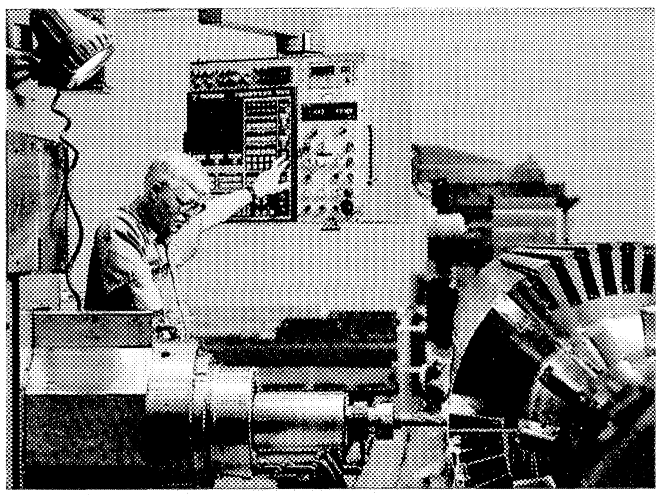


FIGURE 14.17 Horizontal Mill

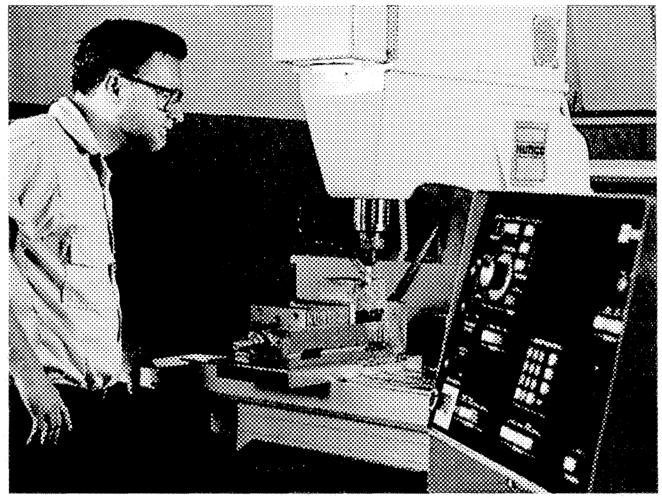


FIGURE 14.18 Part Being Machined on a Vertical Mill

Cutters fall into four basic categories:

- End mills
- Shell mills
- Face mills
- Plane milling cutters, including side mills

End mills are versatile cutters used for many types of machining work, especially where close tolerances must be maintained. An end mill is shown milling parts in Figure 14.18. End mills are also employed for pocketing parts. **Shell mills** are intended for simple facing or cutting steps that can't be done by a face mill. **Face mills** are used for facing flat surfaces and are found primarily on horizontal milling machines. Face mills either come with inserted teeth or are slab types.

14.3.12 Grinding

Grinding is also a cutting process except that the cutters are grinding wheels made from irregular-shaped abrasive grit. This abrasive grit cuts or grinds a part. The basic purpose of a grinding wheel is to provide a fine-finished surface and to maintain accurate size control.

Edges and corners can be removed from a part with stones and sandpaper or hand grinders. As an example, the note on the pull link detail in Figure 14.19 requires that the

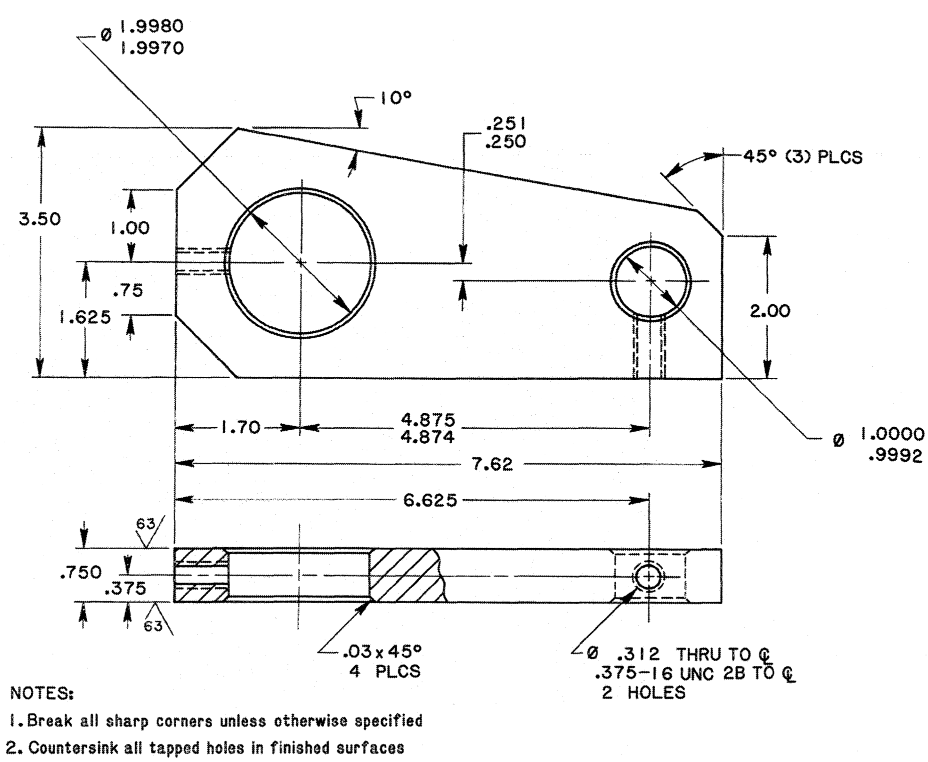


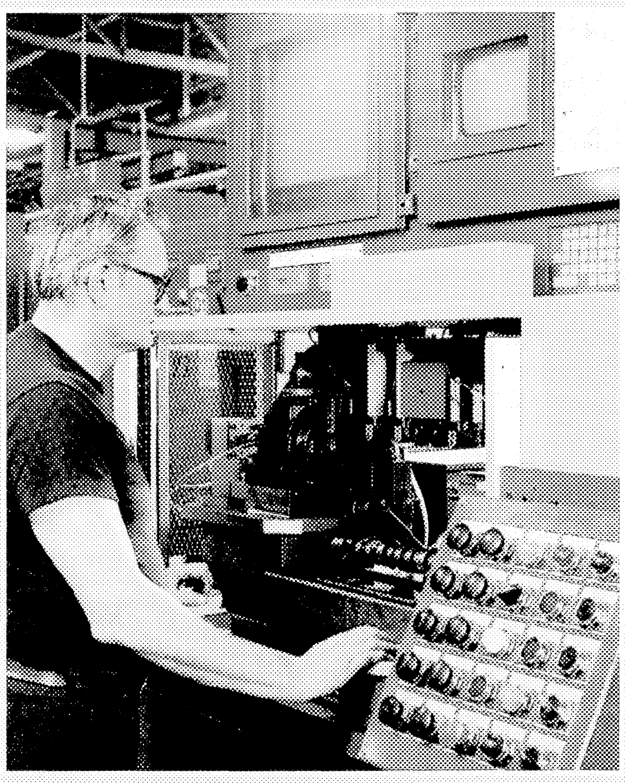
FIGURE 14.19 Pull Link Detail

Focus On . . .

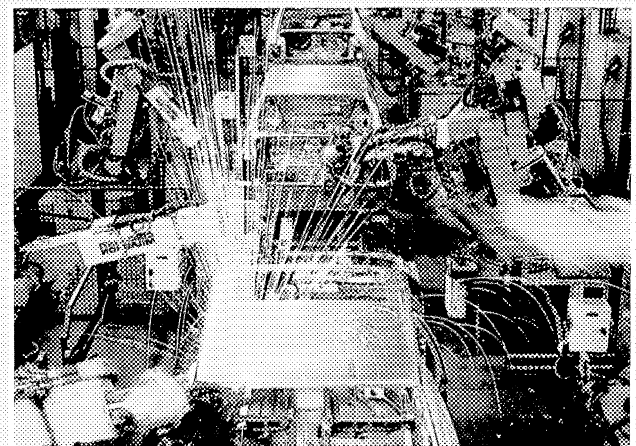
COMPUTERS IN MANUFACTURING

Computer numerically controlled (CNC) machines have transformed manufacturing methods and techniques during the past twenty years. Today, they are integral parts of flexible manufacturing systems (FMS) that can machine one part, a thousand parts, or several different kinds of parts. Changes to the computer program controlling the system modify what part the system machines by redefining the sequence of events needed to complete the machining steps.

Numerical control (NC) began in 1947 with John Parsons' experiments on producing aircraft components with three-axis curvature data to control machine tools. The U.S. Air Force awarded Parsons a contract in 1949 to build the first NC machine. The Massachusetts Institute of Technology took over the development contract in 1951 and produced the first machine in 1952. Refined industrial machines followed in 1955.



Flexible manufacturing system (FMS).



Coordinate measuring machine (CMM).

Early NC machines used either punched tape or punched cards to send commands to the machine. Most machines used punched tape and tape readers. The tape was fragile and broke easily in industrial settings, and if 1000 parts were to be made, the reader read the tape 1000 times. Because of the need to make NC more efficient, computer control was developed. The part programmer employs English-like commands to write the program, and the computer translates the commands into machine code.

Distributed numerical control (DNC) allows control of a system of CNC machines via a networked computer. By planning a network of computer control effectively, it is possible to control an entire factory. FMS systems are networked into the computer control scheme.

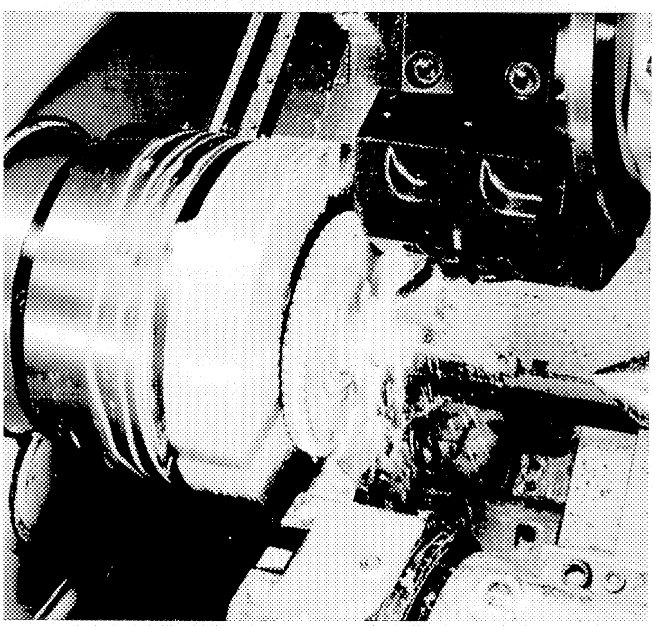
Numerical control was developed to increase productivity, increase quality, increase accuracy, reduce labor costs, and do jobs that were considered impossible or impractical. CNC machines require a large initial investment and have higher per-hour operating costs than traditional machines tools, but the other advantages outweigh these disadvantages.

NC, CNC, and DNC machines will play increasingly important roles in automated and flexible manufacturing in the future. Today, stand-alone or networked CNC machines are found widely in both large and small production shops. Because of the great advances in and great advantages of this technology, the "factory of the future" will rely on these machines to be the backbone of the machining processes.

machinist **Break all sharp corners unless otherwise specified.**

Grinding machines are divided into surface types: cylindrical, internal, and centerless. Vertical-spindle surface grinders machine flat surfaces. Single-purpose abrasive machines, such as abrasive cutoff machines and snagging grinders, are common. Figure 14.20 shows a pedestal grinder. Figure 14.21 shows CNC OD and ID grinding equipment. This system monitors the diameter being ground as linear probes maintain accurate linear dimensions.

FIGURE 14.20 Pedestal Grinder



IGURE 14.21 CNC OD and ID Grinding Equipment

14.3.13 Saws

lany types of **sawing machines** are found on the shop loor. The power saw is a band-saw cutoff machine with a ontinuous band-saw blade. This type of saw can cut bar tock to length. On thin material, it can also cut irregular hapes, make beveled cuts on tubing or solid stock, or make lots or slits.

.4.3.14 Shapers and Planers

hapers and **planers** are limited to straight-line cuts. A naper can handle relatively small parts; a planer is for parts veighing up to several thousand pounds. Planers and

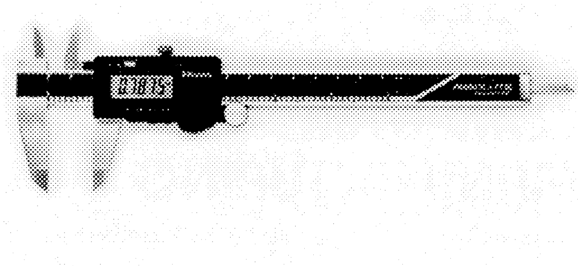


FIGURE 14.22 Digital Vernier Calipers

shapers make facing cuts (both top and side), slotting, step cuts, and dovetails (both male and female). Both machines are capable of creating finished surfaces. Multiple pieces can be machined at the same time with a planer. The planer can machine large iron castings or steel weldments that weigh hundreds of pounds. Shapers come in both horizontal and vertical types. Vertical shapers are sometimes called **slotters.**

14.3.15 Hand-Held Measuring Devices

A variety of measuring tools are used in manufacturing, including the **pocket steel ruler,** inside and outside **calipers,** micrometers, and vernier or dial calipers. **Vernier calipers** (Fig. 14.22) measure both the inside and the outside of a part. They have a beam or bar marked in inches and hundredths or in centimeters and millimeters.

The **micrometer,** also referred to as the micrometer caliper, is available in inside and outside versions. The micrometer is the most accurate of the precision hand-held measuring instruments. Digital versions of vernier calipers (Fig. 14.22) and micrometers are available in a variety of sizes.

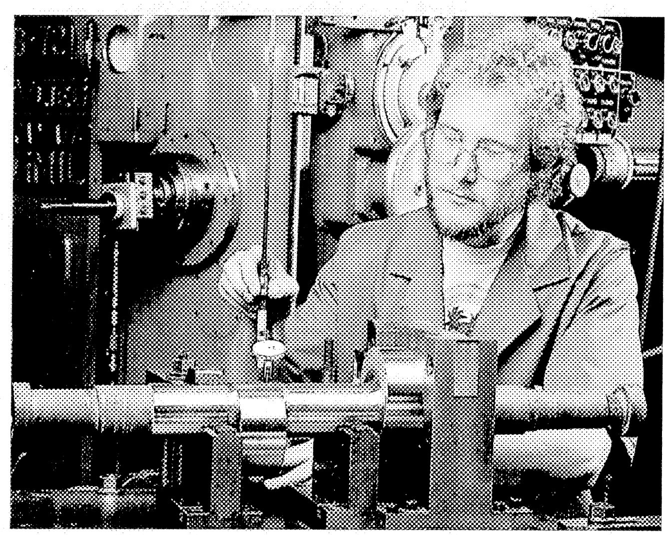


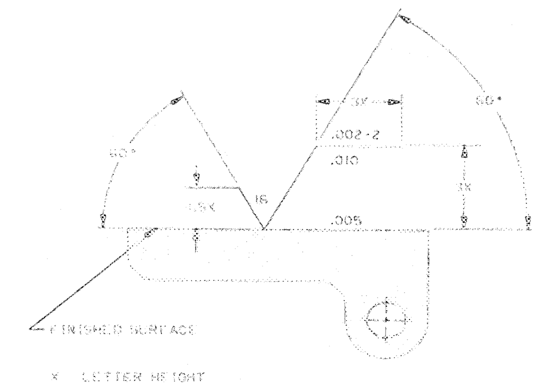
FIGURE 14.23 Measuring a Part

14.4 SURFACE TEXTURE SPECIFICATION

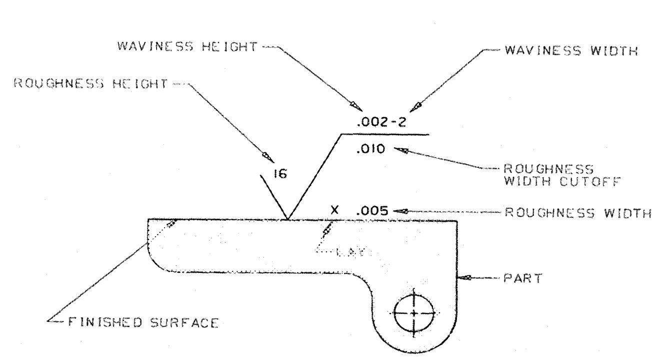
A variety of standards have been developed by the American National Standards Institute (ANSI) and American Society of Mechanical Engineers (ASME) for specifying **surface textures.** The **surface roughness measurement** is important in machining. The finer the finish, the more expensive the machine process required. Processes such as milling, shaping, and turning can produce precise surface textures ranging from 125 to 32 μin. Only a lathe can produce 8 μin. on a production basis. Grinding operations produce surface textures ranging from 64 to 4 μin. The Greek letter μ (microinch, μin; micrometer, μm) is used on the drawing.

Surface texture is specified as part of the design specifications. The surface texture value is used along with the **surface texture symbol** [Fig. 14.24(a)]. The surface texture symbol designates the waviness, lay, and classification of roughness. **Roughness** is the irregularity on the surface of the part. It is *not* the distance between the peaks and valleys of the roughness, but the average amount of irregularity above and below an assumed centerline. **Waviness** is the irregularity from the centerline. The **waviness height** is the peak-to-valley height of the roughness.

Roughness is caused by the machining action during the production process. The roughness height is designated above the **V** portion of the surface texture symbol [Fig. 14.24(b)]. The symbol is constructed with the measure-



(a) Surface texture symbol specification



(b) Surface texture symbol description

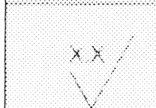
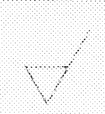
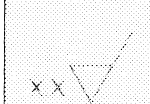
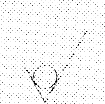
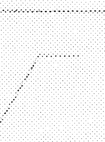
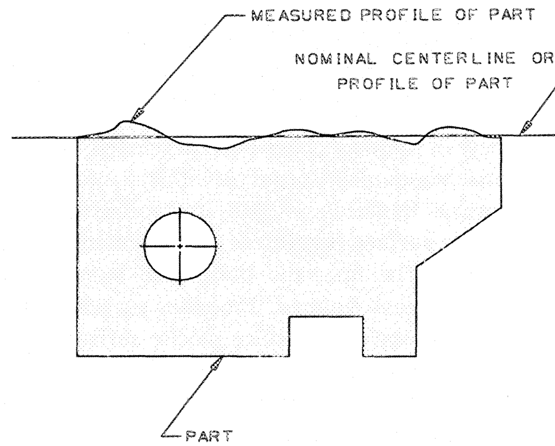
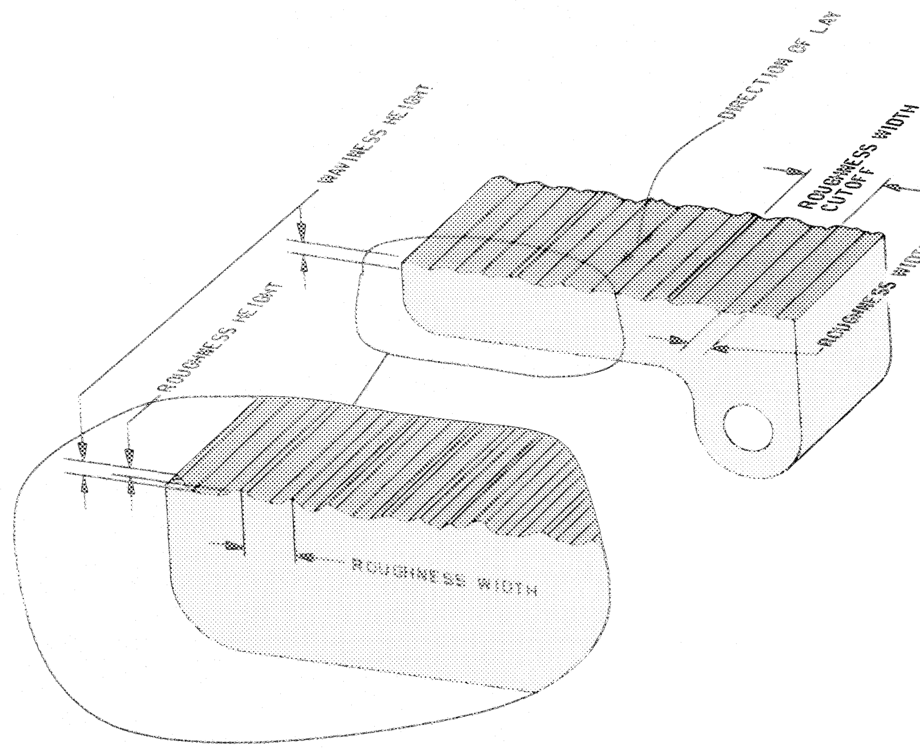
Symbol	Purpose	Intent
	Basic symbol: roughness average specified	Where roughness height only is indicated, the surface maybe produced by any method.
	Removal of material required to produce part	Material removal by machining is required. The horizontal bar indicates that the material removal is required to produce the surface, and material must be provided for that purpose.
	Removal of material required to achieve surface	Material removal allowance. The number indicates the amount of stock to be removed by machining (mm or inches). Tolerances may be added to the basic value shown or by note.
	No material removal permitted	Material removal prohibited. The circle indicates that the surface must be produced by processes such as casting, forging, hot or cold finishing, etc. without subsequent material removal.
	Special surface characteristics indicated	Surface texture symbol. Used when any surface characteristics are specified above the horizontal line or to the right of the symbol. Surface may be produced by any method except when the bar or circle is specified.

FIGURE 14.24 Surface Texture (c) Surface texture symbol variations

FIGURE 14.25
Surface Texture Concepts



(a) Nominal center and measured profile of a part's surface



(b) Surface texture terminology

ments provided. Figure 14.24(b) defines each of the portions of this symbol and what they mean. *The symbol provides information on the waviness height, the waviness width, roughness height, and width.* The surface texture symbol variations are shown in Figure 14.24(c).

Figure 14.25(a) shows a part with an exaggerated measured profile. The **nominal centerline** or **profile of the part** helps establish the surface roughness deviation. A profilometer measures the **smoothness** of a surface texture roughness in microinches or micrometers. Surface texture is the deviation from the nominal center line or nominal surface that forms the pattern of the surface, and includes flaws, lay, waviness, and roughness. The direction of lay, roughness width, and roughness height are shown in Figure 14.25(b).

The centerline or nominal surface line [Fig. 14.25(a)] is a line about which the roughness is measured and is parallel to the direction to the profile, within the limits of the roughness width cutoff. The roughness consists of the finer irregularities in the surface texture, including those that result from action in the production process. These include transverse feed marks and other irregularities. **Roughness height** is an average deviation, expressed in microinches or micrometers, measured normal to the centerline. **Roughness width** is the distance parallel to the nominal surface between

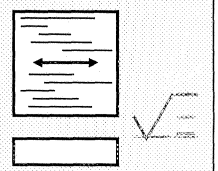
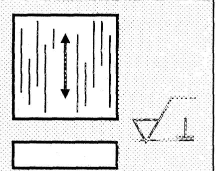
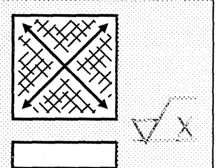
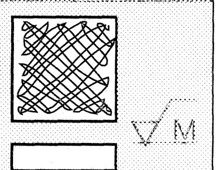
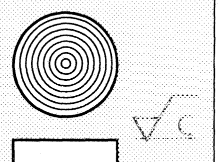
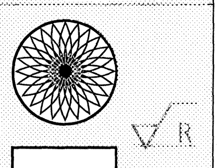
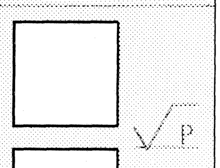
Lay symbol	Meaning	Direction of tool marks
=	Lay is parallel to the line that represents the surface to which the symbol is applied	
⊥	Lay is perpendicular to the line that represents the surface to which the symbol is applied	
X	Lay is angular in both directions to the line representing the surface to which the symbol is applied	
M	Lay is multidirectional	
C	Lay is circular relative to the center of the surface to which the symbol is applied	
R	Lay is radial relative to the center of the surface to which the symbol is applied	
P	Lay is nondirectional, or protuberant in nature	

FIGURE 14.26 Lay Symbols

successive peaks or ridges on the part. *Nominal surface* is the surface contour shape that is usually shown and dimensioned by the designer. The **roughness width cutoff** is the distance over the surface on which the roughness measurement is made.

Waviness is caused by vibration of the machine during the machining process, heat treatment, or other processes applied to the part. The **waviness width** is rated as a measurement of spacing of successive wave peaks or wave valleys. The **lay** is the direction of surface pattern. Lay symbols are shown in Figure 14.26. **Flaws** are the irregularities, including cracks, blowholes, checks, ridges, and scratches.

Figure 14.27(a) shows how to specify the removal of material via machining by varying the surface texture symbol: optional, required, prohibited, and removal allowance. The preferred series of roughness height values are shown in Figure 14.27(b); the surface roughness produced by common production methods is shown in Figure 14.27(c).

14.5 PRODUCTION PROCESSES

Production processes include casting, forging, bending, rolling, press work, injection molding, dies, EDM, ECM, blow molding, and variations of other hot and cold processes.

Designing for automated production helps ensure a more efficient and cost-effective production process. *Design for manufacturability* ensures that the right process is chosen, existing factory resources are utilized, setup times are minimized, and tolerances are specified correctly. These procedures reduce labor costs and break down barriers between different areas (islands) of information in the company.

14.5.1 Casting

Casting is the process of forming parts to approximate rough sizes by introducing liquid material into a formed cavity called a mold, allowing the material to solidify by cooling, then removing the mold, leaving the solid shaped part. Casting methods available include sand casting, mold casting, die casting (Fig. 14.28), and investment casting. **Molding** and **die casting** is similar to casting except that the material involved is not in liquid form but is softened to a plastic state and forced into the mold under high pressure.

Everyday items, from toys to electronic components, are cast. One common type of casting is **sand casting.** Figure 14.29 shows a sand-cast part before machining. Casting is divided into two basic processes, **gravity** and **pressure.** Sand-casting molds are formed by patterns. **Patterns** look like the cast part and are used to create a shape in the mold cavity. The wood pattern in Figure 14.30(a) is inserted into sand to create the proper configuration of the part (front). Figure 14.30(b) shows another example of a wood pattern. Here, the pattern is designed to shape six identical parts.

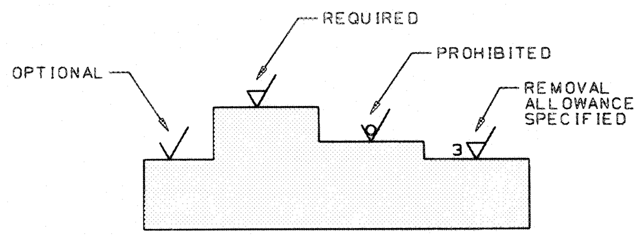
A designer prepares a combination casting and machining drawing. Some companies require separate drawings, however. The **casting detail** (Fig. 14.31) is used by the pattern maker, and the **machining drawing** is used by the machinist. The notes establish the heat treatment requirements and the size of the fillets and rounds. The **draft angle** is the angle of the **taper** of the part that makes it easier to withdraw the pattern from the mold. After the material hardens, the sand is removed from the casting (destroying the mold). In Figure 14.31 the draft angle is specified as 3° maximum per side.

Tooling points on three **datum planes** (that are perpendicular to one another) locate dimensions on the casting. 'he planes are established by the tooling points on the asting.

Since it is not possible to cast sharp corners and angles ccurately, the internal angles on a casting are filled with a naterial to eliminate sharp corners. Contoured surfaces that ill the sharp inside corners are **fillets** (Fig. 14.32). **Rounds** re the exterior corners that have been smoothed out to emove their sharp edges. In Figure 14.31, the notes state hat fillets are to be R .25 maximum and rounds R .12 naximum.

Aluminum, magnesium, zinc, copper, bronze, brass, iron, nd steel are all used to make castings. Designing a casting equires an understanding of how much the material will hrink during the cooling process. The dimensions shown on the casting drawing must reflect the **shrinkage allowance.**

Centrifugal casting involves feeding the molten material into a rotating mold. The rotation forces the molten material



(a) Surface texture symbols

Roughness height rating		Surface description	Process
Micrometers	Microinches		
25.2	1000	Very rough	Saw and torch cutting, forging or sand casting.
12.5	500	Rough machining	Heavy cuts and coarse feeds in turning, milling and boring
6.3	250	Course	Very course surface grind, rapid feeds in turning, planning, milling, boring and filing.
3.2	125	Medium	Machine operations with sharp tools, high speeds, fine feeds and light cuts.
1.6	63	Good machine finish	Sharp tools, high speeds, extra fine feeds and cuts.
0.8	32	High grade machine finish	Extremely fine feeds and cuts on lathe, mill and shapers required. Easily produced by centerless, cylindrical and surface grinding.
0.4	16	High quality machine finish	Very smooth reaming or fine cylindrical or surface grinding, or course hone or lapping of surface.
0.2	8	Very fine machine finish	Fine honing and lapping of surface.
0.05 0.1	2-4	Extremely smooth machine finish	Extra fine honing and lapping of surface.

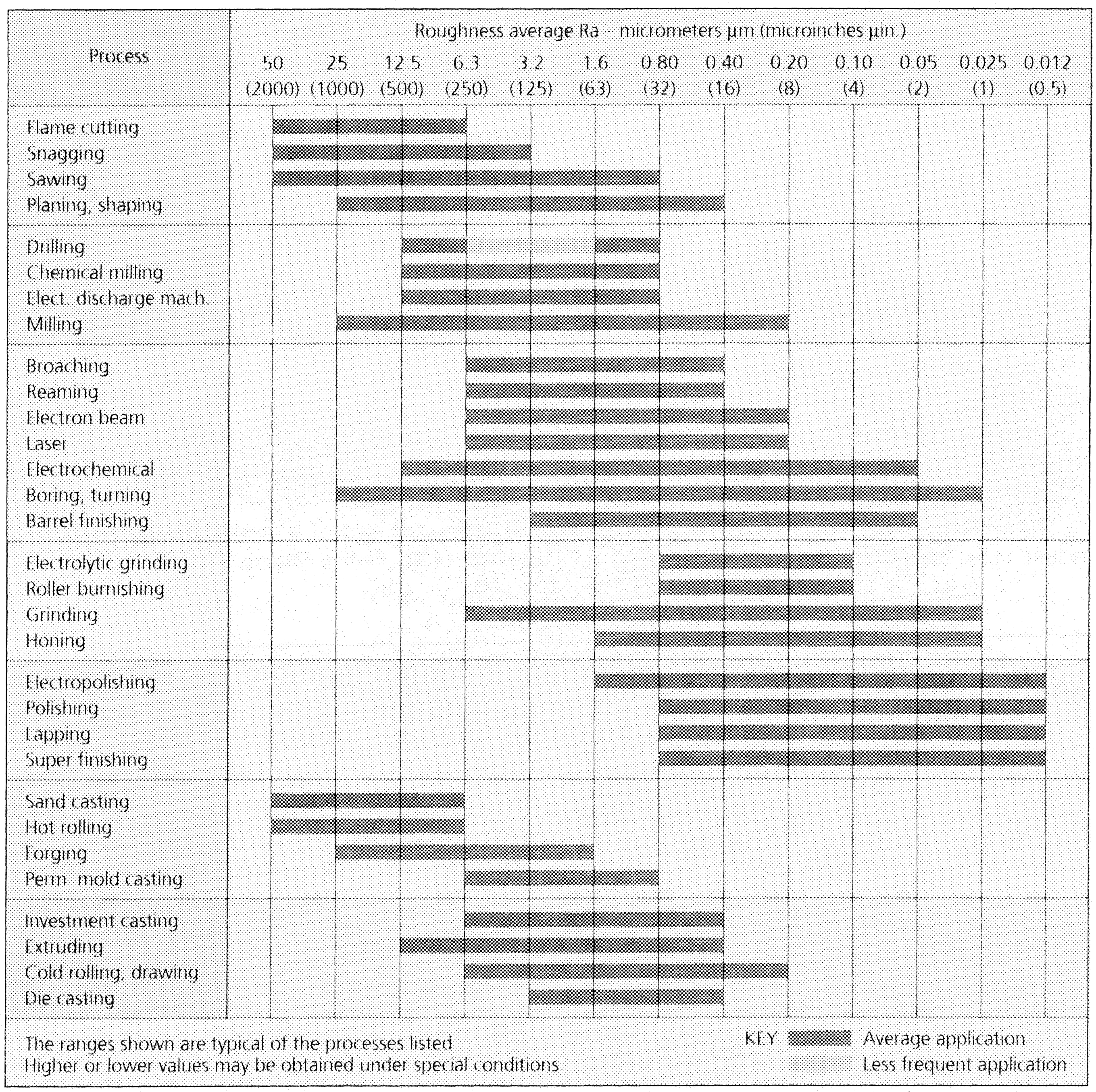
GURE 14.27 **Surface Texture** (b) Description of roughness height values on symbols

to fill the cavity or mold. Permanent molds are used for this process. **Die casting** is a permanent mold process that uses pressure to force the molten material into a metal die. **Injection molding** is also a type of permanent mold casting. Figure 14.33 shows an injection-molded part before and after machining. Injection molds are very similar to die-casting molds. There are many other types of molding processes, including blow molding, compression molding, transfer molding, layup molding, pressure molding, and vacuum molding.

14.5.2 Extruding

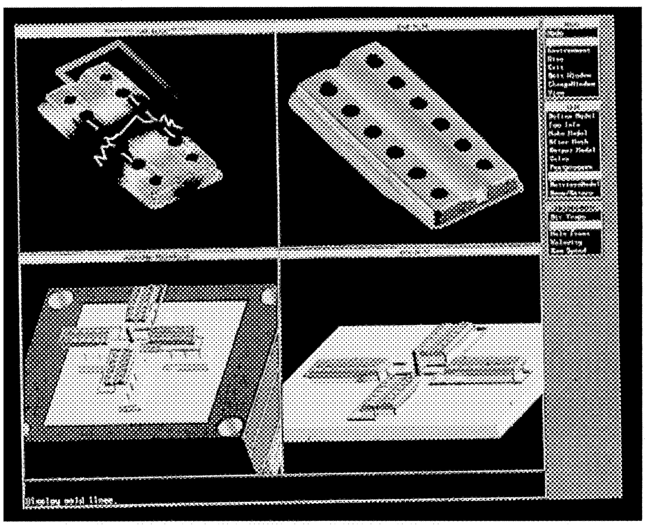
Materials-forming processes employ pressure to change the shape or the size of the material. This category of processes includes extruding, forging, stamping, punching, rolling, bending, and shearing.

Extrusion is a metal-working process for producing long, straight, semifinished products having constant cross sections (Fig. 14.34), such as bars, tubes, solid and hollow sections, wire, and strips. The metal is squeezed from a

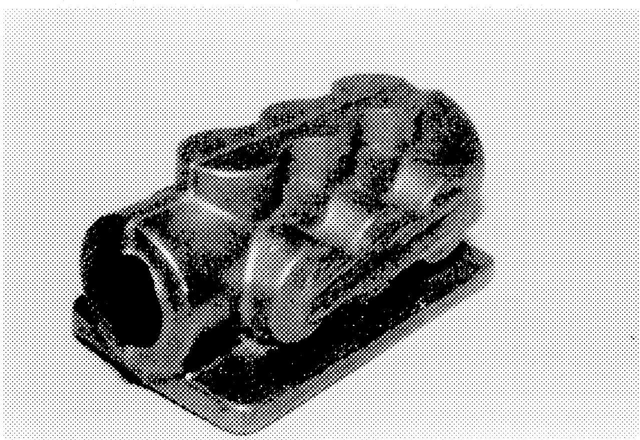


(c) Surface roughness produced by common production methods

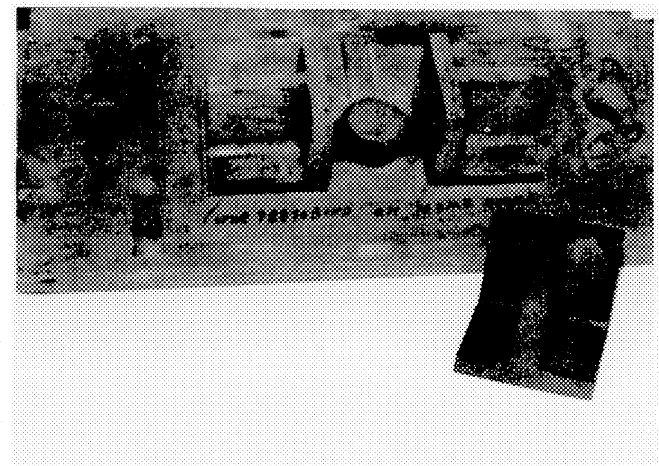
FIGURE 14.27 **Surface Texture—*Continued***



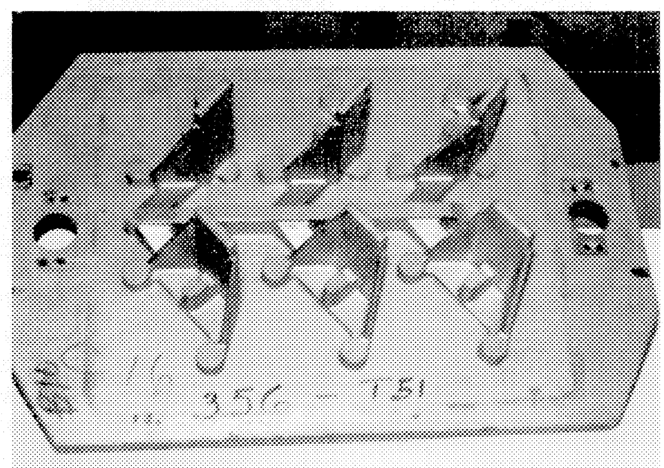
'IGURE 14.28 Die Casting



IGURE 14.29 Sand-Cast Part Before Machining



(a) Wood pattern and cast part



(b) Wood pattern designed for casting multiple parts

FIGURE 14.30 Casting Patterns

losed container through a die. **Cold extrusion,** also called **npact forming** or **cold forming,** is similar to cold forging see next section).

Hot extrusion is a way to make long and irregular-haped parts. The billets and slugs are heated above their ritical temperature, placed on a press, and squeezed rough a die into the required shape. Figure 14.34(a) shows luminum extrusions designed to fit together in an inter-ocking assembly [Fig. 14.34(b)].

4.5.3 Forging

orging utilizes impact and pressure to form parts. Types nclude smith forging, upset forging, and drop forging. A orging is a metal part shaped to its desired form by ammering, pressing, or upsetting. The metal is usually eated to an elevated temperature. Forging without heat is nown as **cold forging.** A forging drawing is shown in igure 14.35.

In **drop forging,** the hot metal is forced into dies by means of drop hammers. The material itself is very hot, but not molten, and is forced into the die by pounding. This pounding force pushes the metal into the shape of the cavity of the die, but does not create a very accurate part. Tolerances are large for this process, and the dies are expensive; however, forging produces stronger parts than many manufacturing processes. Low-carbon and low-alloy steels and aluminum alloys are the most common materials.

14.5.4 Stamping

In **stamping,** a punch and a die are used to cut or form sheet material. The assembled tool is called a die, as is the cutting part of the tool. **Progressive dies** require that several operations take place in sequential order. Stamping includes cutting, parting, blanking, punching, piercing, perforating, trimming, slitting, shaving, forming, bending, coining, embossing, and drawing.

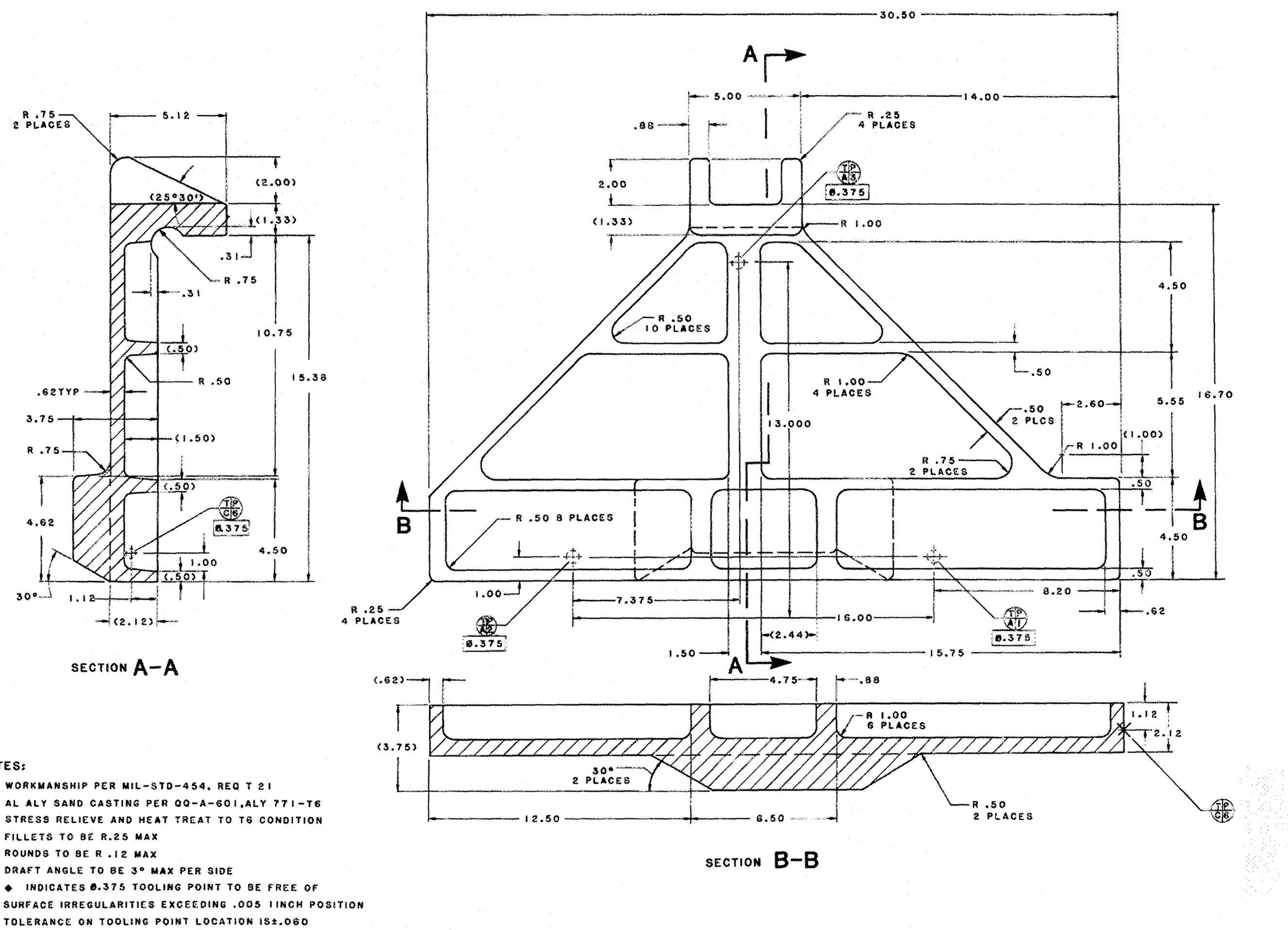


FIGURE 14.31 Casting Detail for Adapter

The part in Figure 14.36 was made by a progressive stamp that uses dies to cut or form the metal sheets into the desired form. Dies are assemblies that include a housing and the cutter.

14.5.5 Punching

Punching operations include shearing, cutting off, and blanking. **Shearing** is done along a straight line on a part. **Cutting** is performed on a part so as to produce an edge other than a straight edge. **Blanking** produces parts with a

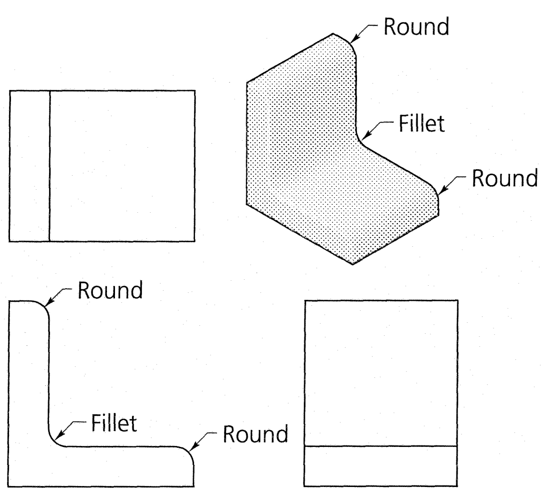


FIGURE 14.32 Fillets and Rounds

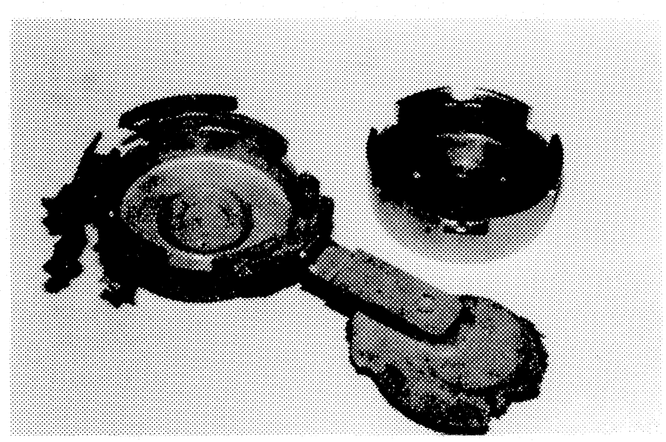
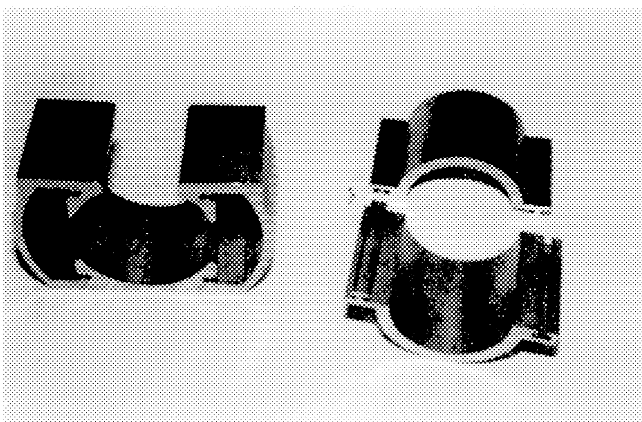
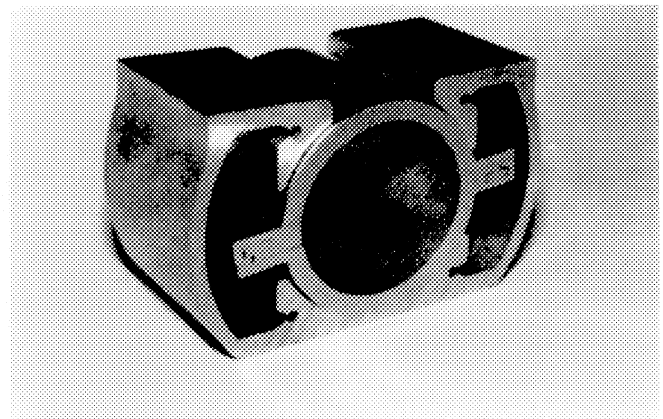


FIGURE 14.33 Injection Mold and Part



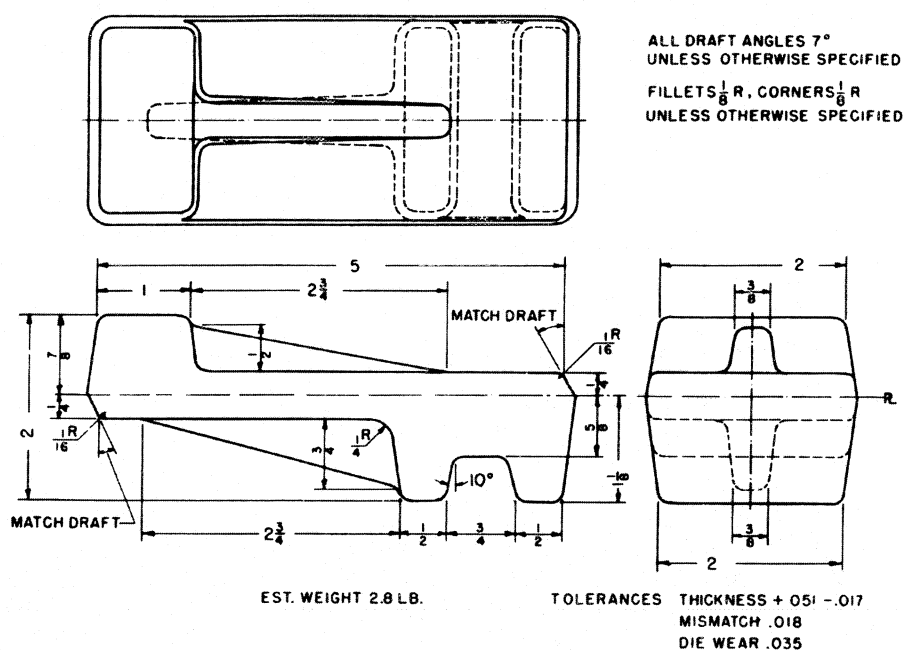
a) Extruded shapes

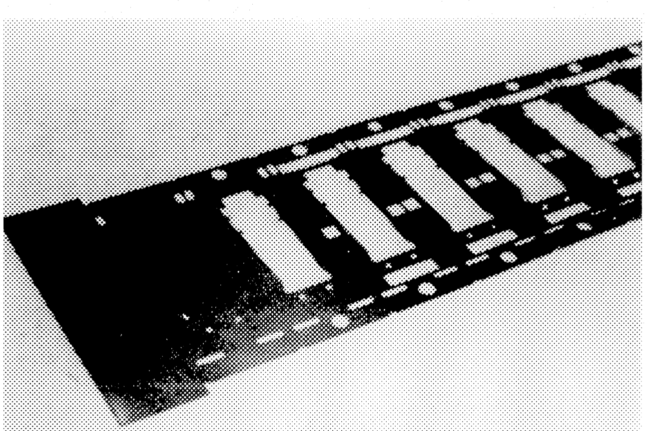


(b) Assembled extrusions

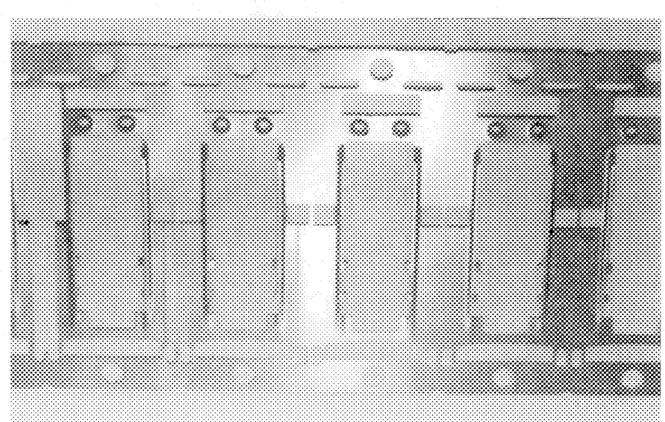
IGURE 14.34 Extrusions

IGURE 14.35 Forging Drawing





ı) Stamped part



(b) Progressive stamping

IGURE 14.36 Stamps

punch and a die. Holes are also produced in thin sheets of material by punching. **Piercing** is similar to punching, except that no scrap is produced. **Perforating** is a stamping operation performed on sheets to produce a hole pattern or decoration.

14.5.6 Electrical Discharge Machining and Electrochemical Machining (ECM)

Electrical discharge machining (EDM) is machining by removing small particles of metal via an electric spark. The material is vaporized by exposing the metal to sparks from a shaped electrode. The electrical discharge machine is a vertical-spindle milling machine with a rectangular tank on the worktable. The table can be moved along the **X** and **Y** axes, or it can be numerically controlled. Originally, EDM was used as a rough method for removing metal. EDM has been refined to do precision work in the electronics, aerospace, and tool-making industries.

Electrochemical machining (ECM) has many of the same machining capabilities as EDM, but will machine a part much faster. ECM requires more electricity and is more expensive. This process uses electrolyte fluid and electric current to ionize and remove metal from the part.

14.6 HEAT TREATMENT

Heat treatment is the process of applying heat to a material to change the material's properties but not its shape or size (Fig. 14.37). Heat treatment can increase a part's strength and hardness, improve its ductility, change the grain size and chemical composition, and improve its machinability. Heat treatment also is used to relieve stresses, harden a part, and modify the electrical and magnetic properties of the material.

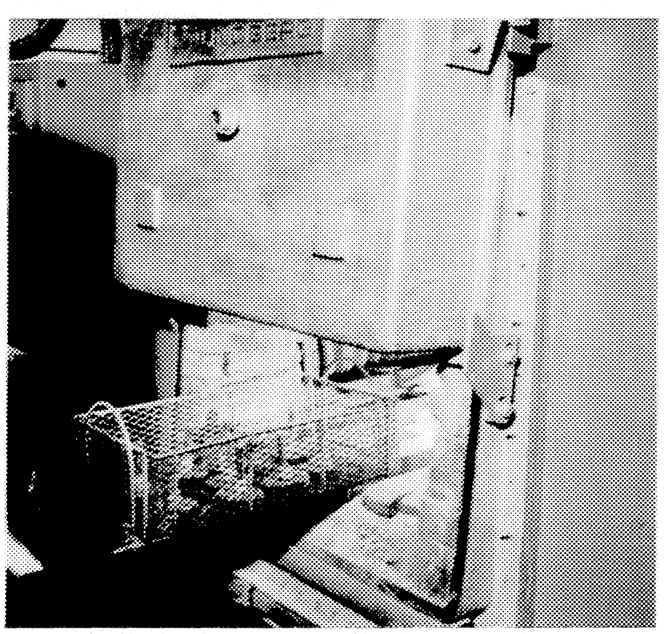


FIGURE 14.37 Heat Treatment of Gear Blanks

Heating metal to just above its upper critical temperature for a specified period of time followed by controlled slow cooling in the furnace is called **annealing.** This results in a fully softened, stress-free part. Heating the metal to just below the lower critical temperature and then cooling it by a predetermined method is called **process annealing.** Process annealing is often used on metals that have been work-hardened. Process annealing softens the metal for further cold work.

Heating metal to above its lower critical temperature and then **quenching** it in water, oil, or air is called **hardening.** The resulting hardness is tested with the Rockwell Hardness Test. The **Rockwell Hardness Number** refers to the hardness of the steel. Although there are many different hardness scales, for steel the higher the number the harder it is.

Tempering, also called **drawing,** involves reheating hardened steel to a predetermined temperature below its lower critical temperature and then cooling it at a specified rate. Tempering removes brittleness and toughens the steel (**tempered martensite**).

Heating steel to just below the upper critical temperature and then cooling the material in air is called **normalizing.** This improves the grain structure and removes the stresses. **Lower critical temperature** is the lowest temperature at which steel may be quenched to harden it. **Upper critical temperature** is the highest temperature at which steel can be quenched to attain the finest grain structure and the maximum hardness (martensite). In a drawing, heat treatment requirements are typically listed in notes or in the title block.

Heat treatment is normally applied after the part has been machined, welded, or forged. To avoid problems during machining and heat treatment, consider doing the following during the design stage: Balance the areas of mass, avoid sharp corners and internal recesses, and keep hubs of gears, pulleys, and cutters a consistent thickness.

14.7 AUTOMATED MANUFACTURING PROCESSES

Automated manufacturing techniques are used throughout industry. The role of CAM in a CAD/CAM environment includes helping firms achieve the benefits of **computer-integrated manufacturing (CIM)**. The CIM concept encompasses manufacturing and computer-based automation applications. CIM can be thought of as a system whose primary inputs are product requirements, and whose outputs are finished products. CIM comprises a combination of software and hardware for product design, for production planning/control, and for production processes.

CAD/CAM is the CIM integrator for computer-based

Applying Parametric Design . . .

PARAMETRIC MODELS AND MACHINING

Pro/MANUFACTURING (Fig. A) is a module for Pro/ENGINEER that provides the tools to simulate numerical control manufacturing processes. Information created can be updated quickly should the engineering design model change. Capabilities from Pro/MANUFACTURING include NC programs in the form of ASCII CL data files, tool lists, operation reports, and in-process geometry.

Pro/MANUFACTURING will create the data necessary to drive an NC machine tool to machine a part. It lets the manufacturing engineer follow a logical sequence of steps to progress into NC machine data.

The **design model** (Fig. B), representing the finished product, becomes the basis for all manufacturing operations (features, surfaces, and edges are selected on the design model as references for each manufacturing operation). Referencing the geometry of the design model sets up a parametric relationship between the design model and the workpiece. Because of this relationship, when the design model is changed, all associated manufacturing operations are updated to reflect the change. Multiple-part machining is possible through such capabilities as nesting the part in the workpiece (Fig. C).

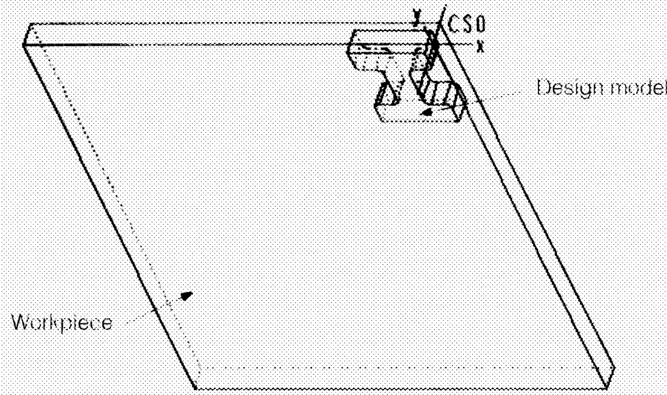


FIGURE B Design Model and Workpiece

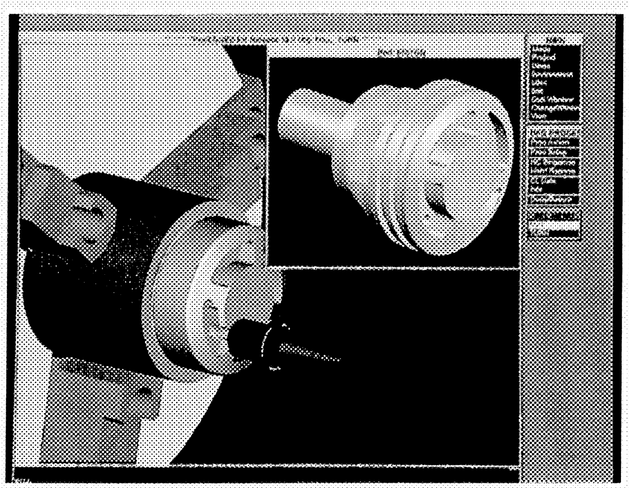


FIGURE A Pro/MANUFACTURING

The **workpiece** (Fig. D) represents the raw stock that is going to be machined by the manufacturing operations. It can be any form of raw stock: bar stock, casting, etc. It can easily be created by copying the design model and modifying the dimensions or deleting or suppressing features to represent the real workpiece.

A regular **manufacturing model** consists of a design model (also called *reference part*, since it is a reference for creating NC sequences) and a workpiece assembled together. As the manufacturing process is developed, the material removal simulation can be performed on the workpiece (Fig. E). Generally, at the end of the manufacturing process the workpiece geometry should be coincident with the geometry of the design model. However, material removal is an optional step. The Pro/MANUFACTURING process consists of the following steps.

1. Set Up the Process Environment.

The setup may contain the following components:

- Operation name
- Workcell (machine tool)

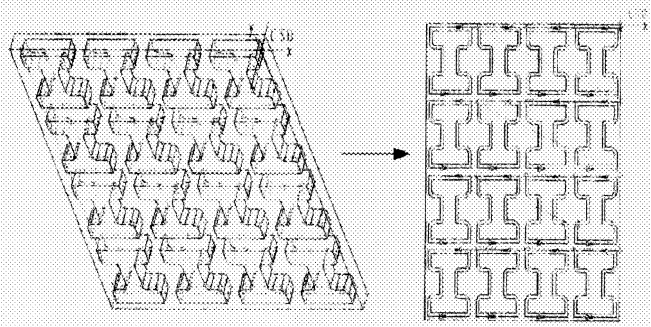


FIGURE C Nesting the Design Model in the Workpiece of Multiple-Part Machining

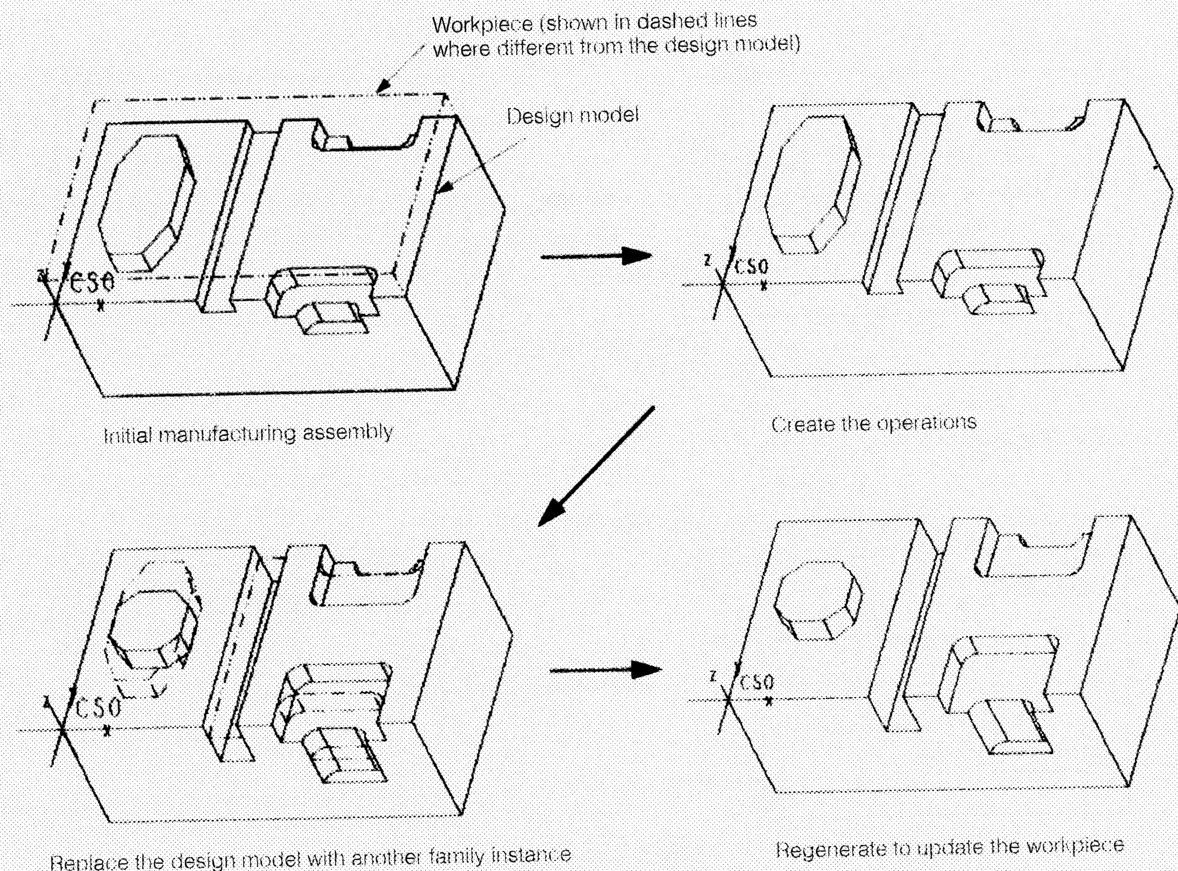


FIGURE D **Workpiece and Manufacturing Assembly**

- Fixture configuration
- Site parameters
- Tool to be used
- Coordinate system for CL output
- Retract plan, if applicable, i.e., the plane to which the tool is retracted after a cut

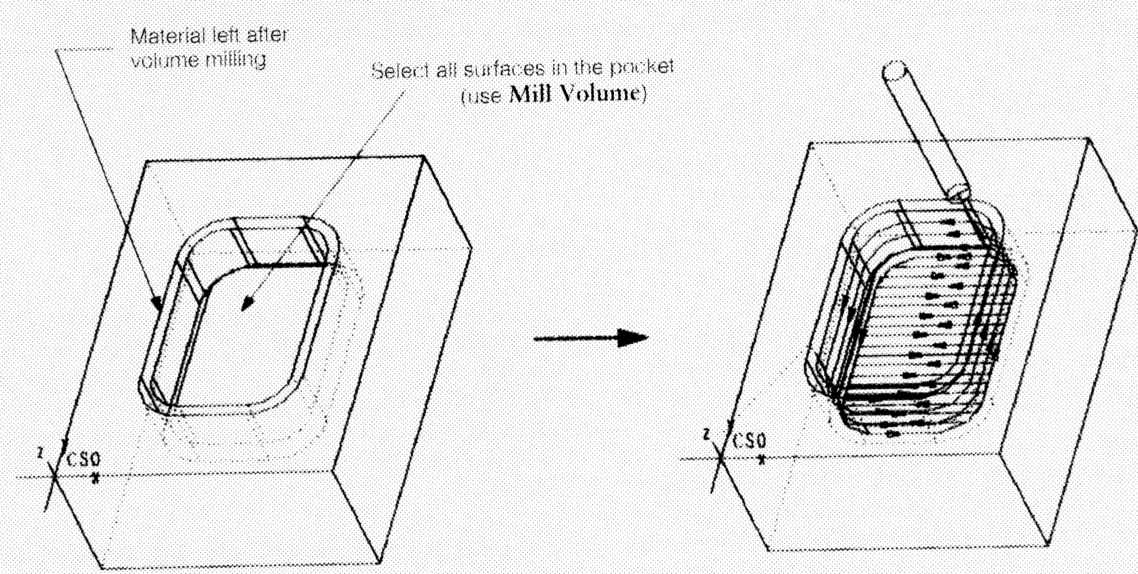


FIGURE E **Volume Milling, Material Removal, and Cutter Path Generation**

(Continued)

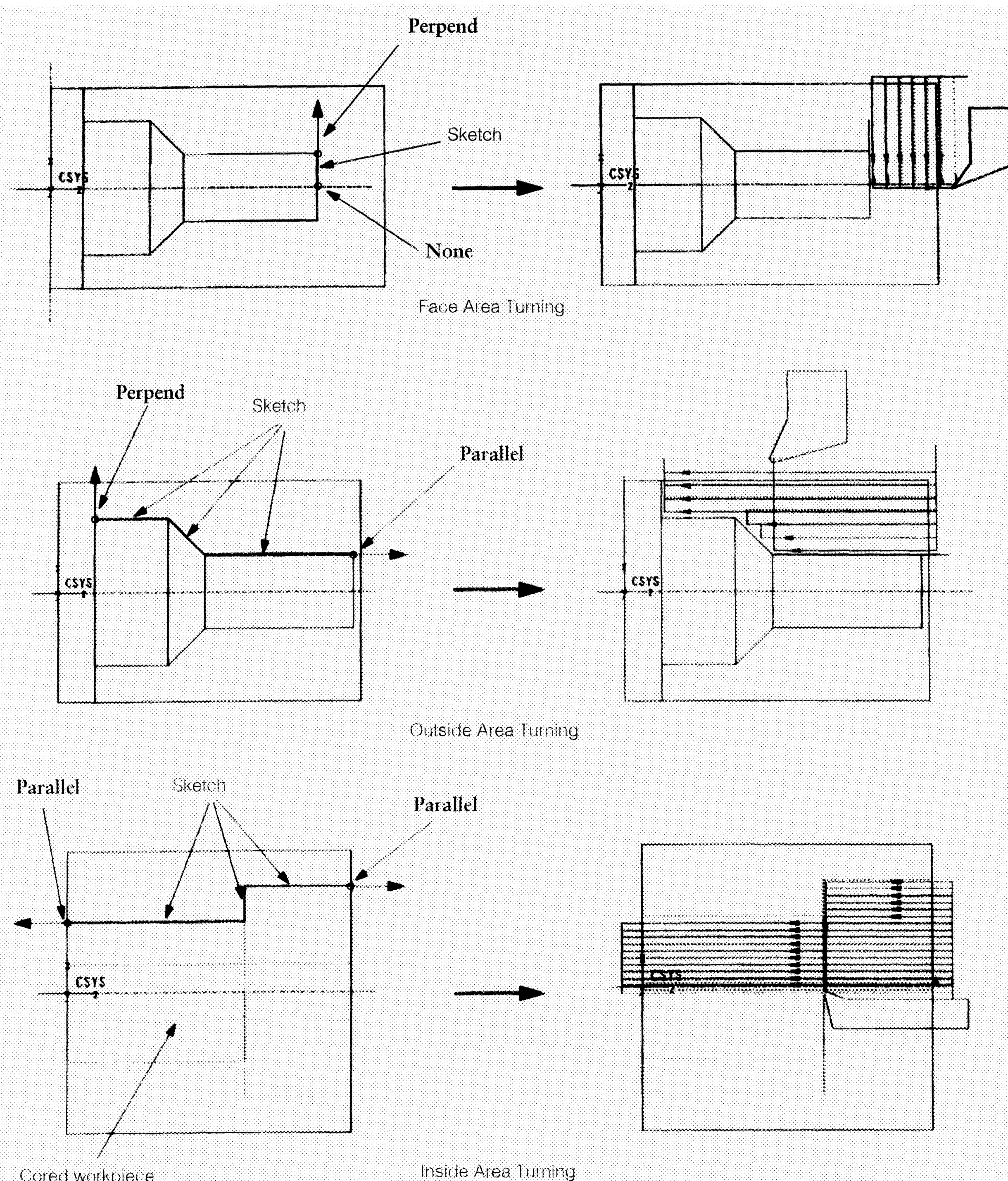


FIGURE F Turning Operations

You have to define an operation name and a workcell before you can start creating NC sequences. Other setup components are either optional or can be specified when creating the NC sequence.

A **workcell** is a workpiece (or assembly) feature that specifies a machine tool via its name, type, set of parameters, and associated tools. The workcell type determines the types of NC sequences that can be created with it [four-axis lathe allows you to perform two- and four-axis turning (Fig. F) and hole making].

Fixtures are parts or assemblies that help orient and hold the workpiece during a manufacturing operation. They can be created and saved in Part or Assembly mode, and retrieved into the Manufacturing mode during fixture setup. Creating the fixture in Assembly mode is advantageous, since fixtures can be created as needed during the intermediate process steps by referencing the workpiece.

2. Create NC Sequences Under the Specified Setup. Each NC sequence is a series of tool motions with the addition of specific postprocessor words that are not motion-related but

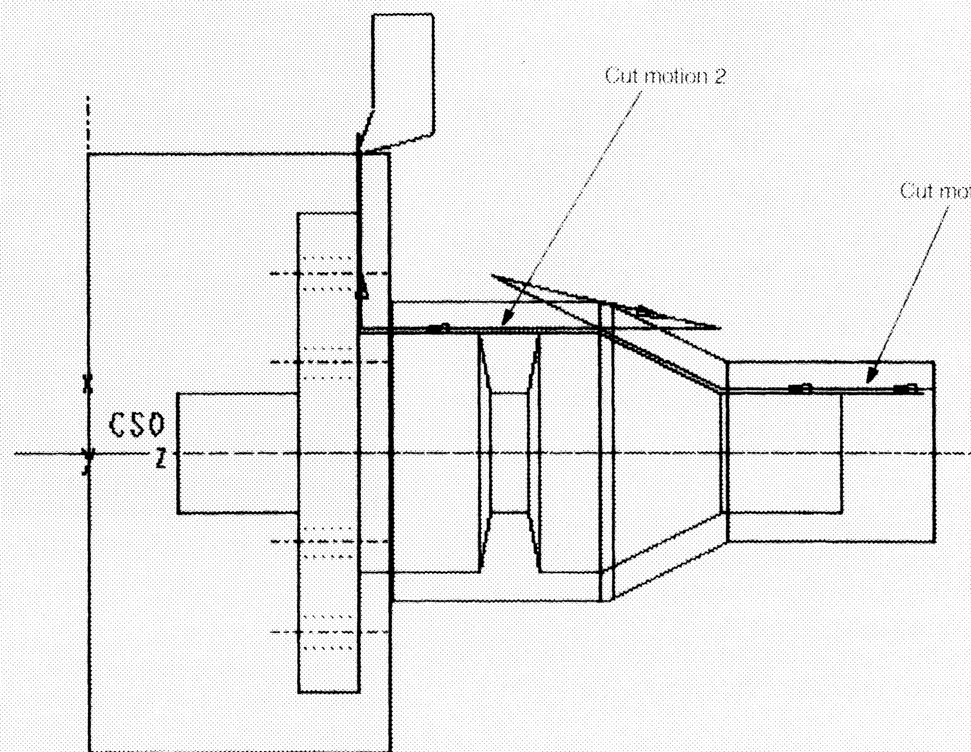


FIGURE G Cut Motions

are required for the correct NC output. **Tool motions** are generated automatically by the system, based on the NC sequence type (e.g., volume milling, outside turning), cut geometry, and manufacturing parameters (Fig. G).

For each completed NC sequence, you can create a material removal feature, either by making the system remove material automatically (where applicable) or by manually constructing a regular feature on the workpiece (slot, hole, etc.).

The **interactive path control** controls the motion of the tool when creating or redefining NC sequences (Fig. H). You can use it if you are not satisfied with the tool path generated automatically by the system. Pro/MANUFACTURING provides two forms of interactive path control:

Cut Motion—Generate the cut motions, i.e., the path followed by the tool while actually cutting work material

Build Path—Finalize the tool path by specifying which cut motions to follow, defining approach and exit motions, and inserting CL commands

Cut motions depend on the type of the NC sequence. Generally, cut motions are generated automatically by the system, based on the cut geometry and the manufacturing parameters. The **Cut Motion** option in the NC SEQUENCE menu provides low-level control over cut motions.

For most NC sequences, you can either accept the cut motions generated automatically by the system or generate your own. For trajectory milling, profile turning (see Fig. H), and 2D contouring (wire EDM, laser, etc.), you have to apply interactive cut motion control. Automatic cut motions are described in appropriate NC sequence sections.

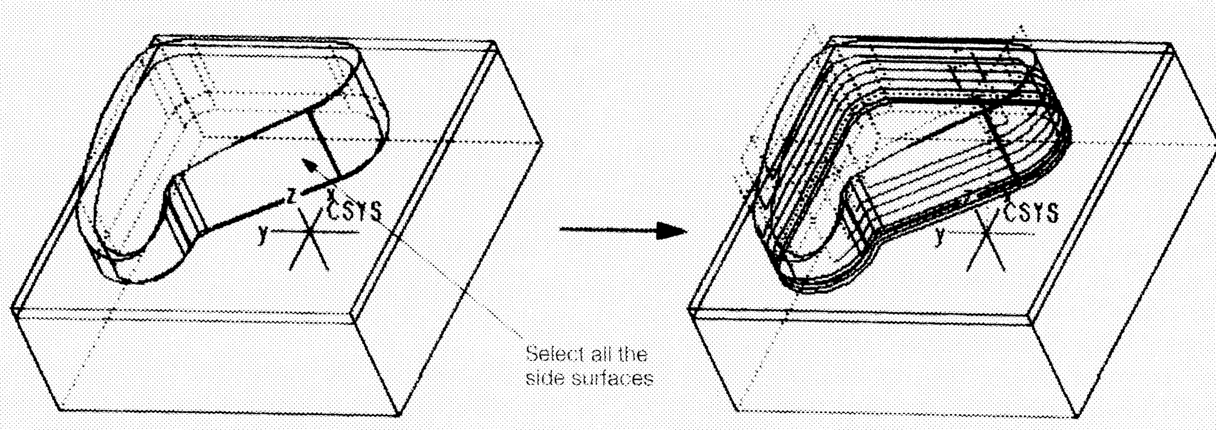


FIGURE H Profile Cutting and Path Generation

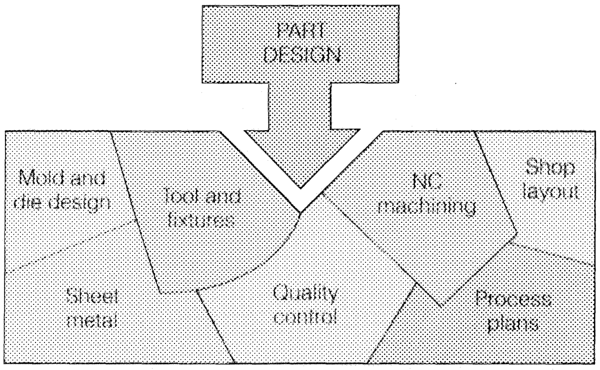


FIGURE 14.38 Part Design. The part database created during the design phase is used by all groups associated with the manufacturing process.

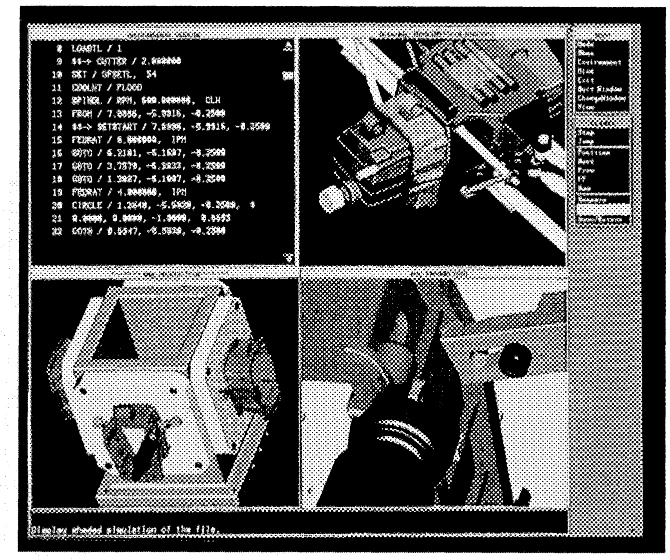


FIGURE 14.39 On-Screen Setup of Part Machining

applications in manufacturing, especially computer numerical control programming and robotics. CAD/CAM depends on a common engineering and manufacturing database. This database allows engineering to define a product model (part design) and the manufacturing department to use that same model definition to produce the product (Fig. 14.38).

14.7.1 Computer-Aided Manufacturing (CAM)

Computer-aided design uses a computer to help create or modify a design. *Computer-aided manufacturing (CAM) uses a computer to manage and control the operations of a manufacturing facility.* CAM includes computer numerical control (CNC) for machining operations, tool and fixture design and setup, and integration of industrial robots into the manufacturing process. The integration of computer-aided design and computer-aided manufacturing eliminates duplication of effort by the engineering/design and manufacturing or production departments. An engineering drawing created on a graphics terminal defines the product geometry, which otherwise must be manually derived from the drawing by the manufacturing department before the product is produced.

The production process is computerized, from the original graphics input through to the manufacture of the part on a numerically controlled machine (Fig. 14.39). Shop production drawings have been entirely eliminated with this process. By obtaining the product geometry directly from the engineering data, the programmer can extract accurate geometric data, replicating the engineer's definition of the part to be manufactured.

As mentioned, CAM speeds the manufacturing process because it uses the database initially created in the design-and-drafting cycle. This database, representing the part (model) design, is used by the manufacturing group. The system serves all applications, promotes standardization to enhance management control, accumulates (rather than randomly collecting) manufacturing information, and reduces redundancy and error.

Many design-through-manufacture processes require skilled labor, which is, and probably will continue to be, in short supply. One of the major goals of the CAD/CAM system is to transfer the experience and skills of a few individuals to the database. This provides less experienced personnel with access to technical information. Design for manufacturability usually simplifies the part design and the manufacturing requirements for production of the part, thereby reducing the level of skilled labor required to produce the product.

Using a CAD/CAM system, the engineer or designer applies the CAD features to create a model of the part. Then, using the information stored in the database, the manufacturing engineer applies the CAM capabilities. A CAD system may have a variety of specialized CAM capabilities, including the following:

- Group technology
- Process planning
- Shop layout
- Programming of machining operations
- CNC postprocessing
- Sheet metal applications
- Tool and fixture design
- Mold design and testing
- Technical publications and manufacturing documentation
- Quality control

Computer-aided manufacturing goes through, the following steps:

1. *Process planning:* The engineering drawing of the part to be tooled must be interpreted in terms of the manufacturing processes to be employed. This step should be given thought and consideration *before* part programming is begun.

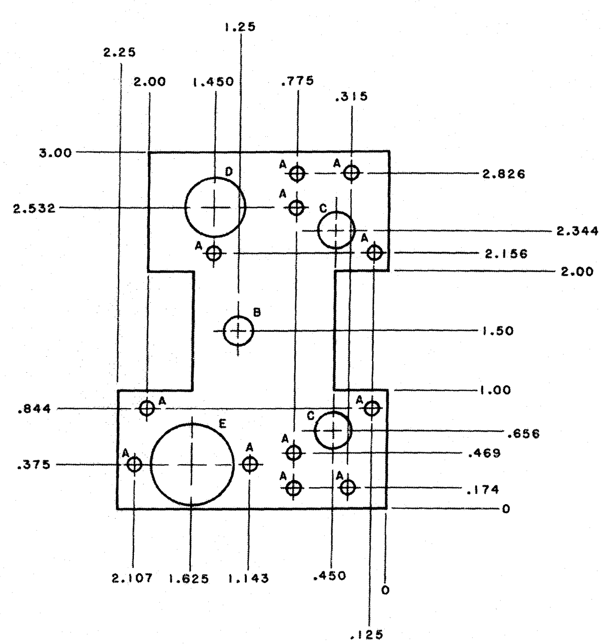
2. *Part programming:* Part programmers plan the process for the portions of the job to be accomplished by computer numerical control. They are knowledgeable about the machining process, and they have been trained to program for computer numerical control. They are responsible for planning the sequence of machining steps to be performed by CNC and to document these in a special format. There are two ways to program for CNC: manual part programming and computer-assisted part programming.

   In **manual part programming,** the machining instructions are prepared on a form called a *part program manuscript.* This is a listing of the relative cutter positions that must be followed to machine the part. In **computer-assisted part programming,** much of the computational work required in manual part programming is transferred to the computer. This is especially advantageous for complex part geometries and jobs with many machining steps. In computer-assisted part programming, the computer interprets the list of part programming instructions, performs the necessary calculations to convert this into a detailed set of machine tool motion commands, and develops a chosen transfer medium containing the CNC data for the specific CNC machine.
3. *Verification:* The program is checked by plotting the tool movements on paper. In this way, errors in the program can be discovered. The test of the part program is making a trial part on the machine tool. A foam or plastic material is sometimes used for this test. CAD systems with CAD/CAM capabilities allow verification of toolpaths and cutter motion on the display
4. *Transfer media preparation:* Originally, punched tape was the medium for transferring a part program from the computer to an NC machine. Disks, minidisks, and direct computer networks are now the preferred transfer media.
5. *Production:* Production involves ordering the rough parts, specifying and preparing the tooling and any special fixturing that may be required, and setting up the CNC machine. The machine tool operator's function during production is to load the data into the machine and to establish the starting position of the cutting tool relative to the rough part. The CNC system then machines the part according to the programmed instructions. When the part is completed, the operator removes it from the machine and loads the next part. In more automated operations, a programmable robot performs these tasks in conjunction with computer control instead of an operator.

14.7.2 Numerical Control

Numerical control (NC) can be defined as a form of programmable automation in which the process is controlled by numbers, letters, and symbols. In NC, the numbers form a program of instructions designed for a particular part or job. When the job changes, the program of instructions is changed. This capability to change the program for each new job gives NC its flexibility. It is much easier to write new programs than to make major changes in the production equipment.

Programming an NC machine requires a good working knowledge of machine tools, tool design, print reading, and manufacturing processes. Figure 14.40 shows a part dimensioned for ease of NC programming. Each hole and edge has a dimension taken from the **X0,Y0,Z0** position of the piece, which in this case is in the lower right-hand corner. The **X0,Y0,Z0** position is established according to the machine and the part configuration and machining requirements.



HOLE	DESCRIPTION	QTY
A	.125 DIA	12
B	.250 DIA	1
C	.312 DIA	2
D	.500 DIA	1
E	.688 DIA	1

.063 ALY ALUM 6061-T6 ANODIZE BLACK

FIGURE 14.40 Connector Plate Dimensioned for NC Programming

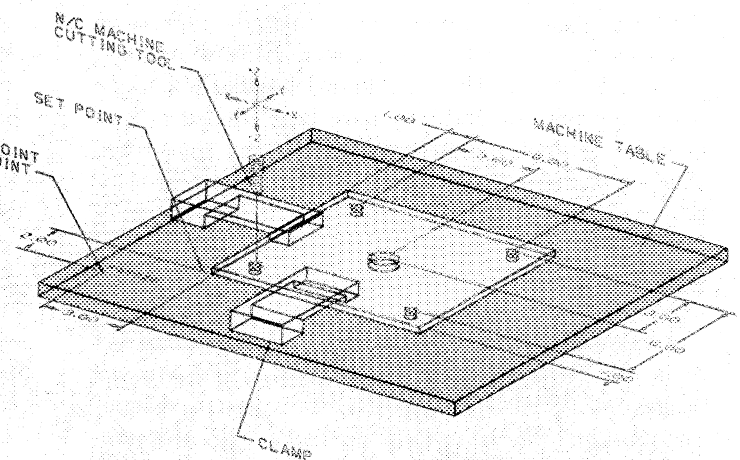


FIGURE 14.41 CNC Part Setup

Figure 14.41 shows the machining table, the part, and the clamps holding the part. The starting point is **X0,Y0,Z0.** Note the 3D coordinate system shown at the top of the cutting tool.

The two major types of NC machines in use today are point-to-point and continuous-path machines. The movement of the tool in reference to the workpiece establishes the difference between the two. **Point-to-point** machines operate on a series of programmed coordinates to locate the position of the tool. When the tool finishes at one point, it continues to the next point (position). This type of control is typical of drilling and punching machines. Milling machines require continuous control of tool position and therefore use a **continuous path.** Complicated operations, including contouring, angle surfaces, fillets, and radii, can be programmed by the continuous-path method. The **toolpath** can be displayed on the CAD/CAM system, thereby verifying the cutter's movement without running an actual part on the machine. The toolpath is the trace of the movement of the tip of a cutting tool used to guide or control machining equipment.

Computer numerical control (CNC) is eliminating the older form of programming. When the program is complete, repetitive productions are accomplished by controls having memory of the part in the computer system. Figure 14.42 shows a CNC turning center. In CNC, the design database is passed directly form the CAD/CAM system to the machine's computer. The description of the part developed with the computer-aided design system is the input to the computer-aided manufacturing system, which in turn commands the machine tool postprocessor to complete the machine instructions.

The programmer defines cutting tools, creates a tool library, and retrieves these tools later to create toolpath information. CAM packages support most types of cutting tools; therefore, the programmer can describe many types of cutting tools (flat, ball, tapered) in general use. The CAM system allows for definition of machining characteristics, such as retract and clearance plane, cutting depth, feed rate (rate of travel), and spindle speed (rate of spindle rotation). Figure 14.43 shows a sequence of design, analysis, simulation, and manufacturing for a spindle. The menu shown in Figure 14.43(a) helps manage the engineering data needed to model and test the part. The solid model of Figure 14.43(b) assists the designer in creating, analyzing, and visually displaying the part. In Figure 14.43(c), **cutter paths** for CNC machining are defined and modified by the part programmer. In Figure 14.43(d), output from the postprocessor is then utilized for machining the actual part. As a last step, the finished assembly can be displayed and reviewed, as shown in Figure 14.43(e).

14.7.3 Machining Operations

A variety of machining operations are possible, from simple two-axis point-to-point functions to complex multiaxis machining. These operations may include drilling, punching, milling, turning, profiling, pocketing, surface machining,

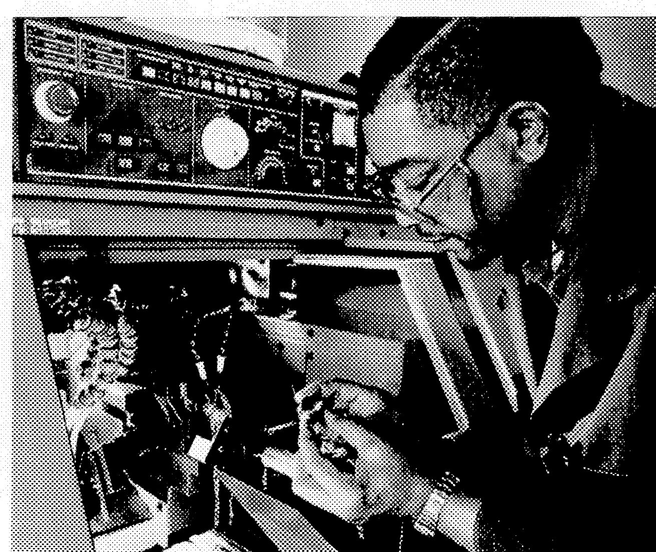
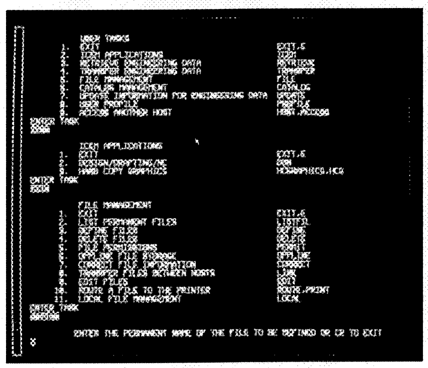
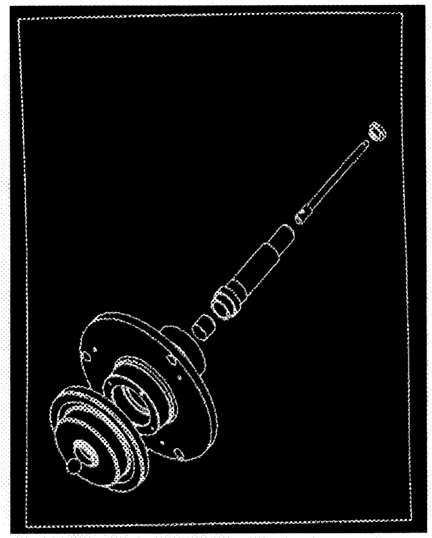


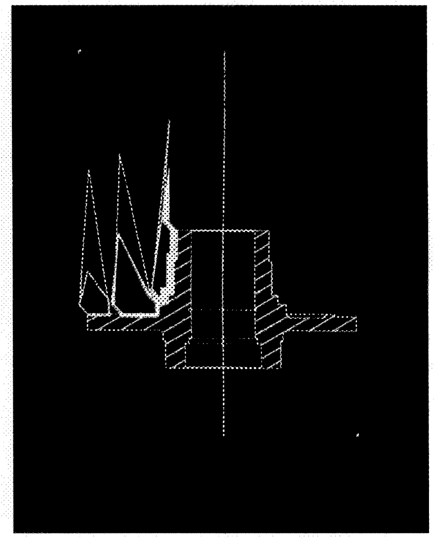
FIGURE 14.42 CNC Machining



(a) Task menu from Control Data's ICEM engineering library

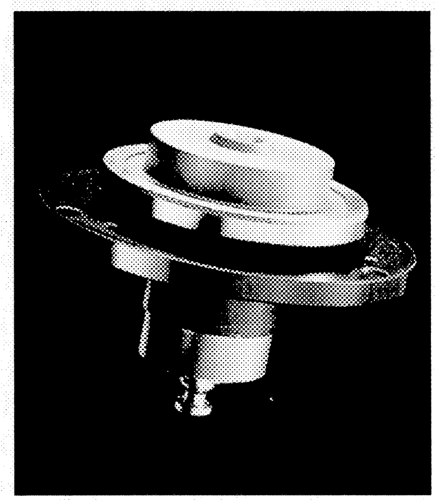


(b) The solid model can be rotated, exploded, and viewed from any angle



(c) Cutter paths for numerical control machining can be defined and modified at the CAD terminal

(d) Numerical output can be utilized for CNC machining of the actual part



(e) Finished assembly review

FIGURE 14.43 On-Screen Programming

and flame cutting. The types of parts that may be produced on CNC equipment from output generated by CAD/CAM systems include:

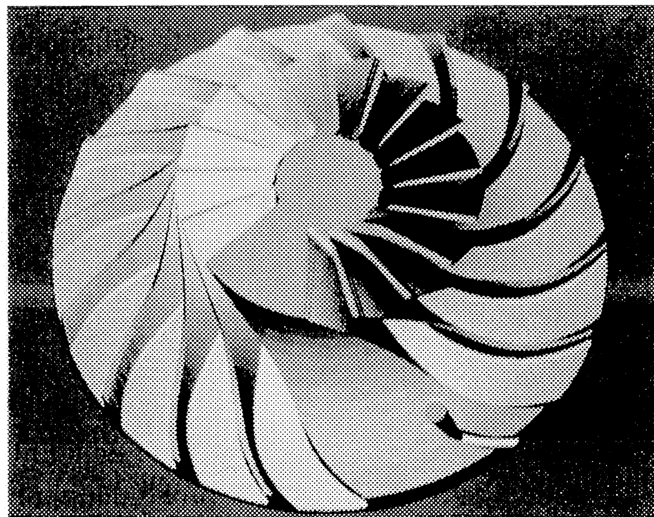
- Irregular or uniquely machined parts [Fig.14.44(a)]
- 2D parts created by point-to-point operations
- Parts produced by turning operations
- $2\frac{1}{2}$D parts, which may require pocketing and profiling operations (Fig. 14.44(b)]
- 3D parts produced by using all of the CNC operations provided on the CAD/CAM system [Fig. 14.44(c) and (d)]

Pocketing involves completely removing material within a bounded area (Fig. 14.45). Machine pocket programs provide automatic pocketing on a CAD system by generating a toolpath to remove the material contained within a closed boundary. Capabilities include multiple-base **rough cutting** [Fig.14.45(a)], **multiple-side cutting** [Fig.14.45(b)], a designer-specified final **finishing pass**, and **islands** defined within a pocket [Fig. 14.45(c)].

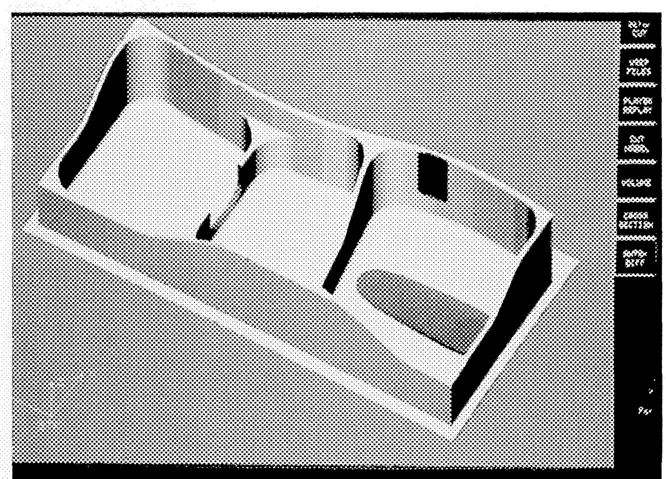
Profiling is the automatic generation of a continuously contoured toolpath around a boundary (Figs. 14.46 and 14.47). The cutting tool moves outside or inside a profile. Capabilities include multiple-base rough cutting, multiple-side rough cutting, and a designer-specified final finishing pass.

14.7.4 Toolpath Simulation and Verification

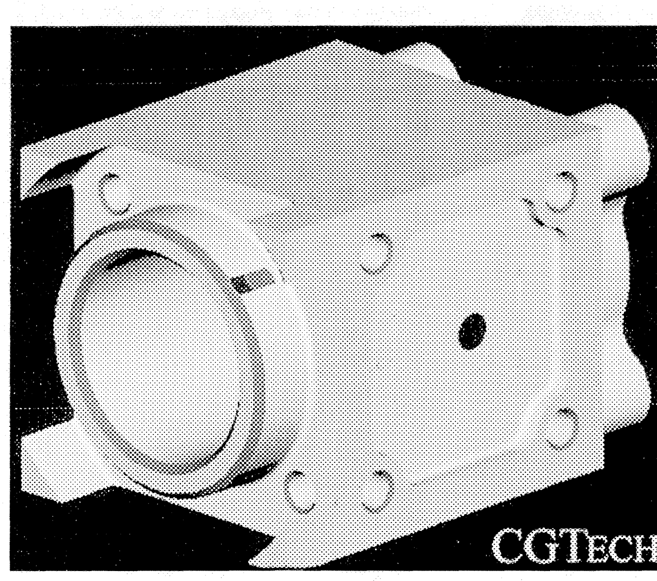
CAD/CAM systems provide accurate and realistic verification of both 2D and 3D toolpaths without cutting metal. The programmer can simulate and visually verify the toolpath on



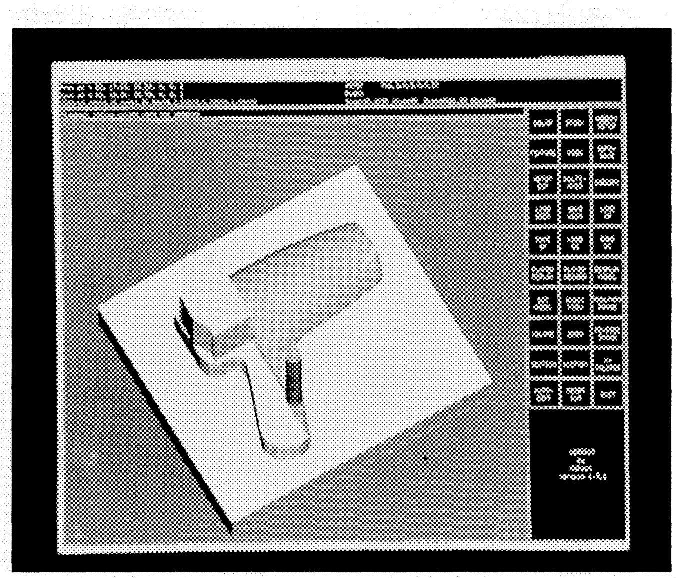
(a) Complex surfaces for a turbine blade



(b) Pocketing

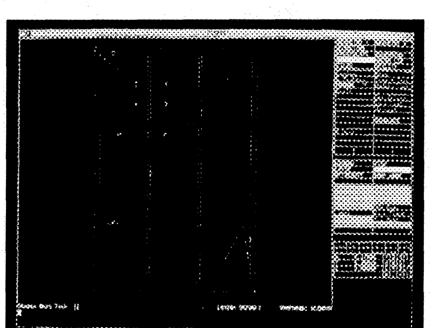


(c) Multiaxis machined part

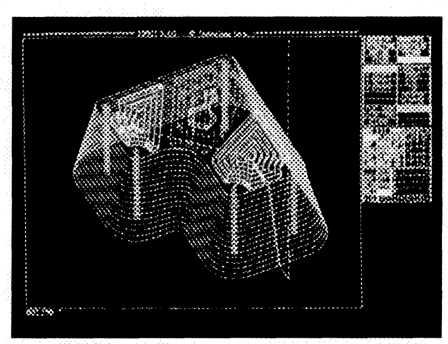


(d) Toolpath generation on a complex surface

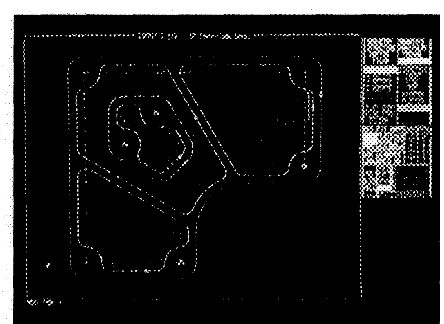
FIGURE 14.44 Machined Parts



(a) Pocketing



(b) Complex-surface machining



(c) Pocketing and islands

FIGURE 14.45 Toolpath Generation

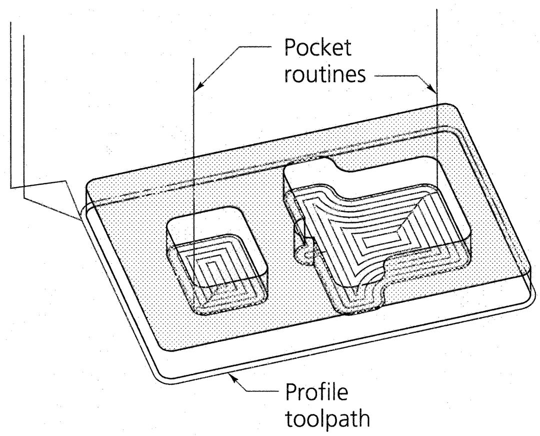
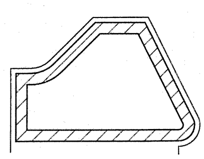


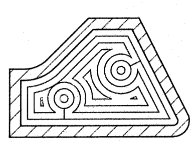
FIGURE 14.46 Toolpath Generation. A variety of toolpaths can be created, including profiling and pocketing.

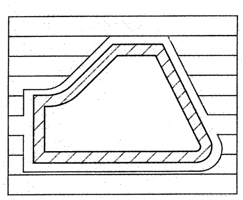
the display (Fig. 14.48). The toolpath seen on the display may show the tool and holder actually moving along the part, from any viewing angle. This permits the designer to check for toolpath correctness and clearance of tools, parts, and fixtures. Once toolpaths are created, they may be edited and assembled into sets, machining statements may be added, and then toolpaths may be output to a specific machine. Toolpaths may also be transformed into a programming language, such as APT or COMPACT.

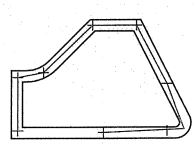
14.7.5 Tools, Fixtures, and Mold Design

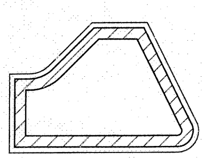
In general, a tool is a piece of equipment that helps create a finished part. It may be anything that must be designed


(a) Absolute machining


(b) Pocketing with islands


(c) Lace cutting a surface with containment


(d) Point-to-point


(e) Profiling

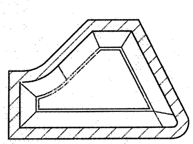
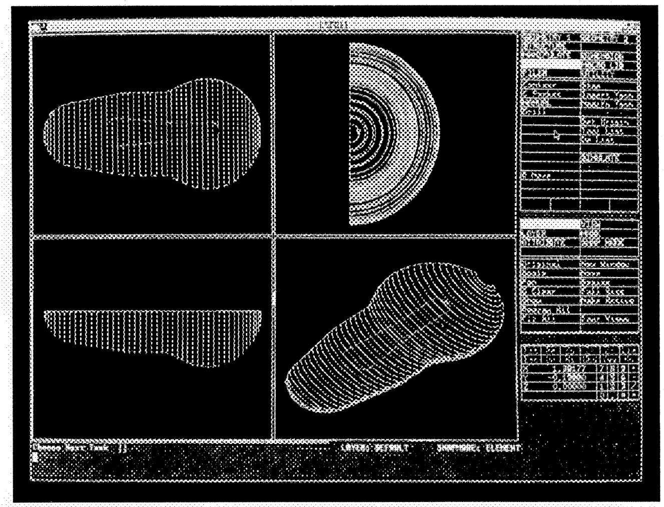

(f) Machining intersections of surfaces

FIGURE 14.47 Toolpaths. Six examples of toolpath generation are shown.


(a) Displaying a toolpath

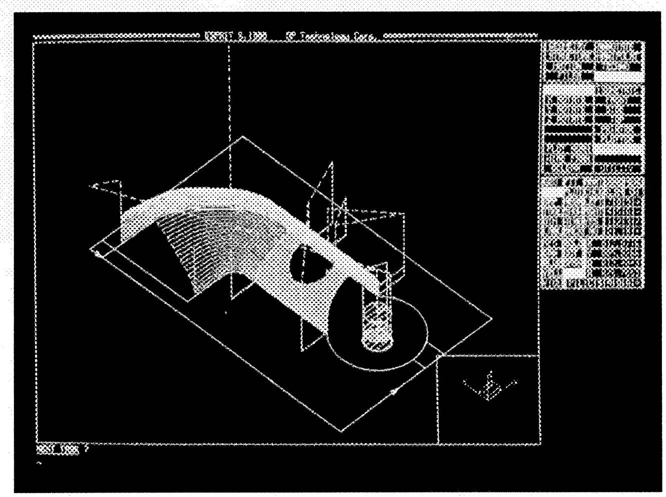

(b) Surface machining

FIGURE 14.48 On-Screen Toolpath Generation

and/or made in order to manufacture the part. CAD systems may support the design and manufacture of the following tools.

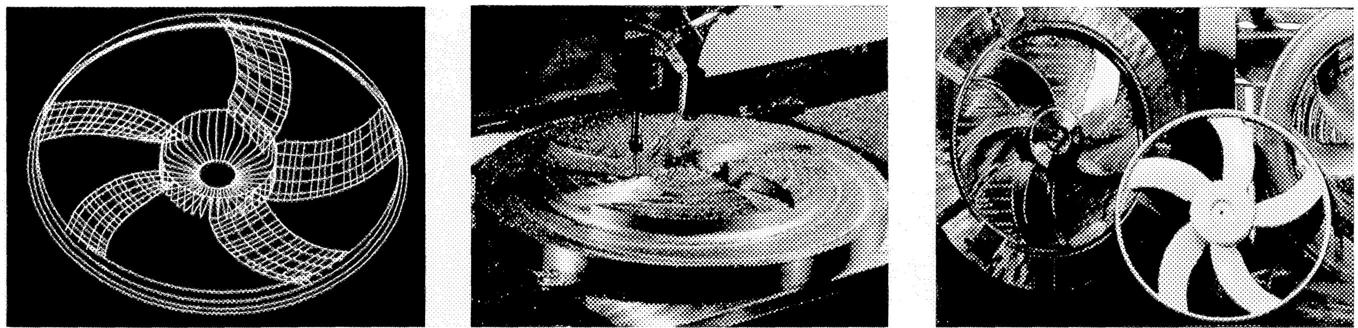
Molds Used to form a variety of parts for consumer, industrial, and medical applications

Dies Used to forge, cast, extrude, and stamp materials while in various physical states (solid through fluid)

Tooling The individual component of mold or die; might include a cavity, nest, core, punch, bushing, slide, or sleeve

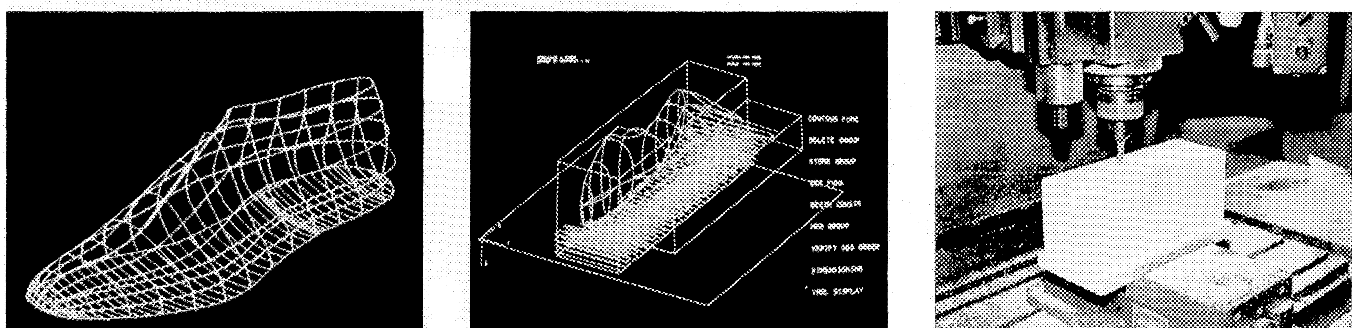
Figure 14.49(a) shows an example of mold design on a CAD system. The mold for the part being machined in (b) is shown complete in (c). Figure 14.50 shows a shoe designed and displayed on a CRT using a mesh model [(a)]. The mold was also designed on the system [(b)] and is being machined in (c).

Fixtures function to hold and locate parts of assemblies



(a) Computer design of part (b) Mold being machined (c) Finished part and mold

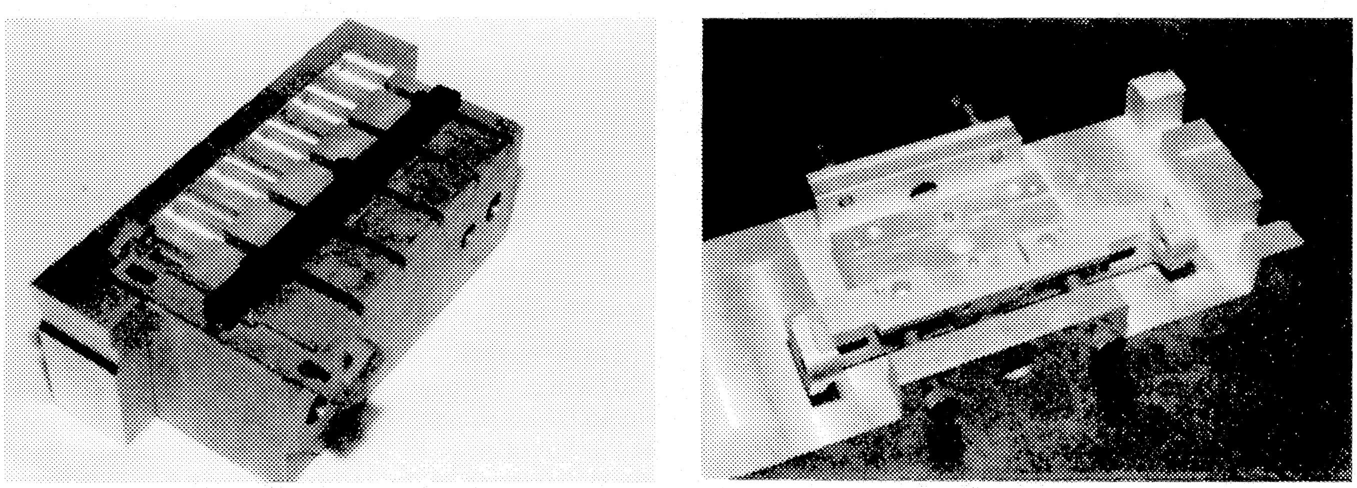
FIGURE 14.49 **Mold Design**



(a) Mesh model of a shoe design (b) Shoe mold design (c) CNC machining of a shoe mold

FIGURE 14.50 **Shoe Mold**

during machining or other manufacturing operations (Fig. 14.51). The accuracy of the product being produced determines the precision with which a fixture is designed. To design and manufacture a finished part efficiently, product design engineers must work with tool and fixture designers as well as manufacturing engineers. CAD promotes this interaction by providing a common database for the product design and the associated tool/fixture design, manufacture, and production. When designing a tool or fixture, the manufacturing engineer retrieves the part design from the database to determine how the tool or fixture should be built to produce the finished product.



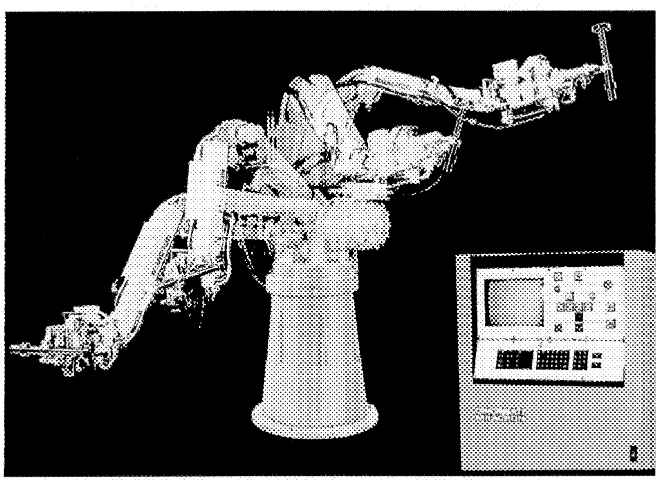
(a) Fixture for machining multiple parts (b) Fixture for machining two parts

FIGURE 14.51 **Fixtures**

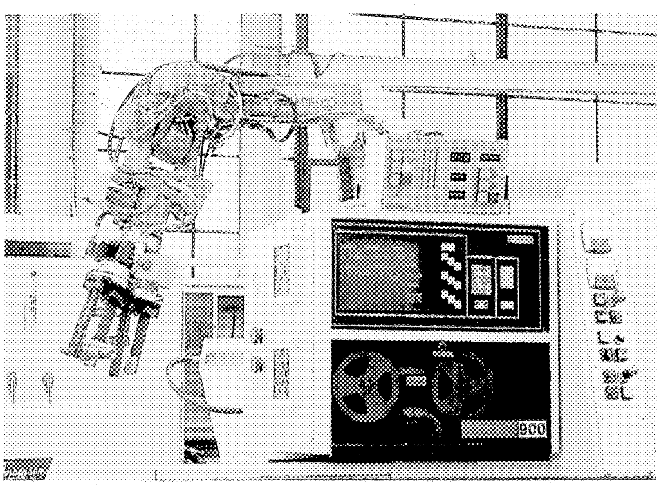
To determine the materials needed to produce a tool/fixture designed on the system, CAD can output a bill of materials for the purchasing department automatically. This lists quantities and associated information needed to manufacture the product(s). Process planners can then access the database to create process instructions and plans.

14.8 ROBOTICS

Robotics is the integration of computer-controlled robots into the manufacturing process. Industrial robots (Fig. 14.52) are used to move, manipulate, position, weld, machine, and do a variety of other manufacturing processes. A **robot** is a reprogrammable, multifunction manipulator designed to move material, parts (including the workpiece),



(a) Cincinnati Milicron robot



(b) Control panel, gripper, and arm of robot

FIGURE 14.52 **Industrial Robots**

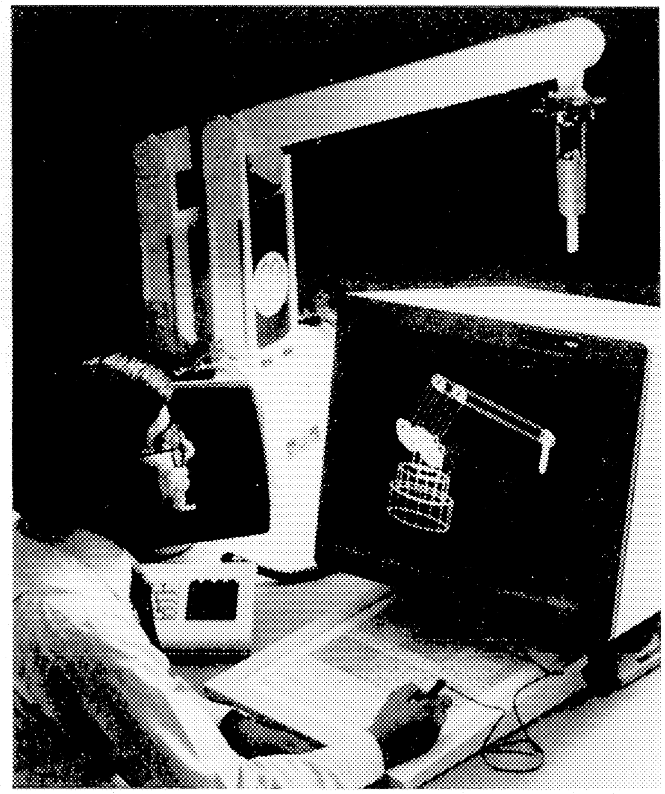
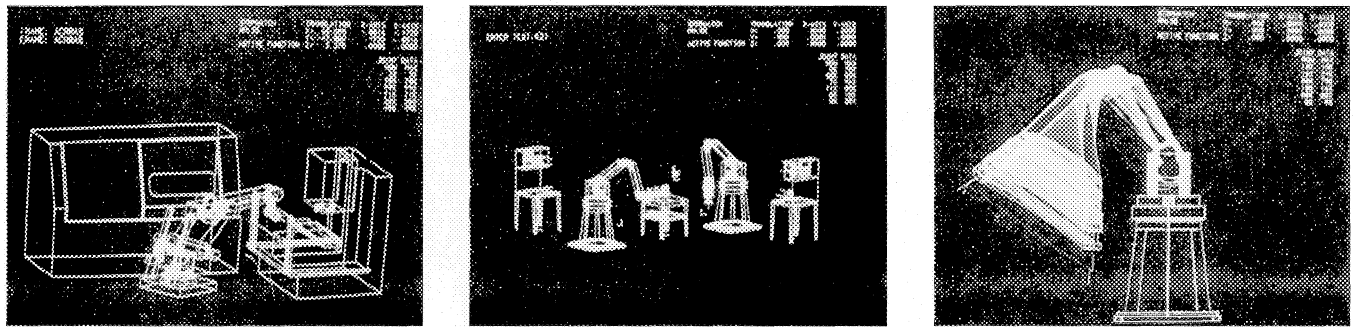


FIGURE 14.53 **Robot Simulation. Robotics simulation program enables automation engineers to put a robot through its paces on the computer screen rather than via trial-and-error on the factory floor. You can design a factory workcell, simulate a robot's movements and performance in it, and then modify both the robot's movements and the surrounding machinery for optimal efficiency. This can be accomplished at the computer terminal, without employing any robotic hardware, material-handling devices, part-presentation equipment, or robot grippers.**

tools, or specialized devices through variable, programmed motions for the performance of a variety of tasks. Robotics includes the control and synchronization of the equipment with which the robot works, a capability that can eliminate the need for humans to work in hazardous environments. Robots are controlled by a microprocessor and are composed of a separate, stand-alone computer station, the robot mechanism itself, and an electrical-hydraulic power unit.

The part workpiece being placed by the robot can be visualized on the screen via simulation (Fig. 14.53). To take fullest advantage of robotic control and movement of the workpiece during manufacturing, the designer needs to design the part with robotic manufacturing methods in mind—not after the fact. A 3D CAD database for the part allows this type of robotic programming before manufacturing begins. DFM includes part design, with robotic manu-



(a) Robot and related machinery workcell evaluation simulation shown on a display

(b) Robotic workcell library

(c) Robot simulation of arm movement

FIGURE 14.54 Robotics

facturing techniques designed into the part at the earliest stages of the project.

14.8.1 CAD/CAM Robotic Applications

The integration of CAD/CAM and robotics results in increased productivity for robotic implementation activities. CAD/CAM robotic applications include robotic workcell design, robotic workcell programming, and robotic workcell simulation.

The **robotic workcell** contains all the physical equipment needed to create a functioning robot application [Fig. 14.54(a)]. Besides the robot, a workcell can have special fixturing, automated machines (CNC machines, coordinate measuring machines, or visual-inspection equipment), materials-handling devices, part-presentation equipment, and robot grippers.

The equipment in the workcell must be arranged so that the **robot work envelope** includes all required device areas. The work envelope is controlled by the size of the robot. Libraries of workcell components can be stored on the CAD/CAM system and recalled when needed [Fig. 14.54(b)]. For example, a **robot library** could contain commercial robots along with their work envelopes.

CAD/CAM workcell design has many benefits. First, the design activity is more productive, plus design time and costs are reduced. Second, CAD/CAM for workcell layout allows more alternatives to be considered, resulting in an optimal layout. Third, the lead time to design and lay out the cell is reduced. Fourth, quality of the designed components and the overall cell quality are increased.

With **graphic robotic simulation**, CAD systems can simulate the programmed robot path. Simulation checks whether or not the robot can position its end-effector to the specified positions and orientations. If the robot's end-effector cannot assume the desired position and required orientation, revision of the path or workcell may be necessary. Also, the robot's **degrees of freedom** [Fig. 14.54(c)] may not be sufficient to accomplish a given task. The degrees of freedom are the total area and movement capability of the robot. Simulation creates the actual robot trajectory using end-effector positions available from graphic robotic programming.

QUIZ

True or False

1. Patterns are made smaller than the real size of the part to allow for expansion of the metal (expansion allowance).
2. The surface texture symbol designates the classification of roughness, waviness, and lay.
3. Roughness is the distance between ridges or peaks on a surface.
4. Robots can be programmed and their movement verified without touching the actual robot hardware.
5. NC is a form of programmable automation controlled by numbers, letters, or symbols.
6. Pocketing is the process of removing material from the outer boundaries of a part.
7. A true CAD/CAM system can create a common database that is then used to derive part geometry for all areas of manufacturing and design.
8. Reamers are used to produce precise holes.

Fill in the Blanks

9. __________ , __________ , and __________ are done on a drill press.
10. __________ , __________ , __________ , __________ , and ____________ are the five basic types of machining processes.
11. A __________ __________ is used to allow the cast part to be removed from the form more easily.
12. __________ is the process of pouring molten metal into a mold.
13. Machining a continuous toolpath about a part is called __________ .
14. The creation of a common __________ enables the part geometry to be used by many departments.
15. Toolpaths can be __________ and __________ on the display.
16. __________ is basically the same process as counterboring.

Answer the Following

17. Describe the difference between drilling, reaming, and boring.
18. From your own experience, name five metal parts that have been cast.
19. Drilling is used before what types of basic tooling operations?
20. What are robots, and how are they being used in industry? What type of tasks are they doing, and why?
21. What part does CAD play in the total CAM process? How does the use of a common database effect the design-through-manufacturing process?
22. How can a CAD system aid in verification? Discuss its uses and effects on CAM in general. Describe CNC, tooling design, and robotics in your evaluation.
23. What is a robotic workcell, and how can a CAD system help its overall efficiency?
24. What are profiling and pocketing?

PROBLEMS

For each of the following problems, draw (or model) the part. Display the part using the minimum number of views necessary to describe the design graphically. Leave sufficient space for dimensioning. After completing Chapter 15, dimension each of these projects as assigned by your instructor.

On a separate sheet of paper, list the operations required for manufacturing each of the parts—drilling, reaming, boring, threading, milling machine operations (including profiling, pocketing, etc.), and lathe operations (including facing and parting, etc.). List the material and whether the part is to be made from a stock piece or to be cast, forged, stamped, or created via some other process.

Problem 14.1 Draw or model the detail of the cylinder lip ring shown in Figure 14.2.

Problem 14.2 Redraw the plate in Figure 14.9.

Problem 14.3 Draw or model the pivot pin in Figure 14.12.

Problem 14.4 Draw or model the cylinder rod shown in Figure 14.15.

Problem 14.5 Draw or model the link shown in Figure 14.19.

Problem 14.6 Draw or model the adapter shown in Figure 14.31.

Problem 14.7 Redraw the detail of the part in Figure 14.35. Use decimal inches and the latest ANSI standards.

Problem 14.8 Draw the plate in Figure 14.40.