Manufacturing Processes

Learning Objectives

After studying this chapter, you will be able to:

- List and describe common machining operations.
- Specify dimensions for features to be machined using proper drafting conventions.
- Explain how computer numerical control machines carry out tool operations.
- Identify common positioning systems used for specifying distances and directions in CNC machining.
- Describe the principles of computer-aided manufacturing (CAM) and computer-integrated manufacturing (CIM).
- Explain the principles of just-in-time (JIT) manufacturing.

Technical Terms

Abrasive machining
Absolute positioning system
Artificial intelligence (AI)
Automated guided vehicles (AGVs)
Blanking
Boring
Broach
Broaching
CAD/CAM
Callout
Chamfer
CNC program
Computer-aided drafting (CAD)
Computer-aided manufacturing (CAM)
Computer-integrated manufacturing (CIM)
Computer numerical control (CNC) machining
Conical taper
Counterboring
Counterdrilling
Countersinking
Database
Direct numerical control (DNC)
Distributed numerical control (DNC)
Expert systems
Fixed zero setpoint
Flat taper
Flexible manufacturing cell (FMC)
Flexible manufacturing system (FMS)
Floating zero setpoint
Grinding
Group technology (GT)
Honing
Incremental positioning system
Just-in-time manufacturing (JIT)
Knurling
Ladder logic
Lapping
Machining center
Neck
Network
Numerical control (NC)
Profilometer
Programmable logic controller (PLC)
Reaming
Robot
Spotfacing
Stamping
Surface texture
Taper
Undercut
Work-in-progress (WIP)
Zero point

An important aspect of the work done by drafters in preparing drawings is specifying the features on a machine part and the related manufacturing operations to be performed. Drafters should be familiar with the common machining processes used in industry. This chapter presents many of the most commonly used manufacturing processes and the conventions used to specify them on drawings. This chapter also discusses the role that design plays in industrial production and the impact of newer technologies on design and manufacturing.

Machine Processes

Certain features on drawings, such as drilled holes, may be dimensioned by simply giving the diameter, **Figure 21-1**. However, in cases where features are to be machined in a certain way (such as to produce a desired surface texture or to hold a certain tolerance), the machining specifications must be given. This is done by placing dimensions or notes known as callouts. A ***callout*** is a note that gives a dimension specification or a machine process. The following sections discuss common machine processes and the drafting conventions used to specify related dimensions.

Drilling

Drilled holes are usually produced by a drill bit chucked in a drill press or portable power drill (depending on the nature of the piece and the accuracy required). Different methods for representing and dimensioning drilled holes are shown in **Figure 21-2**. Note that the specification may be made entirely by a callout or by a callout and a dimension for depth on the feature.

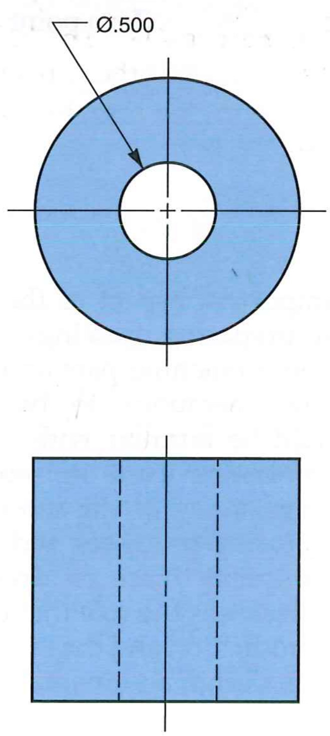


Figure 21-1. A drilled hole is indicated on a drawing with a diameter dimension.

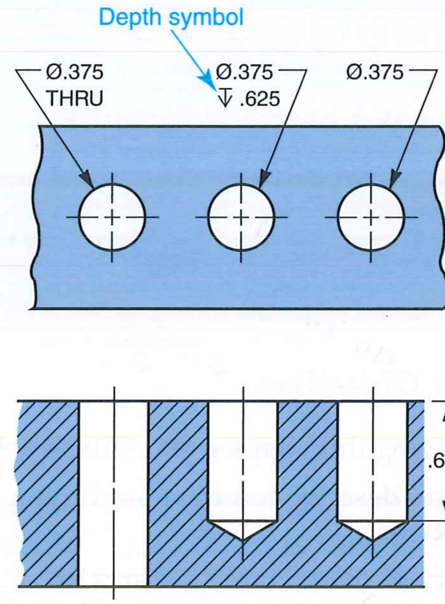


Figure 21-2. Methods used to dimension drilled holes.

When indicating a hole dimension, the manufacturing process to be performed is not given unless it is essential to convey the manufacturing or engineering requirements. That is, the hole size is given without indicating a specific operation, such as drilling, boring, or reaming. The specific operation to be performed is determined when the part is manufactured.

Spotfacing

Spotfacing is a cutting process used to clean up or level the surface around a hole to provide a bearing for a bolt head or nut. A spotfaced hole may be indicated on the drawing by a note with the spotface dimension symbol, **Figure 21-3A**. A spotface may also be specified by a general note only and need not be shown on the drawing.

Counterboring

Counterboring involves cutting deeper than spotfacing to allow fillister and socket head screws to be seated below the surface. The same dimension symbol used for spotfacing is used to indicate a counterbored hole, **Figure 21-3B**.

Countersinking

Countersinking is done by cutting a beveled edge (chamfer) in a hole so that a flat head screw

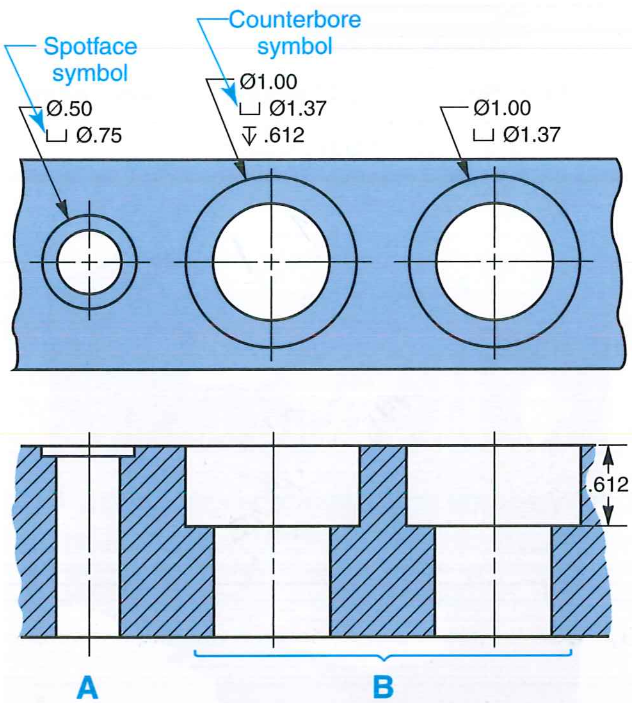


Figure 21-3. Methods used for representing and dimensioning spotfaced and counterbored holes.

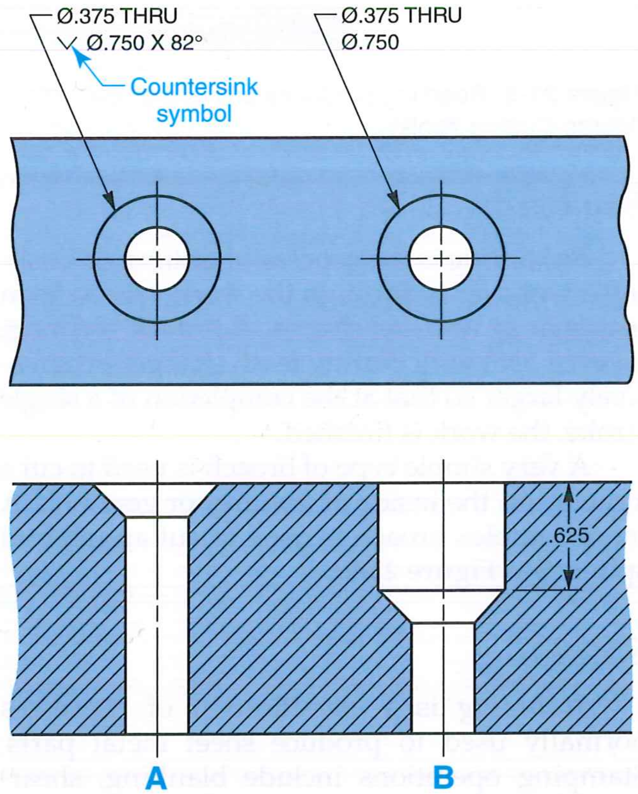


Figure 21-4. Methods used for representing and dimensioning countersunk and counterdrilled holes.

will seat flush with the surface. A countersunk hole is indicated on the drawing by a note with the countersink symbol, **Figure 21-4A**. The outside diameter of the countersunk feature on the surface of the part and the angle of the countersink are dimensioned.

Counterdrilling

Counterdrilling is similar to countersinking. It involves drilling a small hole and a larger hole to a given depth, **Figure 21-4B**. Counterdrilling allows room for a fastener or feature of a mating part.

Boring

Boring is enlarging a hole to a specified dimension. Boring is used when an extremely accurate hole with a smooth surface texture is required. It may be done on a lathe or on a boring machine or mill, **Figure 21-5**.

Reaming

Reaming is finishing a drilled hole to a close tolerance. After a hole is drilled, it may be reamed for greater accuracy and a smoother surface texture, **Figure 21-6**. The hole is drilled slightly undersize, and then reamed to the desired diameter. A reaming tool can only be used on an existing hole.

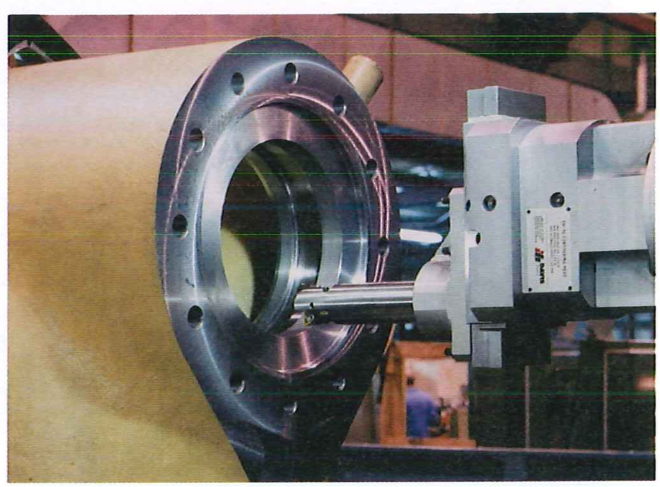


Figure 21-5. Boring enlarges a hole to a specified dimension. Shown is a boring tool with a contouring head for use on a horizontal boring machine. (Innovative Tooling Solutions)

Figure 21-6. Reaming produces a finished hole with a smooth surface. Shown is a 1/2″ straight chucking reamer. (Morse Cutting Tools)

Broaching

Broaching is the process of pulling or pushing a tool over or through the workpiece to form irregular or unusual shapes. A ***broach*** is a long, tapered tool with cutting teeth that get progressively larger so that at the completion of a single stroke, the work is finished.

A very simple type of broach is used to cut a keyway on the inside of a pulley or gear hub. A more complex broach is used to cut an internal spline. See **Figure 21-7**.

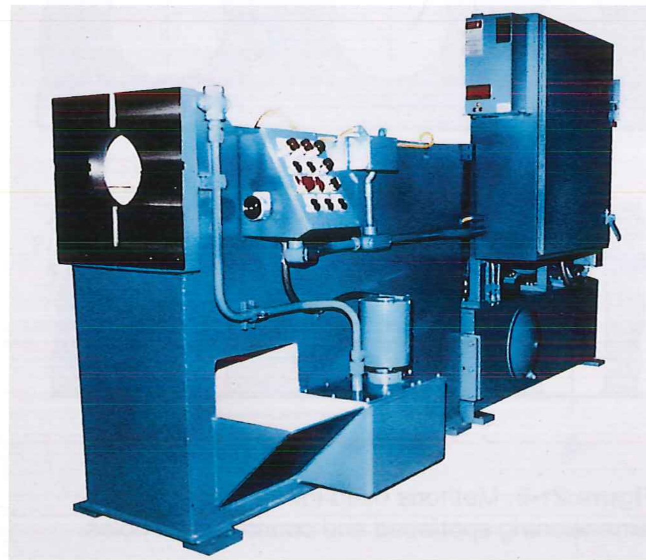
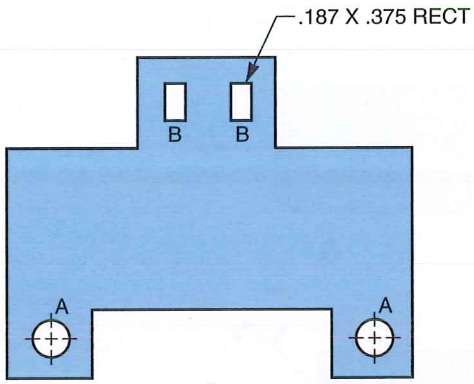


Figure 21-7. In broaching operations, a cutting tool is pulled or pushed over or through a workpiece to form shapes. Shown is a 36″ internal horizontal broaching machine. (Broaching Machine Specialties)

Stamping

Stamping is a classification of processes normally used to produce sheet metal parts. Stamping operations include blanking, shearing, bending, and forming. In ***blanking***, a punch press uses a die to cut blanks from flat sheets of metal, **Figure 21-8**. Circular or irregular holes and other features are often produced by this process. On a drawing, the features may be dimensioned directly, placed in a callout, or specified in tabular form. See **Figure 21-9**.

Figure 21-8. Large punch presses, like this 33-ton hydraulic precision turret model, are used to punch and form sheet metal. (Finn-Power International)



A

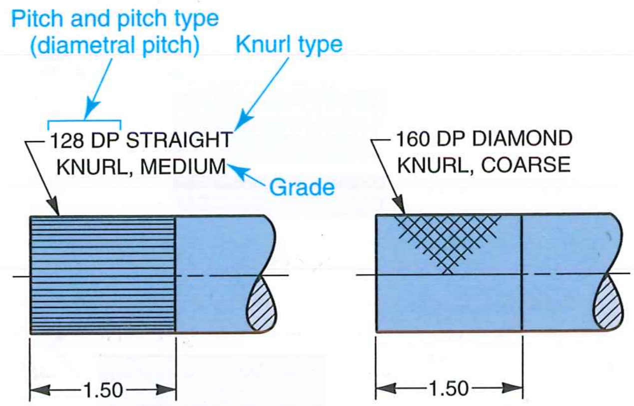
DESCRIPTION OF HOLES		
SIZE	DESCRIPTION	QTY
A	Ø.375 THRU	2
B	.187 X .375 RECT	2

B

Figure 21-9. Blanking is commonly used to produce parts from light gauge metals. Shown are methods for dimensioning blanked features. A—Using a callout specification. B—Using a dimension table.

Knurling

Knurling is the process of forming straight-line or diagonal-line (diamond) serrations on a part to provide a better hand grip or interference fit, **Figure 21-10A**. The pitch, type, grade, and length of knurl should be specified. The knurled surface may be fully or partially drawn, as shown in **Figure 21-10B**. It may be omitted from the drawing entirely, since the callout provides a clear description.



A B

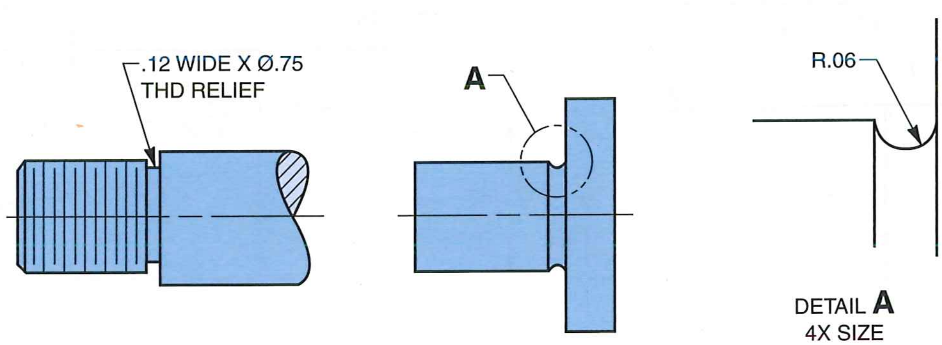
Figure 21-10. Methods of representing knurling on a drawing. A—Straight knurling (shown as a fully drawn surface). B—Diamond knurling (shown as a partially drawn surface).

Necks and Undercuts

A ***neck*** is a groove or recess cut into a cylindrical machine part. Necks are commonly used to provide recesses on shafts to terminate threads, **Figure 21-11A**. An ***undercut*** is similar to a neck. An undercut is machined where a shaft changes size and a mating part, such as a pulley, must fit flush against a shoulder, **Figure 21-11B**. When too small to detail on the part itself, a neck or undercut should be drawn as an enlarged detail, **Figure 21-11C**.

Chamfers

A ***chamfer*** is a small bevel cut on the end of a hole, shaft, or threaded fastener to facilitate assembly. Chamfers are dimensioned as shown in



A B C

Figure 21-11. Specifying necks and undercuts on drawings. A—Necks may be specified with a note. B—Small undercuts may require an enlarged detail. C—The detail drawing clarifies the feature.

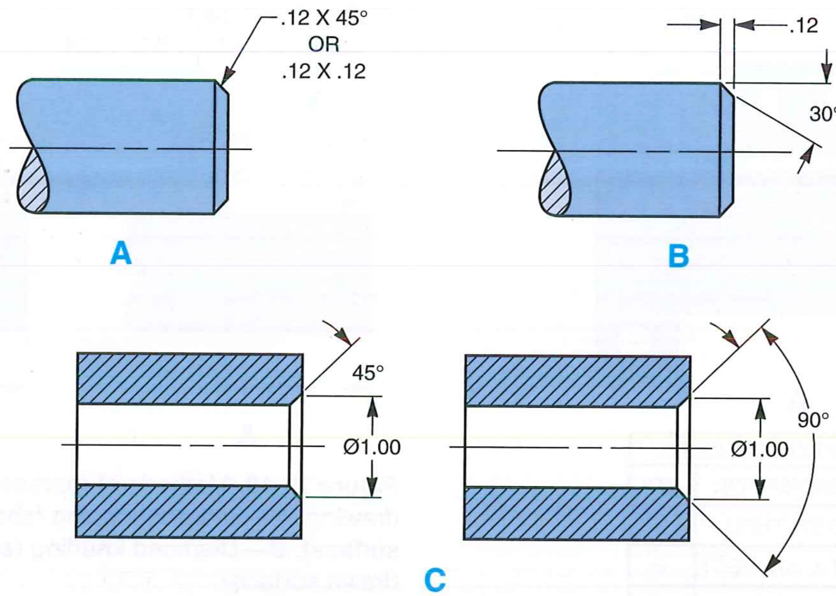


Figure 21-12. Methods of representing and dimensioning chamfers on a drawing. Note that angles other than 45° must be given.

Figure 21-12. When the chamfer angle is 45°, the dimension should be noted as in **Figure 21-12A**. Angles other than 45° must be included in the dimension note, **Figure 21-12B**. Internal chamfers are dimensioned as shown in **Figure 21-12C**.

Tapers

A ***taper*** is a section of a part that increases or decreases in size at a uniform rate. A ***conical taper*** is a cone-shaped section of a shaft or a hole. Standard machine tapers are used on various machine tool spindles, with mating tapers on the drill bits and tool shanks that fit into them. An American Standard series conical taper is shown in **Figure 21-13A**.

A ***flat taper*** has a wedge shape, similar to a doorstop. It may be specified as shown in **Figure 21-13B**. Note that the taper ratio may be shown as a note on the drawing.

Grinding, Honing, and Lapping

Grinding is the process of removing metal by means of abrasives. This is usually a finishing operation. Some actual shaping of parts is also done by grinding, which is then referred to as ***abrasive machining***. Wheels

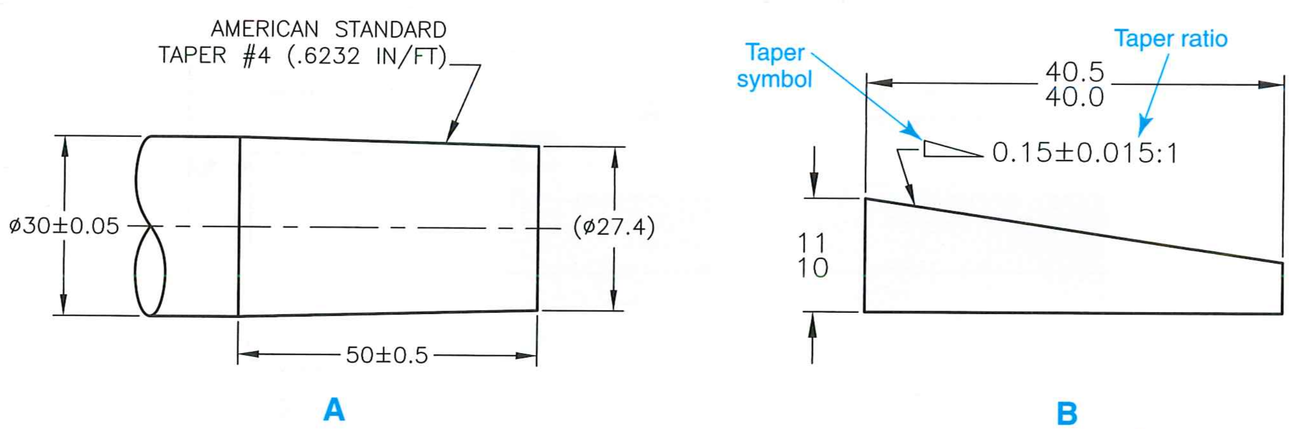


Figure 21-13. Methods of representing and dimensioning tapers on a drawing. A—Conical taper. B—Flat taper. (American Society of Mechanical Engineers)

Figure 21-14. This automatic centerless external cylindrical grinder is used for high-speed production grinding of cylindrical workpieces up to nearly 4″ in diameter. It operates under computer numerical control. (Mikrosa)

used for most grinding operations come in a variety of sizes, shapes, and abrasive coarseness grades.

To produce a finished surface, grinding may be done on a surface grinder for flat work, or on a horizontal spindle machine for precision tool and die work. For internal or external grinding of cylindrical parts, a lathe or cylindrical grinder is used, **Figure 21-14**. The surface texture of a machine part is usually produced with a grinding operation, particularly finer finishes.

Honing is an abrasive operation done with blocks of very fine abrasive materials under light pressure against the work surface (such as inside of a cylinder). They are rotated rather slowly and are moved backward and laterally. ***Lapping*** is quite similar to honing, except a lapping plate or block is used with a very fine paste or liquid abrasive between the metal lap and work surface.

Computer Numerical Control Machining

Computer numerical control (CNC) machining is a computer-operated means of controlling the movement of machine tools, **Figure 21-15**. CNC machining has been applied extensively to milling, drilling, lathe work, punch press work, and wire wrapping.

CNC machining is very flexible and can be used for machining long- or short-run production items. There is a great reduction in conventional tooling and fixturing made possible by the programmed instructions.

CNC machining systems are operated from computer software, rather than from the perforated paper tape traditionally used with ***numerical control (NC)*** machines. When several machines are controlled by a central computer directly wired to the machines, the system is called *direct numerical control (DNC)*. The abbreviation *DNC* is also used to stand for *distributed numerical control*. This system, used in large manufacturing situations, places a number of smaller intermediate computers between the central computer and the CNC machine tools. The distributed control method provides greater flexibility and more rapid response to changing conditions.

Drawings for CNC Machining

There are two basic reference point systems used to position CNC machine cutting tools

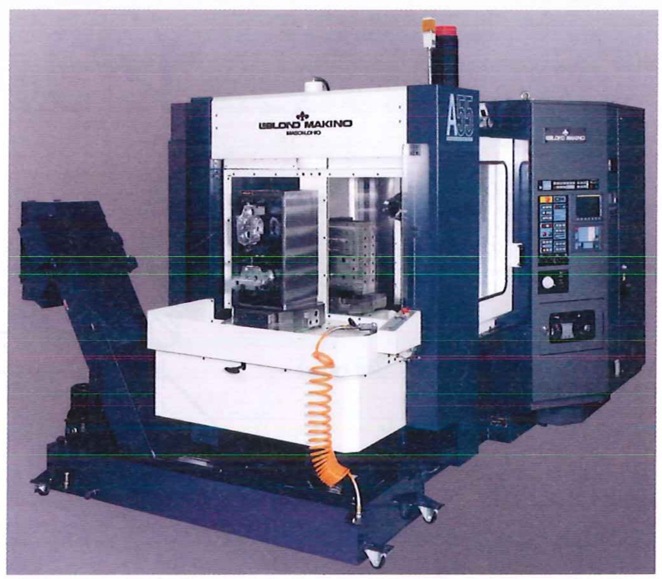


Figure 21-15. This horizontal CNC machining center automatically performs a variety of operations needed to completely process aluminum, steel, or cast iron components from rough castings to finished parts. Workpieces are mounted on square pallets (foreground) and rotate through the machine. Up to 128 cutting tools are stored in the tool changer and automatically mounted as needed. (LeBlond Makino)

for work on parts. These systems are based on the use of absolute and incremental coordinates. Drawings used in programming CNC machines are much the same as those used for more traditional machining. However, the dimensioning system used on the drawing must be compatible with the reference point system of the CNC machine. The absolute and incremental reference point systems are discussed next.

Absolute Positioning

Many CNC machines use the ***absolute positioning system***, or *zero reference point system*, to position the cutting tool. In this system, all locations are given as distances and directions from a ***zero point***. Each move the tool makes is given as a distance and direction from this point, **Figure 21-16**. Referring to the workpiece shown, the X dimension of the coordinate for the first hole is 1.0 + .625 or +1.625. The Y dimension is 1.0 + .625 or +1.625. The location for the second hole is X = +1.625, Y = +5.875 (1.625 + 4.250). The remaining holes are located in a similar manner.

Absolute dimensions on drawings for CNC machining should be drawn as datum dimensions. Two types of datum dimensions, coordinate and ordinate, are shown in **Figure 21-17**. In coordinate dimensioning, each dimension is measured from a datum plane. Ordinate dimensions are also measured from datums and are shown on extension lines without the use of dimension lines or arrowheads.

Incremental Positioning

The ***incremental positioning system*** or *continuous path system* of cutting tool movement is based on programming the tool to move a specific distance and direction from its current position rather than from a fixed zero point. That is, each move the tool must make is given as a distance and direction from the previous location or point.

The first dimension is given as a distance and direction from the starting (zero) point to the first location where the tool will perform its work. Referring to **Figure 21-16**, the distance and direction from the starting point to the first hole is defined as X = 1.625, Y = 1.625. The location of

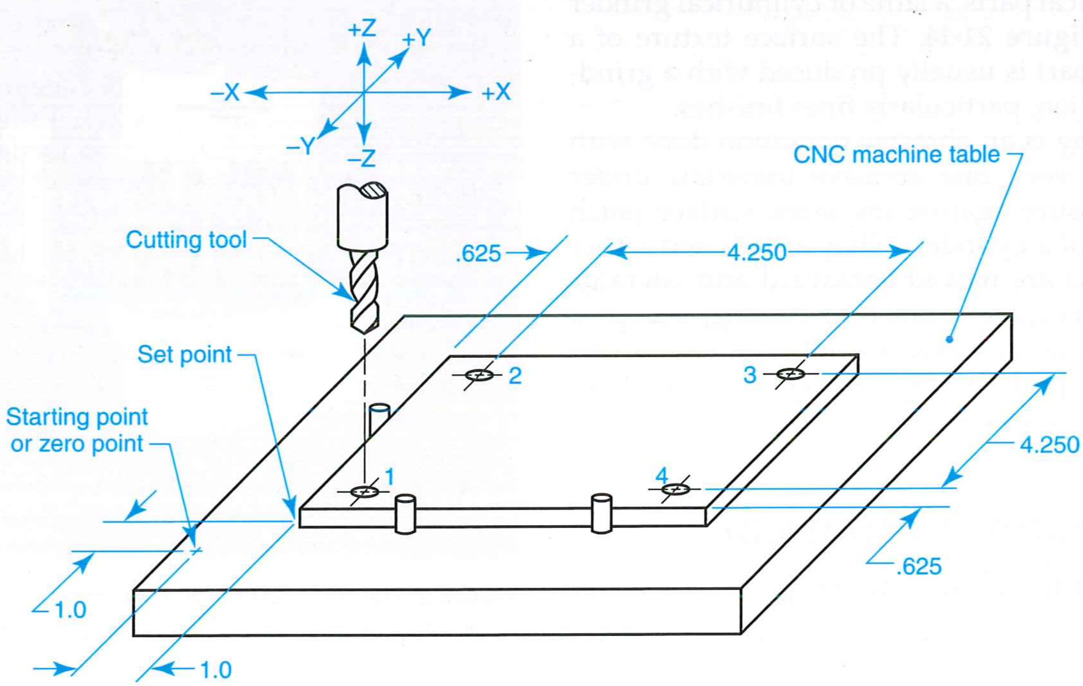


Figure 21-16. Cutting tool movement on a CNC machine is commonly based on the absolute positioning or incremental positioning reference point system. In the absolute positioning system, each move is referenced to the zero point (shown at lower left). In the incremental positioning system, distance and direction are referenced to the end point of the last move.

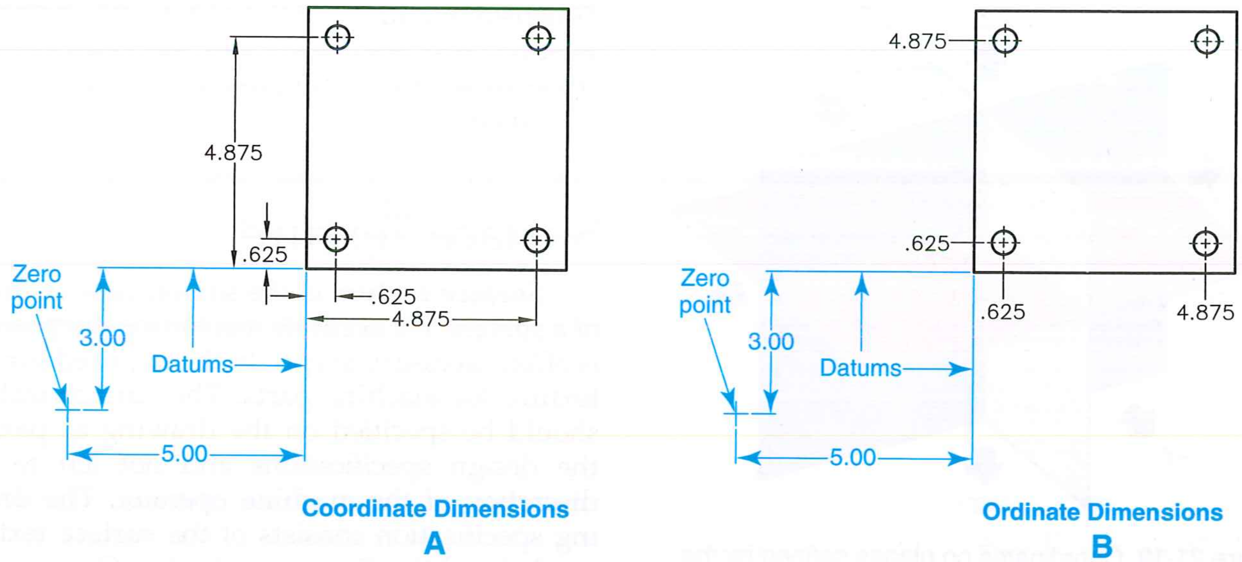


Figure 21-17. Drawings used with the absolute positioning system in CNC machining are dimensioned with datum dimensions. A—Coordinate dimensions. B—Ordinate dimensions.

the second hole is defined as X = 0.0, Y = 4.250 from the previous location. The third hole is defined as X = 4.250, Y = 0.0. The fourth hole is defined as X = 0.0, Y = 4.250. The programming to return the CNC tool to its zero point would be X = 5.875, Y = 1.625.

Incremental dimensions should be represented on drawings as chain (or successive) dimensions, **Figure 21-18**. The programmer can read these directly without having to calculate individual settings for preparing the documents needed to write the program that feeds information into the CNC machine control unit. These dimensions are the same as basic dimensions in that they are untoleranced. The tolerances that can be held between features in CNC machining are built into the machine. Toleranced dimensions on the drawing would not change the machined part.

Interpreting a CNC Program

In CNC machining, a drawing is used to prepare a set of instructions called a ***CNC program***. It will help you in drawing for CNC machining if you understand how a CNC machine responds to commands and moves the tool or the workpiece to the desired location.

A CNC machine is configured for either a ***fixed zero setpoint*** or a ***floating zero setpoint***. In the fixed zero system, the machine refers to the established point as the zero point; parts to be machined are located with reference to this point. In the floating zero system, the CNC programmer may establish the zero point at any convenient point by coding it into the program.

Instructions for a CNC program are given as two- or three-dimensional coordinates on planes defined by the axes of the Cartesian coordinate system, **Figure 21-19**. When the operator is facing a vertical spindle machine, table movement to the left or right is along the X axis. Table movement away from the operator or toward the operator is along the Y axis. Vertical movement of the working tool is along the Z axis. Machining of

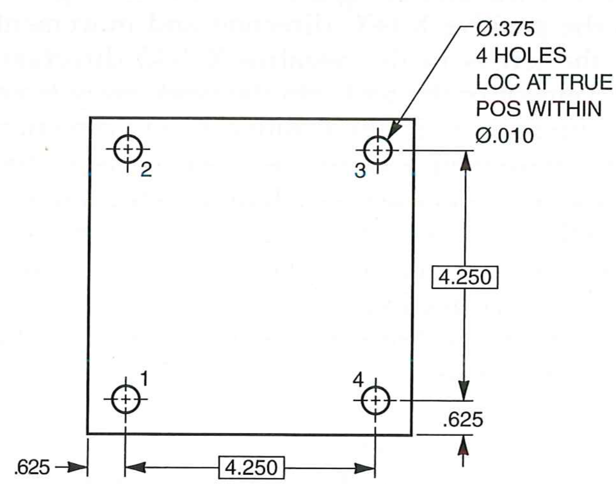


Figure 21-18. Chain dimensions are used for dimensioning drawings for CNC machines that use the incremental positioning system.

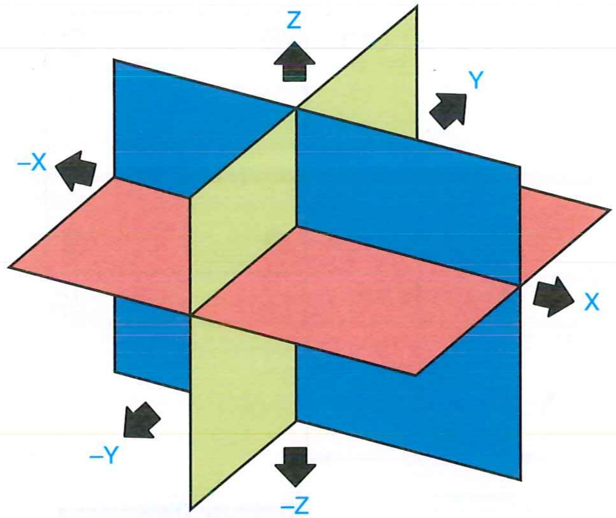


Figure 21-19. Coordinates on planes defined by the axes of the Cartesian coordinate system are used to describe movements of the tool or workpiece on a CNC machine. Movements to the left or right are on the X axis. Movements toward or away from the operator are on the Y axis. Vertical movements are along the Z axis.

some parts requires the use of only the X and Y axes; other operations require X, Y, and Z axis movement.

It is easier to understand the direction of movement if you assume the table remains stationary and the tool moves over the work. When the work is located on the table with the datum zero point at the zero point of the machine, movement of the tool along the X axis to the right is in the positive X (+X) direction and movement to the left is in the negative X (–X) direction. Movement of the tool into the work away from the operator is in the positive Y (+Y) direction and movement toward the operator is in the negative Y (–Y) direction. Tool movement down into the work is in the negative Z (–Z) direction and movement up from the work is in the positive Z (+Z) direction.

Tool movements are assumed to be in the positive (+) direction unless marked negative (–). It is therefore desirable to establish the datum zero point on a drawing in the lower left-hand corner or at a point just off the part to be machined. Refer to **Figure 21-18**.

When the zero point is located in this manner, all datum dimensions are positive (+) dimensions and do not need to be indicated as such. This also eliminates the possibility of errors in working with positive (+) and negative (–) dimensions.

Surface Texture

Surface texture is the smoothness or finish of a surface. For accurate machining purposes, it is often necessary to specify the required surface texture for machine parts. The surface texture should be specified on the drawing as part of the design specifications and not left to the discretion of the machine operator. The drawing specification consists of the surface texture symbol and the dimensional value. Conventions for specifying surface texture are discussed in Chapter 16.

Surface roughness is measured in microinches or micrometers. The abbreviation for *micro* (one-millionth) is the Greek letter μ. A value in microinches uses the abbreviation μin. and a value in micrometers uses the abbreviation μm. Surface texture is measured by using an instrument called a ***profilometer*** or a similar device. See **Figure 21-20**.

Machine processes such as milling, shaping, and turning can produce surface textures in the order of 125 μin. to 8 μin. (3.2 μm to 0.2 μm). Grinding operations can produce surface textures

Figure 21-20. A surface roughness analyzer can measure up to 50 different surface finish parameters and display the results on screen. (Federal Products Co.)

in the range of 64 µin. to 4 µin. This depends on the coarseness of the wheel and rate of feed. Honing and lapping remove only very small amounts of metal and produce surface textures as fine as 2 µin.

Typical surface roughness values, ranging from "very rough" to "extremely smooth machine finish," are listed in **Figure 21-21**.

Linking Design and Manufacturing

Increased global competition in manufacturing is causing industrial leaders to rethink their production plans. Developments in computers and manufacturing continue to prompt these leaders to look at new strategies for remaining competitive and improving the quality of their products. Developments in the computer industry are having a profound impact on manufacturing at all levels from design to machine processing. The management and marketing components of manufacturing companies are also affected.

The following sections are presented to help you develop a knowledge and understanding of modern manufacturing strategies and processes. The advantages of these processes, as well as the effects they are likely to have on the design and drafting component of industry, are also discussed.

Computer-Aided Drafting (CAD)

The growth of ***computer-aided drafting (CAD)*** has had a major impact on design and manufacturing. CAD is an essential tool that is used throughout the design, testing, and manufacture of products. The acronym *CAD* is used to refer to computer-aided drafting as

Surface Roughness

Roughness Height Ratio		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	Coarse	Very coarse surface grind, rapid feeds in turning, planing, milling, boring, and filing.
3.2	125	Medium	Machining 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 finish	Very smooth reaming or fine cylindrical or surface grinding, or coarse 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.

Figure 21-21. Surface roughness values produced by common machine processes.

well as computer-aided drafting and design. In manufacturing applications where CAD is part of the design process, it is assumed that the documentation will result in the production of computer-generated drawings and other documents essential to the entire manufacturing cycle, **Figure 21-22**.

Development of CAD

In the initial development of CAD as a drafting tool, the principal uses of the technology were producing and maintaining drawings. There was significant value even in the generation of drawings, since considerable time savings could be realized through the ready application of drawing symbols, dimensioning elements, and visualization tools. But it was realized that CAD had much more to offer in the design of a product. Related data such as alternate designs for the product, costs, and materials analysis could be stored in a database, ready for instant recall. In addition, information generated in the design process could be extended for use in manufacturing as the concept of the automated factory developed.

Figure 21-22. Computer-generated drawings are essential to the design process. (Hewlett-Packard)

Use of computer networking in design and manufacturing

In today's highly competitive manufacturing environment, the designer does not have the luxury of redesigning or reworking a product once the manufacturing process has begun. The design selected for manufacture must be the best among several that have been tested by thoroughly analyzing alternate designs, material options, machine processes, and labor costs. Anything less than top performance in product design contributes to problems in a number of areas. These include manufacturability, cost overruns, product failure in service, and lack of customer confidence in the company. Poorly designed products eventually contribute to a company's failure.

Perfecting the manufacturability of a product requires the capability to thoroughly examine design alternatives. As part of this process, it is important to be able to access knowledge gathered from previous experience in design work. Computer networking systems help streamline this process. A ***network*** is a group of computers connected together to permit shared access to electronic data and resources. Networks used in large industrial operations, such as a manufacturing plant, make it possible for a number of sources to retrieve information from a database. A ***database*** is a collection of information that can be recalled by a computer from electronic storage. A database may consist of numerical information, text, or graphics. When used in conjunction with manufacturing systems, a database is stored in a central computer that is networked to different computers. The network permits data to be accessed through different phases of production and helps the designer make wise decisions during the design process.

How CAD works as a subsystem of CIM

CAD is one subsystem of computer-integrated manufacturing (CIM), **Figure 21-23**. CIM is an automated manufacturing system that joins the functions of a variety of subsystems. It is discussed in greater detail later in this

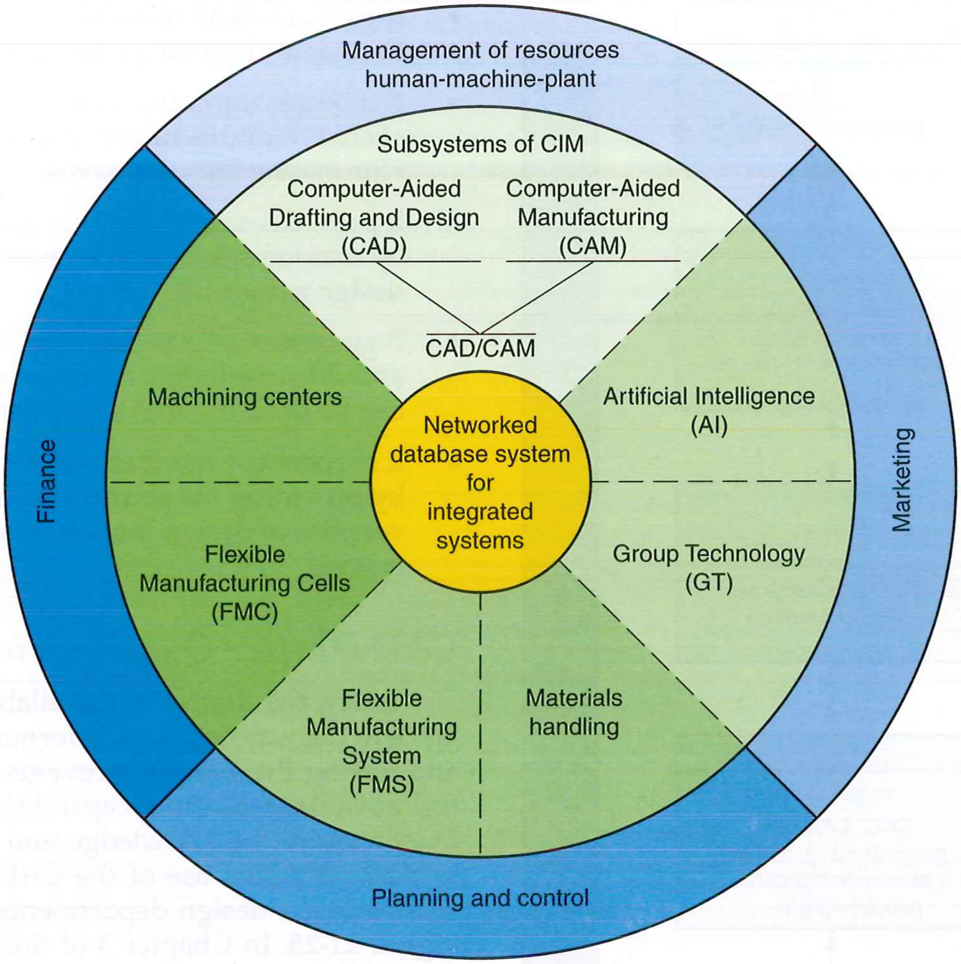


Figure 21-23. Components of computer-integrated manufacturing (CIM). CAD is a subsystem of CIM.

chapter. The CAD subsystem plays an integral role in the design process. With the assistance of CAD equipment, designers are able to analyze, test, and discuss each design decision. Specialists in materials, tooling, process planning, sales, and marketing also provide input to the design process. Once the design decision has been made, information is entered into the central computer's database for use and adaptation to other subsystems in the manufacturing process, **Figure 21-24**. When the accepted design for a product leaves the CAD department, it is assumed to meet all requirements for manufacturability and customer needs.

Advantages of CAD

CAD provides many advantages for the design and drafting department. The following are a few of these advantages:

- It removes the need for tedious calculations by designers and drafters.
- It saves valuable time by allowing the generation of notes, bills of materials, and symbols on drawings.
- It eliminates many of the time-consuming tasks of manual drafting, such as drawing lines, creating geometric shapes, and measuring distances.

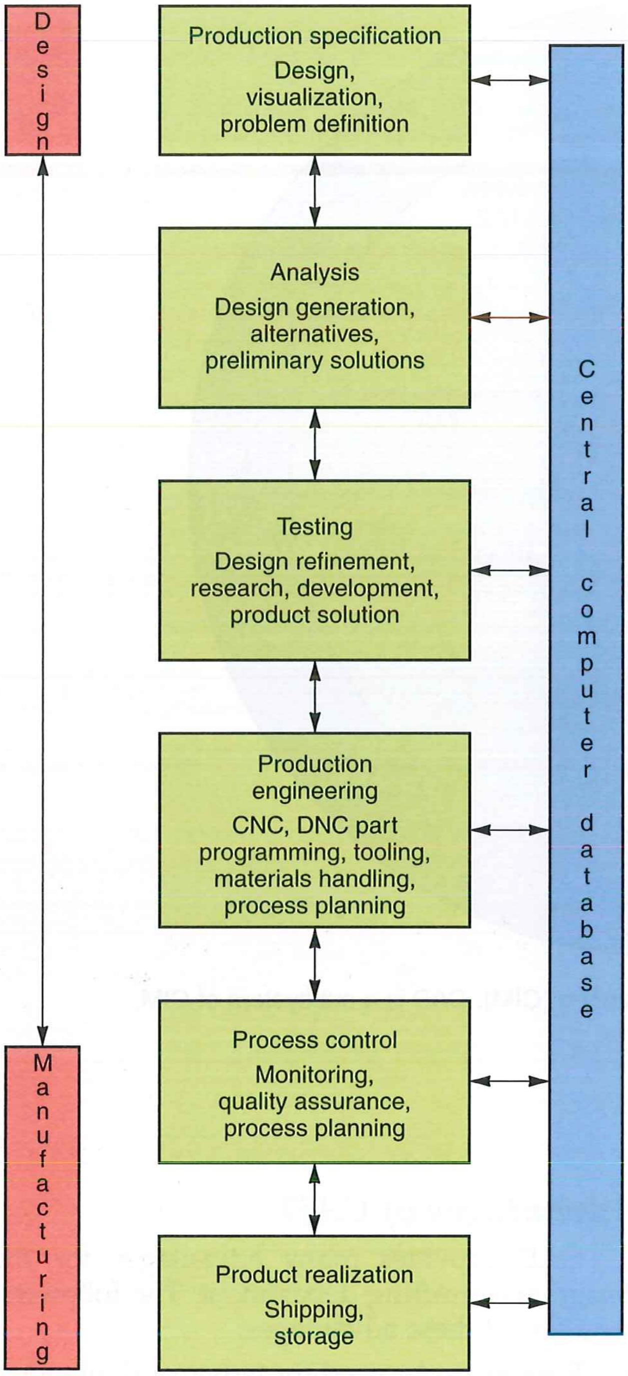


Figure 21-24. In an automated manufacturing system, the central computer database links design and manufacturing.

- It provides both the time and essential data to review alternate design solutions.
- It requires input from other departments, such as manufacturing and sales, thus eliminating later problems.
- It provides more reliability in design work by making relevant information available to design personnel.
- It generates a CAD database on the design and documentation of the product, which can be used in other subsystems of CIM.
- It reduces the number of drawings required by providing the ability to retrieve different versions of design models whenever needed.

CAD Drafter Qualifications

Today, the drafter has available more assistance in the way of design information, analysis, and testing than at any previous time. To take full advantage of these capabilities, the drafter must acquire the knowledge and skills needed to make effective use of the CAD systems that will be in the design departments of tomorrow, **Figure 21-25**. In Chapter 3 of this textbook, the fundamentals of computer-aided drafting and design are presented to assist you in getting started in computer graphics.

Computer-Aided Manufacturing (CAM)

Computer-aided manufacturing (CAM) is a natural extension of CAD technology. CAM can be defined as a manufacturing method that uses mills, lathes, drills, punches, and other programmable production equipment under computer control, **Figure 21-26**. The term ***CAD/CAM*** refers to the combination of CAD

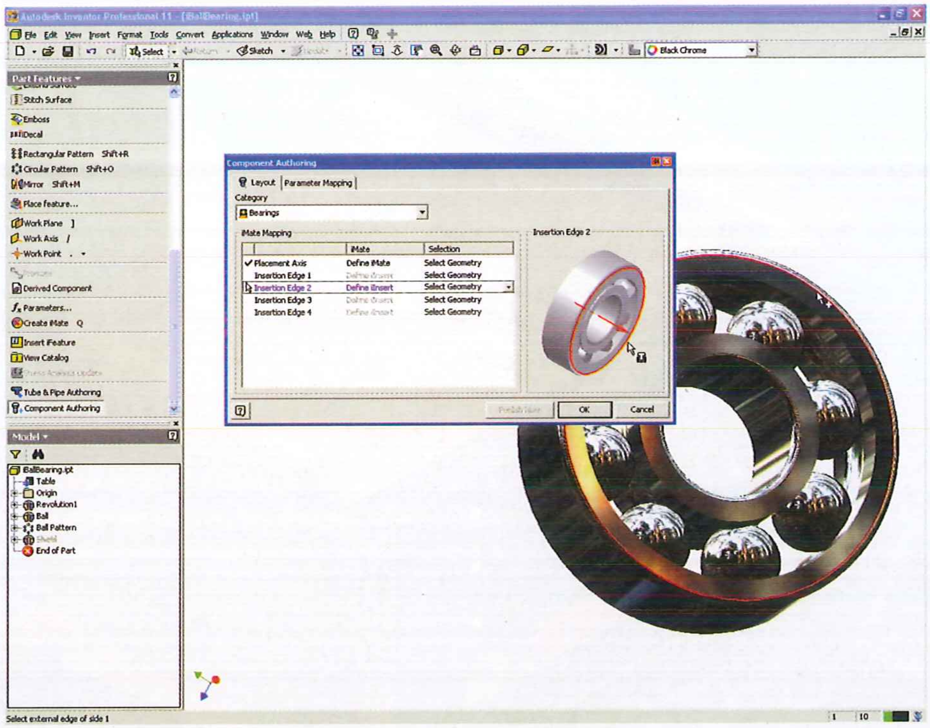


Figure 21-25. Advanced CAD software programs like this parametric modeling program are used to create three-dimensional models based on design data used in manufacturing. This type of modeling ties drafting and design closely together. (Autodesk, Inc.)

Figure 21-26. A CNC electrical discharge machine. The operator is using a multifunction remote control for the unit. (Mitsubishi)

with automated manufacturing. CAM machines are CNC machines that can be programmed to perform a wide variety of machine processes at great speed, while holding close tolerances. Programmable robotic equipment is also essential to a CAM environment.

CAD and CAM are linked together by the design data used in the development of the product, **Figure 21-27**. The same data is used by production engineering to program CAM equipment. Computers are also used in a CAM facility to control production scheduling and quality control, as well as business functions such as purchasing, financial planning, and marketing.

Numerical Control (NC) Machines

When numerical control (NC) was first introduced as a method of programming and controlling production machine tools, instructions (or "programs") were stored on perforated punch cards. Later, punched paper tape was used to store and "play back" a program. Since these methods

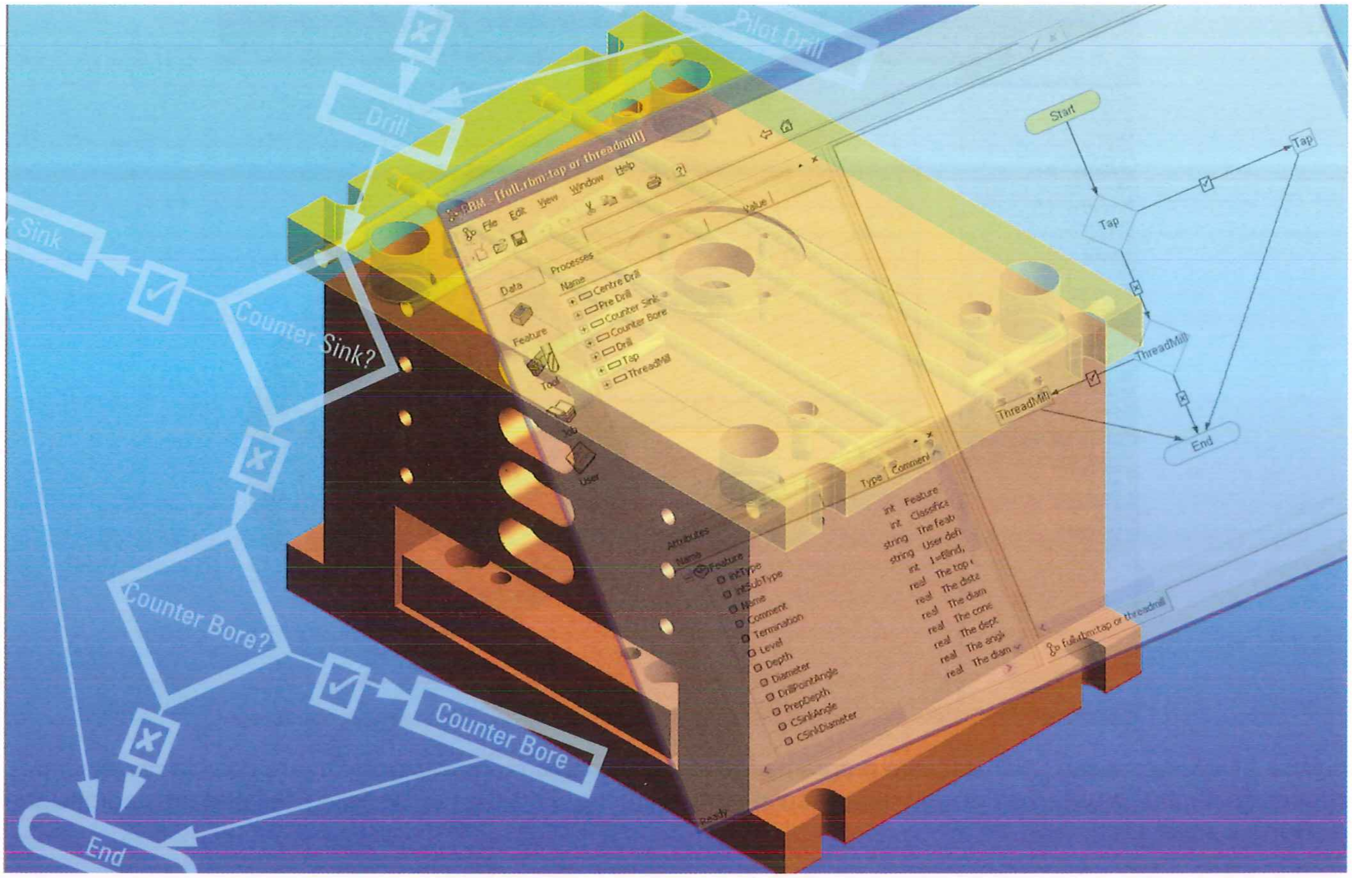


Figure 21-27. In addition to solid modeling tools, CAD/CAM software provides an interface for managing the design data used in manufacturing. The software details the actual tooling operations used in manufacturing the part. (EdgeCAM/Pathtrace)

of numerical control were subject to damage in a machine tool environment, the paper tape was replaced by more durable plastic tape.

Now, computers control NC machines. In CNC machining, a computer is used to write, store, edit, and execute a program. One method of computer numerical control used in manufacturing is ***direct numerical control (DNC)***. In this method, the computer serves as the control unit for one or more CNC machines. See **Figure 21-28**. A more advanced method is ***distributed numerical control (DNC)***. In this method, a main computer controls several intermediate computers that are coupled to certain machine tools, robots, and inspection stations.

Robotic Equipment

For a number of years, robots have been performing tasks of varying difficulty in industry, **Figure 21-29**. Single-purpose devices that cannot be reprogrammed to perform other tasks (such as those that merely transfer a part from one machine to another) do not fit the accepted definition of "robot." The Robotic Industries Association defines a ***robot*** as "a programmable multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks." This defines a tool that is flexible and capable of functioning in a number of industrial settings just like any other programmable machine.

Advantages of CAM

Many of the advantages provided by CAM come from its linkage with CAD as CAD/CAM. As manufacturing becomes more computer-based and moves toward full integration in all

Figure 21-28. A machine operator uses a DNC computer keyboard to load the appropriate program for a part to be processed in a machining center. The computer on the machine is linked with the factory's central computer to make use of the information stored in a central database. (DLoG-Remex)

facets of design, production engineering, process control, and marketing, the advantages of CAD/CAM will become even more pronounced. Advantages provided by CAM include the following:

- Communications are improved by the direct transfer of documentation from design to manufacturing.
- Production is more efficient and output is increased.
- Errors are reduced with design and manufacturing sharing the same database.
- Materials handling and machine processing are more efficient.
- Quality control is improved.
- Lead times are reduced, improving market response.
- The work environment is safer.

How CAM works as a subsystem of CIM

The scope of CAM may be limited to a single machining cell, or it may be expanded to include an entire department or facility, achieving what is referred to as CIM. The following sections describe automated manufacturing systems usually found in a more comprehensive CIM installation.

Machining Centers

A ***machining center*** is a CNC machine that is capable of performing a variety of material removal operations, such as drilling, milling, or boring. Usually, CNC machines are equipped with automatic tool changing and storage capabilities and part delivery or shuttle mechanisms. CNC turning centers, CNC grinding centers, and other machines are also available for stand-alone machining or for systems integration. See **Figure 21-30**.

Operations scheduled for machining centers are numerically controlled by computers. Sensors are built into the system to protect the equipment from overload and to maintain product quality. These sensors enable the controller to monitor the plant, process, and product. The

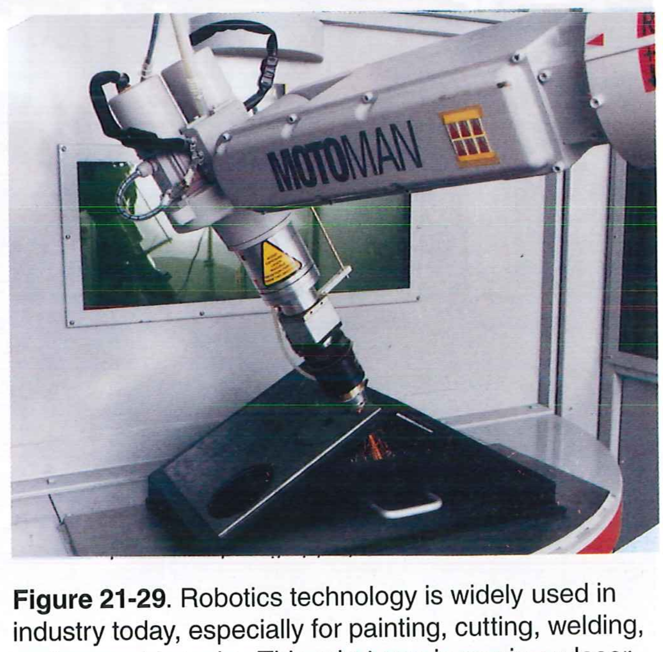


Figure 21-29. Robotics technology is widely used in industry today, especially for painting, cutting, welding, and assembly tasks. This robot arm is moving a laser cutting head, under CNC control, as it removes a precisely dimensioned circle of material from a metal plate. Fiber optic "light piping" channels the light beam from the laser generator to the cutting head. (Motoman)

Figure 21-30. This dual-spindle turning center can work on both ends of a part simultaneously, as well as perform secondary operations such as drilling or tapping. Note the tool-changing turret next to the orange-colored safety cover (the cover has been opened to show the turret). Loading of parts to be processed is done automatically by the gantry-type robotic loader at the left end of the machine. (Mazak Corporation)

flow of lubricants and coolants, tool life, and tool breakage are also monitored.

Machining centers require a minimum of operator supervision; work in process is limited only by pallet storage and the number of tools stored in the tool magazine. Machining centers are usually installed as integral parts of flexible manufacturing systems (FMS). The machining center is considered the smallest building block of a flexible manufacturing system.

Flexible Manufacturing Cells

A ***flexible manufacturing cell (FMC)*** consists of a grouping of machine tools organized into a working unit. This is sometimes referred to as a *flexible manufacturing center*. A flexible manufacturing cell is usually configured to perform virtually all of the machining processes needed to produce a part or a family of parts. Another form of the FMC is a grouping of like machines dedicated to a particular type of machining process, such as a small group of horizontal machining centers. See **Figure 21-31.**

Figure 21-31. This flexible manufacturing cell consists of two horizontal machining centers served by a rail-guided pallet transporter. A load-unload station and a remote staging terminal are used with the 13 parts-holding pallets that help ensure continuous flow of material through the machining centers. (Cincinnati Milacron)

The equipment in an FMC can be linked by automated handling equipment, such as a robot, a conveyor and pallet system, or ***automated guided vehicles (AGVs)***. Automated guided vehicles are typically small, wheeled vehicles that follow a preprogrammed path to deliver parts or assemblies. Operation of the FMC is often directed by a device called a *cell controller*, which may be a computer or a ***programmable logic controller (PLC)***. The PLC is a simpler device than a computer, and is programmed using a step-by-step method called ***ladder logic***. A *ladder logic diagram* is a line diagram made up of rows that resemble the rungs of a ladder. The PLC "looks" along the rungs to determine the programming information.

Flexible Manufacturing Systems

A ***flexible manufacturing system (FMS)*** is a production approach that consists of highly automated and computer-controlled machines (machining cells, robots, and inspection equipment) connected through the use of integrated materials handling and storage systems. The automated manufacturing operation is monitored and controlled from a central location.

The term *flexible* refers to the system's ability to process a variety of similar products and to reroute or reschedule production in the event of equipment failure. Flexible manufacturing systems are designed to deliver quality output in a cost-effective manner and to respond quickly to changing production demands.

Advantages of the FMS

The flexible manufacturing system has many advantages, and is the form of manufacturing that most closely approaches CIM. The FMS offers the following advantages:

- The volume of production is increased while costs are decreased.
- Single parts or batches of parts may be manufactured in random order, as needed.
- Parts may be produced "on order," rather than in large lots that must be warehoused, thereby reducing inventory.
- Quality control is improved by using 100% inspection.
- Hazardous and repetitive work is reduced, making the work environment safer and more pleasant.

Group Technology (GT)

Group technology (GT) is a manufacturing philosophy that consists of organizing components into families of parts for production. These parts are similar in design or in manufacturing requirements. The design characteristics are similar in terms of materials, dimensions and tolerances, shape, and finish. Similarity in manufacturing characteristics might include such factors as tool and machine processes, fixtures required, and sequence of operations. Group technology is considered an essential element in the implementation of CIM.

Advantages of GT

Although there is expense involved in coding and organizing products for the use of group technology, there are also some distinct advantages. In addition to improved product design, group technology provides for standardization and the establishment of families of parts, thereby reducing costs. Tooling and setup costs are also reduced, and ***work-in-progress (WIP)*** manufacturing is reduced. Work-in-progress is a term indicating that a product has not yet been completed, and that more processes have to be performed.

Just-in-Time (JIT) Manufacturing

One of the most widely accepted concepts introduced to manufacturing in recent years has been the ***just-in-time (JIT)*** philosophy. In this method of operation, the goal is to reduce work-in-progress to an absolute minimum. This involves the reduction of lead times, reduction of actual WIP inventories, and reduction of setup times. See **Figure 21-32**.

The conventional approach in industry has been to automate existing processes of machining and assembly, which has resulted in isolated cells of production, or "islands of automation." This leads to costly periods of waiting time between cells, rather than a smooth, efficient flow of material between production processes.

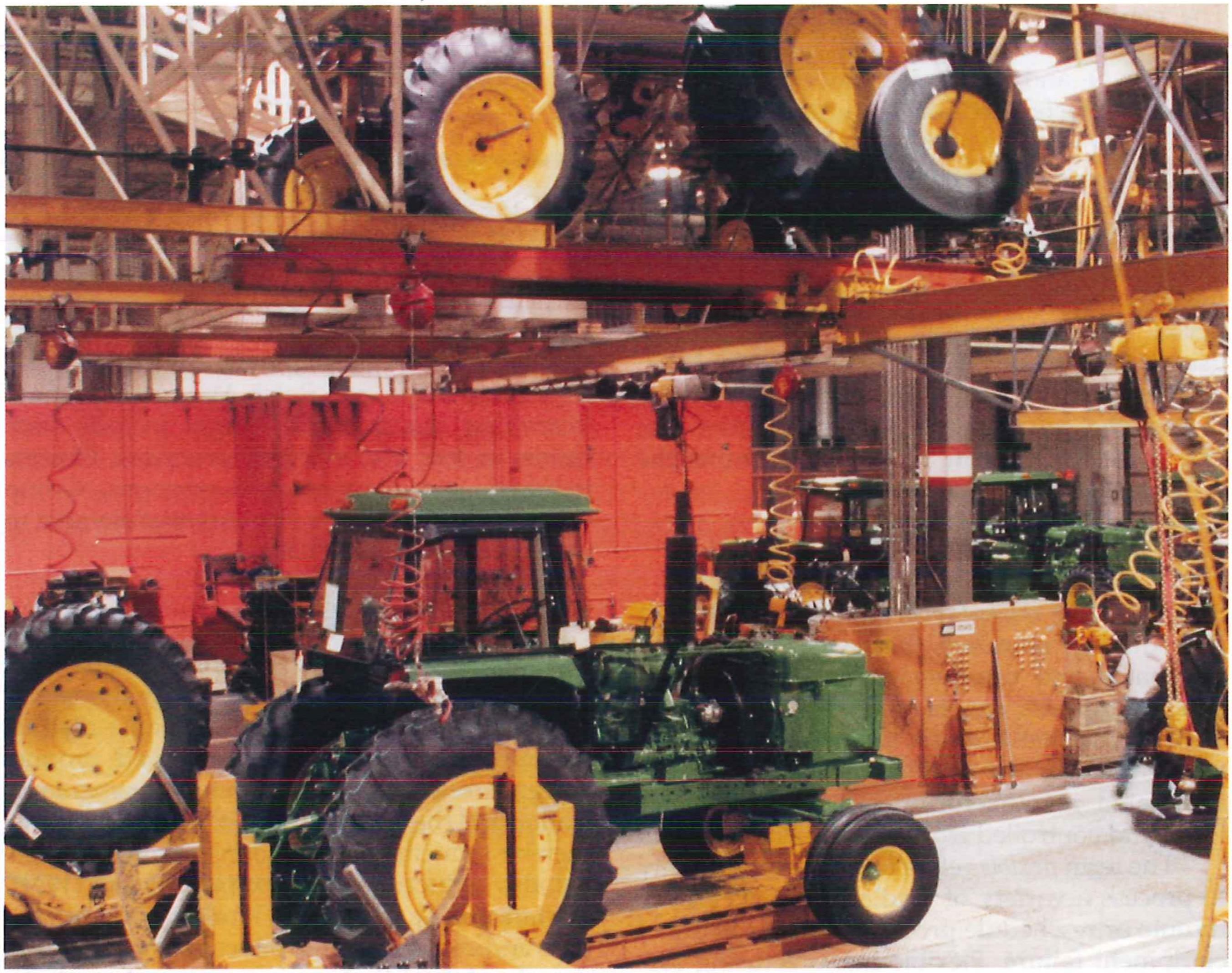


Figure 21-32. Application of the JIT philosophy to manufacturing operations, such as this tractor assembly line, emphasizes delivery of parts in the correct quantity, exactly when needed. By avoiding the stockpiling of materials and parts, costs are reduced and efficiency is increased. (John Deere & Company)

The most efficient system moves the product to be manufactured from the firm's suppliers to its customers in a continuous manner with few or no rejects.

The JIT system regards production processes as the only means of adding value to a manufactured product. All other tasks such as transportation, inspection, and storage are defined as "wastes" to be eliminated wherever possible. An efficient production system requires a highly consistent, short-cycled process with minimal inventory in process.

Suppliers to a manufacturer using JIT are expected to function as a coordinated part of the system, delivering materials or parts "just-in-time" for use on the line. Supply and manufacturing both work in terms of small lot sizes, as opposed to purchasing or manufacturing large quantities and storing a portion until needed. Traditional large inventory practices require capital to be invested in nonproductive supplies and storage facilities.

Artificial Intelligence (AI) and Expert Systems

The application of ***artificial intelligence (AI)*** is an attempt to program a computer with the data and range of possible responses needed to allow it to identify a problem and make decisions on the best solution to that problem. This type of problem solving would normally be associated only with human intelligence. Speech recognition, language interpretation, and visual interpretation (scene interpretation) are among the tools used in this branch of computer science.

Expert systems technology is an application of AI. An expert system's software uses knowledge and inference procedures to solve problems. A fundamental concept involved in the operation of an expert system is its ability to "learn" and adapt its responses from information it gathers, rather than function strictly with firm, programmed decisions.

This brief description is an oversimplification of the applications of AI and expert systems. Until further progress is made in these areas, human interaction with automated manufacturing is likely to remain.

Computer-Integrated Manufacturing (CIM)

In the strictest sense, ***computer-integrated manufacturing (CIM)*** is the full automation and joining of all facets of an industrial enterprise—design, documentation, materials selection and handling, machine processing, quality assurance, storage and/or shipping, management, and marketing. There are few, if any, CIM installations at this time that fully meet the definition. There are, however, many partial CIM systems (such as CAD/CAM, FMS, and FMC installations) in operation, especially in the automotive, aircraft production, electronics, and electrical equipment industries. These partial CIM facilities vary widely in size and complexity.

Advantages of CIM

The advantages of CIM in today's manufacturing enterprises are applicable to some extent to any of the subsystems of CIM. CIM and other types of automation systems improve productivity and efficiency in manufacturing, while reducing costs of production and making industry more competitive. Computer control of production operations also increases the effectiveness of quality control activities, improving product reliability. It also makes the workplace safer and working conditions more pleasant for workers.

Future Developments in CIM

Over a relatively short period of time, computer systems have developed in capacity and speed while significantly decreasing in cost. This reinforces the strong trend toward computer-integrated manufacturing. To become fully effective, however, CIM must be improved in relation to its adaptive characteristics, where the technology adopts the ability to make decisions through self-determination. This will be accomplished when computer designers develop systems that can learn and respond with the kind of decision-making skills a worker gains from experience, **Figure 21-33**. Progress in the area of artificial intelligence and the application of computer technology will further enhance CIM. As CIM becomes more and more the standard in manufacturing, industry will increasingly require individuals who understand the role of computer technology and the design and manufacturing problems that must be solved.

Chapter Summary

Drafters should be familiar with the common machining processes used in manufacturing. Some of these processes include drilling, spotfacing, counterboring, countersinking, counterdrilling, boring, reaming, broaching, stamping, and grinding. Features to be machined in a certain way must have the machine process specified on the drawing.

Computer numerical control (CNC) machining is a means of controlling machine tools. CNC machining involves programming instructions for tool movement and machine operations. Drawings made for CNC machining are dimensioned using one of two positioning methods. Absolute positioning involves specification of all distances and directions from a zero point. In incremental positioning, distances and directions are specified from a previous position, rather than a fixed zero point.

Surface texture is the smoothness or finish of a surface and is specified on drawings using

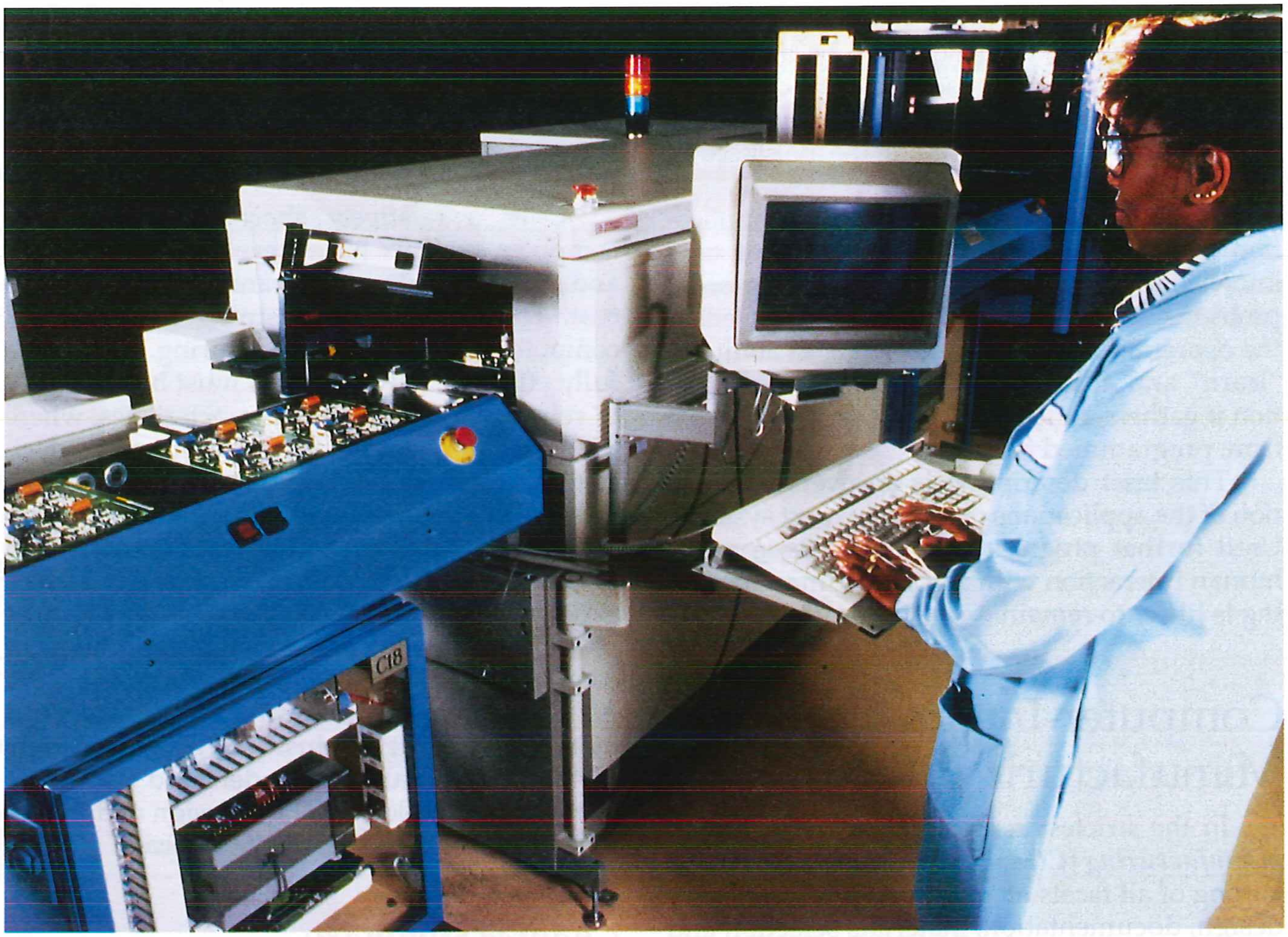


Figure 21-33. Products are tested on an in-line, in-circuit test machine that provides information used to monitor product quality and make necessary changes in manufacturing processes. Computer system designers are attempting to develop software that will be able to make the types of experience-based decisions made by human operators. (Allen-Bradley Company)

standard dimensioning conventions. Surface texture is measured in microinches or micrometers.

Significant advances have been made in automated manufacturing in response to increased competition in industry. The growth of computer technology led to the development of a database that could be applied to the manufacturing process. Computer-aided drafting (CAD) eliminates many time-consuming drafting tasks and increases accuracy by reducing the need for manual calculations. To function effectively in the future, designers and drafters must acquire the knowledge and skills needed to make use of CAD.

Computer-aided manufacturing (CAM) involves the use of programmable machines that can produce parts rapidly to close tolerances. CAD/CAM improves efficiency by permitting the direct transfer of information from design to manufacturing.

Flexible manufacturing cells usually perform all of the machining operations needed to produce a finished part or family of parts. This production approach utilizes fully automated and computer-controlled machines, including machining cells, robots, and inspection equipment.

Group technology (GT) is a manufacturing approach in which similar parts are organized into families of parts for production purposes. The just-in-time (JIT) manufacturing concept improves efficiency and cuts costs by eliminating most work-in-progress inventory.

Computer-integrated manufacturing (CIM) is the ultimate form of automated manufacturing. It involves every facet of a business from product design through manufacturing and marketing.

Review Questions

1. A _____ is a note that gives a dimension specification or a machine process.
2. What is *spotfacing*?
3. What is the difference between counterboring and spotfacing?
4. Countersinking is done by cutting a _____ edge (chamfer) in a hole so that a flat head screw will seat flush with the surface.
5. What is *broaching*?
6. Forming straight-line or diagonal-line serrations on a part to provide a better hand grip or interference fit is called _____.
7. A _____ is a small bevel cut on the end of a hole, shaft, or threaded fastener to facilitate assembly.
8. What is a *taper*?
9. Define *computer numerical control machining.*
10. Does a drawing to be used in preparing a program for CNC machining differ from a standard drawing? Why or why not?
11. Explain the meaning of *surface texture.* How is it measured?
12. What is a *network* and how is it used in conjunction with a database?
13. List some of the advantages provided by a CAD system in design and drafting.
14. The term _____ refers to the combination of CAD with automated manufacturing.
15. How does a machining center differ from a flexible manufacturing cell (FMC)?
16. A programmable logic controller is programmed using a step-by-step method called _____.
17. What is *group technology (GT)*?
18. What is the goal of the just-in-time method of operation?
19. Expert systems technology is an application of _____.
20. What is *computer-integrated manufacturing (CIM)*?