CHAPTER 37

COMPUTER-INTEGRATED MANUFACTURING

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37.1 INTRODUCTION

Modern manufacturing systems are advanced automation systems that use computers as an integral part of their control. Computers are a vital part of automated manufacturing. They control stand-alone manufacturing systems, such as various machine tools, welders, laser-beam cutters, robots, and automatic assembly machines. They control production lines and are beginning to take over control of the entire factory. The computer-integrated-manufacturing system (CIMS) is a reality in the modern industrial society. As illustrated in Fig. 37.1, CIMS combines computer-aided design (CAD), computer-aided manufacturing (CAM), computer-aided inspection (CAI), and computer-aided pro-

Mechanical Engineers' Handbook, 2nd ed., Edited by Myer Kutz.
ISBN 0-471-13007-9

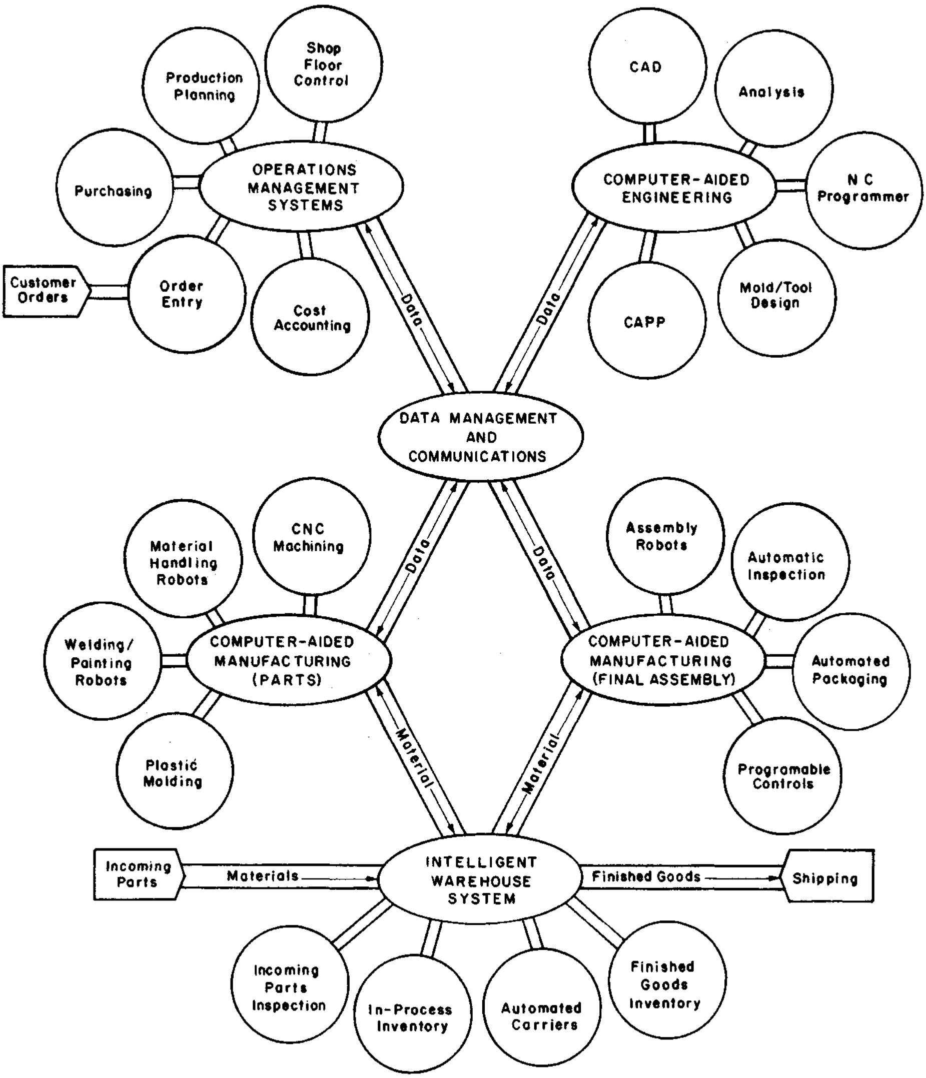

Fig. 37.1 Computer-integrated manufacturing system.

duction planning (CAPP), along with automated material handling. This chapter focuses on computer-aided manufacturing for both parts fabrication and assembly, as shown in Fig. 37.1. It treats numerical-control (NC) machining, robotics, and group technology. It shows how to integrate these functions with automated material storage and handling to form a CIM system.

37.2 DEFINITIONS AND CLASSIFICATIONS

37.2.1 Automation

Automation is a relatively new word, having been coined in the 1930s as a substitute for the word *automatization,* which referred to the introduction of automatic controls in manufacturing. Automation implies the performance of a task without human assistance. Manufacturing processes are classified as manual, semiautomatic, or automatic, depending on the extent of human involvement in the ongoing operation of the process.

The primary reasons for automating a manufacturing process are to

1. Reduce the cost of the manufactured product, through savings in both material and labor
2. Improve the quality of the manufactured product by eliminating errors and reducing the variability in product quality
3. Increase the rate of production
4. Reduce the lead time for the manufactured product, thus providing better service for customers
5. Make the workplace safer

The economic reality of the marketplace has provided the incentive for industry to automate its manufacturing processes. In Japan and in Europe, the shortage of skilled labor sparked the drive toward automation. In the United States, stern competition from Japanese and European manufacturers, in terms of both product cost and product quality, has necessitated automation. Whatever the reasons, a strong movement toward automated manufacturing processes is being witnessed throughout the industrial nations of the world.

37.2.2 Production Operations

Production is a transformation process in which raw materials are converted into the goods demanded in the marketplace. Labor, machines, tools, and energy are applied to materials at each of a sequence of steps that bring the materials closer to a marketable final state. These individual steps are called *production operations*.

There are three basic types of industries involved in transforming raw materials into marketable products:

1. *Basic producers*. These transform natural resources into raw materials for use in manufacturing industry—for example, iron ore to steel ingot in a steel mill.
2. *Converters*. These take the output of basic producers and transform the raw materials into various industrial products—for example, steel ingot is converted into sheet metal.
3. *Fabricators*. These fabricate and assemble final products—for example, sheet metal is fabricated into body panels and assembled with other components into an automobile.

The concept of a computer-integrated-manufacturing system as depicted in Fig. 37.1 applies specifically to a "fabricator" type of industry. It is the "fabricator" industry that we focus on in this chapter.

The steps involved in creating a product are known as the "manufacturing cycle." In general, the following functions will be performed within a firm engaged in manufacturing a product:

1. *Sales and marketing*. The order to produce an item stems either from customer orders or from production orders based on product demand forecasts.
2. *Product design and engineering*. For proprietary products, the manufacturer is responsible for development and design, including component drawings, specifications, and bill of materials.
3. *Manufacturing engineering*. Ensuring manufacturability of product designs, process planning, design of tools, jigs, and fixtures, and "troubleshooting" the manufacturing process.
4. *Industrial engineering*. Determining work methods and time standards for each production operation.
5. *Production planning and control*. Determining the master production schedule, engaging in material requirements planning, operations scheduling, dispatching job orders, and expediting work schedules.
6. *Manufacturing*. Performing the operations that transform raw materials into finished goods.
7. *Material handling*. Transporting raw materials, in-process components, and finished goods between operations.
8. *Quality control*. Ensuring the quality of raw materials, in-process components, and finished goods.
9. *Shipping and receiving*. Sending shipments of finished goods to customers, or accepting shipments of raw materials, parts, and components from suppliers.
10. *Inventory control*. Maintaining supplies of raw materials, in-process items, and finished goods so as to provide timely availability of these items when needed.

Thus, the task of organizing and coordinating the activities of a company engaged in the manufacturing enterprise is complex. The field of industrial engineering is devoted to such activities.

37.2.3 Production Plants

There are several ways to classify production facilities. One way is to refer to the volume or rate of production. Another is to refer to the type of plant layout. Actually, these two classification schemes are related, as will be pointed out.

In terms of the volume of production, there are three types of manufacturing plants:

1. *Job shop production.* Commonly used to meet specific customer orders; great variety of work; production equipment must be flexible and general purpose; high skill level among workforce—for example, aircraft manufacturing.
2. *Batch production.* Manufacture of product in medium lot sizes; lots produced only once at regular intervals; general-purpose equipment, with some specialty tooling—for example, household appliances, lawn mowers.
3. *Mass production.* Continuous specialized manufacture of identical products; high production rates; dedicated equipment; lower labor skills than in a job shop or batch manufacturing—for example, automotive engine blocks.

In terms of the arrangement of production resources, there are three types of plant layouts. These include

1. *Fixed-position layout.* The item is placed in a specific location and labor and equipment are brought to the site. Job shops often employ this type of plant layout.
2. *Process layout.* Production machines are arranged in groups according to the general type of manufacturing process; forklifts and hand trucks are used to move materials from one work center to the next. Batch production is most often performed in process layouts.
3. *Product-flow layout.* Machines are arranged along a line or in a *U* or *S* configuration, with conveyors transporting work parts from one station to the next; the product is progressively fabricated as it flows through the succession of workstations. Mass production is usually conducted in a product-flow layout.

37.2.4 Models for Production Operations

In this section, we will examine three types of models by which we can examine production operations, including graphical models, manufacturing process models, and mathematical models of production activity.

Process-flow charts depict the sequence of operations, storages, transportations, inspections, and delays encountered by a workpart of assembly during processing. As illustrated in Fig. 37.2, a process-flow chart gives no representation of the layout or physical dimensions of a process, but

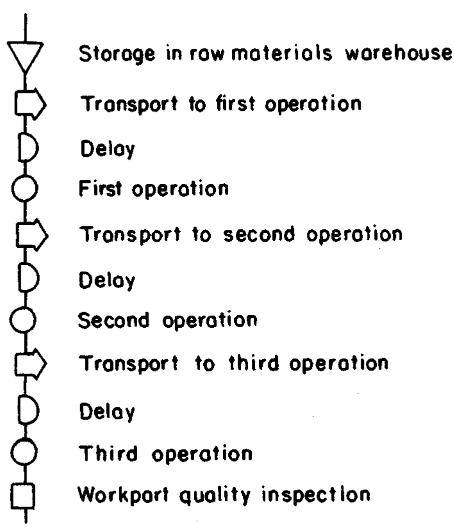

Fig. 37.2 Flow process chart for a sample workpart.

focuses on the succession of steps seen by the product. It is useful in analyzing the efficiency of the process, in terms of the proportion of time spent in transformation operations as opposed to transportations, storages, and delays.

The manufacturing-process model gives a graphical depiction of the relationship among the several entities that comprise the process. It is an input–output model. Its inputs are raw materials, equipment (machine tools), tooling and fixtures, energy, and labor. Its outputs are completed workpieces, scrap, and waste. These are shown in Fig. 37.3. Also shown in this figure are the controls that are applied to the process to optimize the utilization of the inputs in producing completed workpieces, or in maximizing the production of completed workpieces at a given set of values describing the inputs.

Mathematical models of production activity quantify the elements incorporated into the process-flow chart. We distinguish between operation elements, which are involved whenever the work part is on the machine and correspond to the circles in the process-flow chart, and nonoperation elements, which include storages, transportations, delays, and inspections. Letting T_o represent operation time per machine, T_{no} the nonoperation time associated with each operation, and n_m the number of machines or operations through which each part must be processed, then the total time required to process the part through the plant [called the manufacturing lead time (T_l)] is

$$T_l = n_m(T_o + T_{no})$$

If there is a batch of p parts,

$$T_l = n_m(pT_o + T_{no})$$

If a setup of duration T_{su} is required for each batch,

$$T_l = n_m(T_{su} + pT_o + T_{no})$$

The total batch time per machine, T_b, is given by

$$T_b = T_{su} + pT_o$$

The average production time T_a per part is therefore

$$T_a = \frac{T_{su} + pT}{p}$$

The average production rate for each machine is

$$R_a = 1/T_a$$

As an example, a part requires six operations (machines) through the machine shop. The part is produced in batches of 100. A setup of 2.5 hr is needed. Average operation time per machine is 4.0 min. Average nonoperation time is 3.0 hr. Thus,

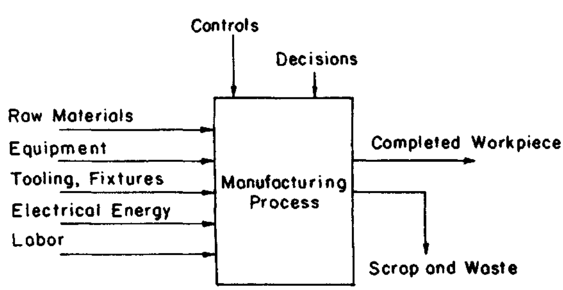

Fig. 37.3 General input-output model of the manufacturing process.

$$n_m = 6 \text{ machines}$$
$$p = 100 \text{ parts}$$
$$T_{su} = 2.5 \text{ hr}$$
$$T_o = 4/60 \text{ hr}$$
$$T_{no} = 3.0 \text{ hr}$$

Therefore, the total manufacturing lead time for this batch of parts is

$$T_l = 6[2.5 + 100(0.06667) + 3.0] = 73.0 \text{ hr}$$

If the shop operates on a 40-hr week, almost two weeks are needed to complete the order.

37.3 NUMERICAL-CONTROL MANUFACTURING SYSTEMS

37.3.1 Numerical Control

The most commonly accepted definition of numerical control (NC) is that given by the Electronic Industries Association (EIA): A system in which motions are controlled by the direct insertion of numerical data at some point. The system must automatically interpret at least some portion of these data.

The numerical control system consists of five basic, interrelated components, as follows:

1. Data input devices
2. Machine control unit
3. Machine tool or other controlled equipment
4. Servo-drives for each axis of motion
5. Feedback devices for each axis of motion

The major components of a typical NC machine tool system are shown in Fig. 37.4.

The programmed codes that the machine control unit (MCU) can read may be perforated tape or punched tape, magnetic tape, tabulating cards, or signals directly from computer logic or some computer peripherals, such as disk or drum storage. Direct computer control (DCC) is the most recent development, and one that affords the help of a computer in developing a part program.

37.3.2 The Coordinate System

The Cartesian coordinate system is the basic system in NC control. The three primary linear motions for an NC machine are given as X, Y, and Z. Letters A, B, and C indicate the three rotational axes, as in Fig. 37.5.

NC machine tools are commonly classified as being either point-to-point or continuous path. The simplest form of NC is the point-to-point machine tool used for operations such as drilling, tapping, boring, punching, spot welding, or other operations that can be completed at a fixed coordinate position with respect to the workpiece. The tool does not contact the workpiece until the desired coordinate position has been reached; consequently, the exact path by which this position is reached is not important.

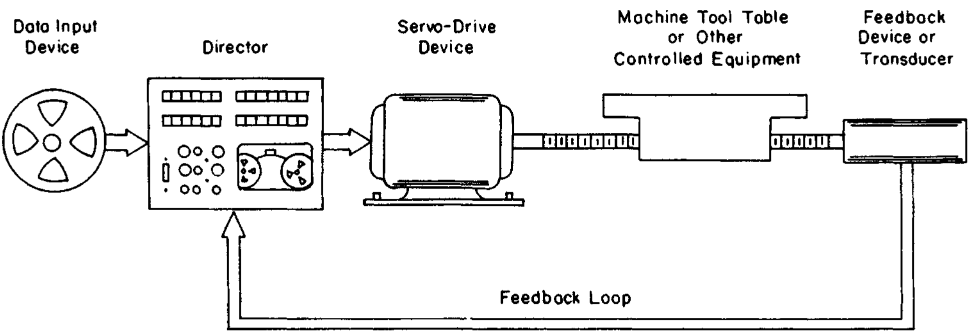

Fig. 37.4 Simplified numerical control system.

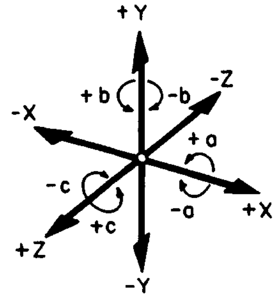

Fig. 37.5 An example of typical axis nomenclature for machine tools.

With continuous-path (contouring) NC systems, there is contact between the workpiece and the tool as the relative movements are made. Continuous-path NC systems are used primarily for milling and turning operations that can profile and sculpture workpieces. Other NC continuous-path operations include flame cutting, sawing, grinding, and welding, and even operations such as the application of adhesives. We should note that continuous-path systems can be programmed to perform point-to-point operations, although the reverse (while technically possible) is infrequently done.

37.3.3 Selection of Parts for NC Machining

Parts selection for NC should be based on an economic evaluation, including scheduling and machine availability. Economic considerations affecting NC part selection including alternative methods, tooling, machine loadings, manual versus computer-assisted part programming, and other applicable factors.

Thus, NC should be used only where it is more economical or does the work better or faster, or where it is more accurate than other methods. The selection of parts to be assigned to NC has a significant effect on its payoff. The following guidelines, which may be used for parts selection, describe those parts for which NC may be applicable.

1. Parts that require *substantial tooling costs* in relation to the total manufacturing costs by conventional methods
2. Parts that require *long setup times* compared to the machine run time in conventional machining
3. Parts that are machined in *small or variable lots*
4. A *wide diversity of parts* requiring frequent changes of machine setup and a large tooling inventory if conventionally machined
5. Parts that are *produced at intermittent times* because demand for them is cyclic
6. Parts that have *complex configurations* requiring close tolerances and intricate relationships
7. Parts that have *mathematically defined complex contours*
8. Parts that require *repeatability* from part to part and lot to lot
9. *Very expensive* parts where human error would be very costly and increasingly so as the part nears completion
10. *High-priority* parts where lead time and flow time are serious considerations
11. Parts with *anticipated design changes*
12. Parts that involve a *large number of operations* or *machine setups*
13. Parts where *non-uniform cutting conditions* are required
14. Parts that require 100% *inspection* or require measuring many checkpoints, resulting in high inspection costs
15. *Family of parts*
16. *Mirror-image parts*
17. *New parts* for which conventional tooling does not already exist
18. Parts that are suitable for *maximum machining* on NC machine tools

37.3.4 CAD/CAM Part Programming

Computer-Aided Design (CAD) consists of using computer software to produce drawings of parts or products. These drawings provide the dimensions and specifications needed by the machinist to produce the part or product. Some well-known CAD software products include *AutoCAD, Cadkey,* and *Mastercam.*

Computer-Aided Manufacturing (CAM) involves the use of software by NC programmers to create programs to be read by a CNC machine in order to manufacture a desired shape or surface. The end product of this effort is an NC program stored on disk, usually in the form of G codes, that when loaded into a CNC machine and executed will move a cutting tool along the programmed path to create the desired shape. If the CAM software has the means of creating geometry, as opposed to importing the geometry from a CAD system, it is called *CAD/CAM*. CAD/CAM software, such as Mastercam, is capable of producing instructions for a variety of machines, including lathes, mills, drilling and tapping machines, and wire electrostatic discharge machining (EDM) processes.

37.3.5 Programming by Scanning and Digitizing

Programming may be done directly from a drawing, model, pattern, or template by digitizing or scanning. An optical reticle or other suitable viewing device connected to an arm is placed over the drawing. Transducers will identify the location and translate it either to a tape puncher or other suitable programming equipment. Digitizing is used in operations such as sheet-metal punching and hole drilling. A scanner enables an operator to program complex free-form shapes by manually moving a tracer over the contour of a model or premachined part. Data obtained through the tracer movements are converted into tape by a minicomputer. Digitizing and scanning units have the capability of editing, modifying, or revising the basic data gathered.

37.3.6 Adaptive Control

Optimization processes have been developed to improve the operational characteristics of NC machine-tool systems. Two distinct methods of optimization are adaptive control and machinability data prediction. Although both techniques have been developed for metal-cutting operations, adaptive control finds application in other technological fields.

The adaptive control (AC) system is an evolutionary outgrowth of numerical control. AC optimizes an NC process by sensing and logically evaluating variables that are not controlled by position and velocity feedback loops. Essentially, an adaptive control system monitors process variables, such as cutting forces, tool temperatures, or motor torque, and alters the NC commands so that optimal metal removal or safety conditions are maintained.

A typical NC configuration (Fig. 37.6*a*) monitors position and velocity output of the servo system, using feedback data to compensate for errors between command response. The AC feedback loop (Fig. 37.6*b*) provides sensory information on other process variables, such as workpiece–tool air gaps, material property variations, wear, cutting depth variations, or tool deflection. This information is determined by techniques such as monitoring forces on the cutting tool, motor torque variations,

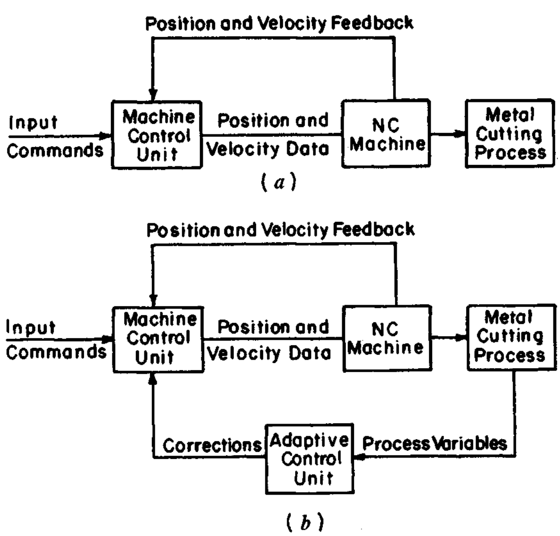

Fig. 37.6 Schematic diagrams for conventional and adaptive NC systems.

or tool–workpiece temperatures. The data are processed by an adaptive controller that converts the process information into feedback data to be incorporated into the Machine Control Unit output.

37.3.7 Machinability Data Prediction

The specification of suitable feeds and speeds is essentially in conventional and NC cutting operations. Machinability data are used to aid in the selection of metal-cutting parameters based on the machining operation, the tool and workpiece material, and one or more production criteria. Techniques used to select machinability data for conventional machines have two important drawbacks in relation to NC applications: data are generally presented in a tabular form that requires manual interpolation, check-out, and subsequent revisions; and tests on the machine tool are required to find optimum conditions.

Specialized machinability data systems have been developed for NC application to reduce the need for machinability data testing and to decrease expensive NC machining time. Part programming time is also reduced when machinability information is readily available.

A typical process schematic showing the relationship between machinability data and NC process flow is illustrated in Fig. 37.7.

37.4 INDUSTRIAL ROBOTS

37.4.1 Definition

As defined by the Robot Institute of America, "a robot is a reprogrammable, multifunctional manipulator designed to handle material, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks."

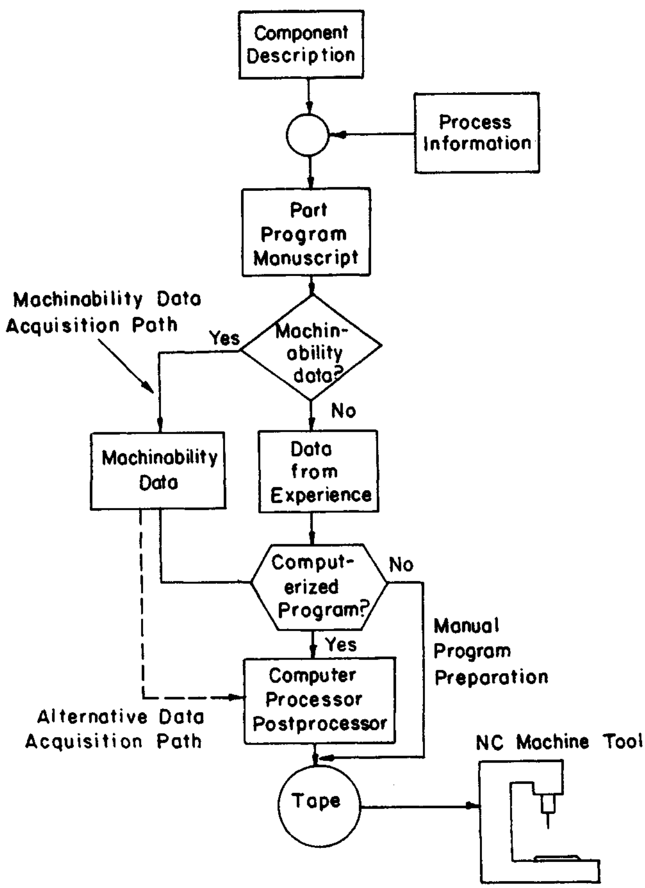

Fig. 37.7 Acquisition of machinability data in the NC process flow.

Robots have the following components:

1. *Manipulator.* The mechanical unit or "arm" that performs the actual work of the robot, consisting of mechanical linkages and joints with actuators to drive the mechanism directly through gears, chains, or ball screws.
2. *Feedback Devices.* Transducers that sense the positions of various linkages or joints and transmit this information to the controller.
3. *Controller.* Computer used to initiate and terminate motion, store data for position and sequence, and interface with the system in which the robot operates.
4. *Power Supply.* Electric, pneumatic, and hydraulic power systems used to provide and regulate the energy needed for the manipulator's actuators.

37.4.2 Robot Configurations

Industrial robots have one of three mechanical configurations, as illustrated in Fig. 37.8. Cylindrical coordinate robots have a work envelope that is composed of a portion of a cylinder. Spherical coordinate robots have a work envelope that is a portion of a sphere. Jointed-arm robots have a work envelope that approximates a portion of a sphere. There are six motions or degrees of freedom in the design of a robot—three arm and body motions and three wrist movements.

Arm and body motions:

1. *Vertical traverse*—an up-and-down motion of the arm
2. *Radial traverse*—an in-and-out motion of the arm
3. *Rotational traverse*—rotation about the vertical axis (right or left swivel of the robot body)

Wrist motions:

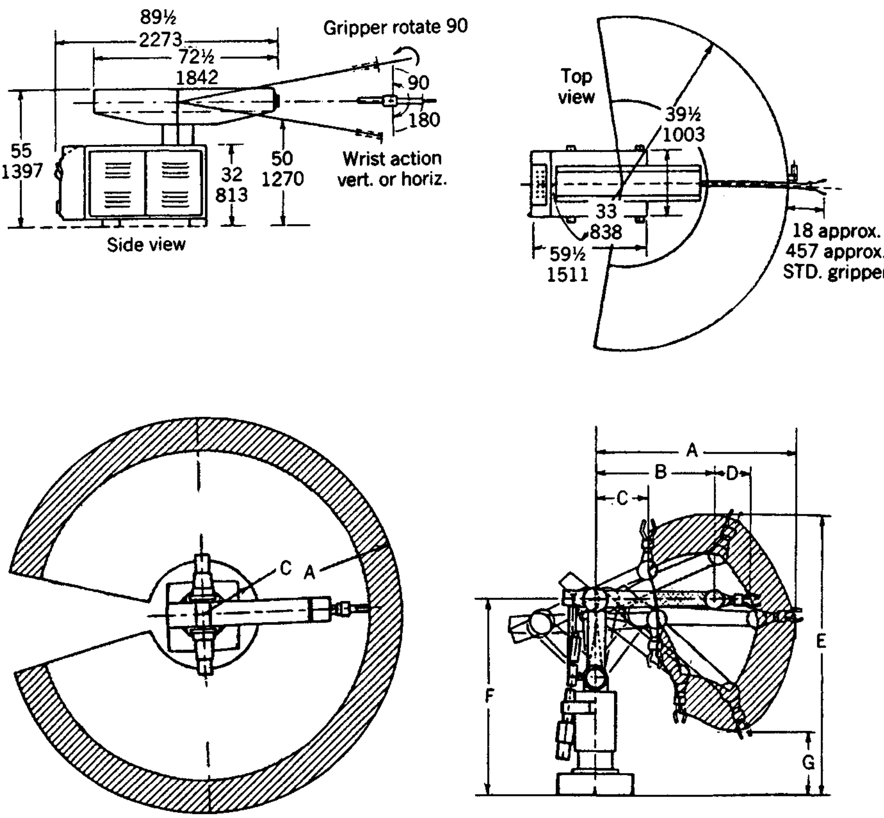

Fig. 37.8 Mechanical configurations of industrial robots.

4. *Wrist swivel*—rotation of the wrist
5. *Wrist bend*—up-and-down movement of the wrist
6. *Wrist yaw*—right or left swivel of the wrist

The mechanical hand movement, usually opening and closing, is not considered one of the basic degrees of freedom of the robot.

37.4.3 Robot Control and Programming

Robots can also be classified according to type of control. Point-to-point robot systems are controlled from one programmed point in the robot's control to the next point. These robots are characterized by high load capacity, large working range, and relative ease of programming. They are suitable for pick-and-place, material handling, and machine loading tasks.

Contouring robots, on the other hand, possess the capacity to follow a closely spaced locus of points that describe a smooth, continuous path. The control of the path requires a large memory to store the locus of points. Continuous-path robots are therefore more expensive than point-to-point robots, but they can be used in such applications as seam welding, flame cutting, and adhesive beading.

There are three principal systems for programming robots:

1. *Manual method.* Used in older, simpler robots, the program is set up by fixing stops, setting switches, and so on.
2. *Walk-through.* The programmer "teaches" the robot by actually moving the hand through a sequence of motions or positions, which are recorded in the memory of the computer.
3. *Lead-through.* The programmer drives the robot through a sequence of motions or positions using a console or teach pendant. Each move is recorded in the robot's memory.

37.4.4 Robot Applications

A current directory of robot applications in manufacturing includes the following:

1. Material handling
2. Machine loading and unloading
3. Die casting
4. Investment casting
5. Forging and heat treating
6. Plastic molding
7. Spray painting and electroplating
8. Welding (spot welding and seam welding)
9. Inspection
10. Assembly

Research and development efforts are under way to provide robots with sensory perception, including voice programming, vision and "feel." These capabilities will no doubt greatly expand the inventory of robot applications in manufacturing.

37.5 COMPUTERS IN MANUFACTURING

Flexible manufacturing systems combined with automatic assembly and product inspection, on the one hand, and integrated CAD/CAM systems, on the other hand, are the basic components of the computer-integrated manufacturing system. The overall control of such systems is predicated on hierarchical computer control, such as illustrated in Fig. 37.9.

37.5.1 Hierarchical Computer Control

The lowest level of the hierarchical computer control structure illustrated in Fig. 37.9 contains stand-alone computer control systems of manufacturing processes and industrial robots. The computer control of processes includes all types of CNC machine tools, welders, electrochemical machining (ECM), electrical discharge machining (EDM), and laser-cutting machines.

When a set of NC or CNC machine tools is placed under the direct control of a single computer, the resulting system is known as a *direct-numerical-control* (DNC) system. DNC systems can produce several different categories of parts or products, perhaps unrelated to one another. When several CNC machines and one or more robots are organized into a system for the production of a single part or family of parts, the resulting system is called a *manufacturing cell.* The distinction between DNC systems and a manufacturing cell is that in DNC systems the same computer receives data from and issues instructions to several separate machines, whereas in manufacturing cells the computer coor-

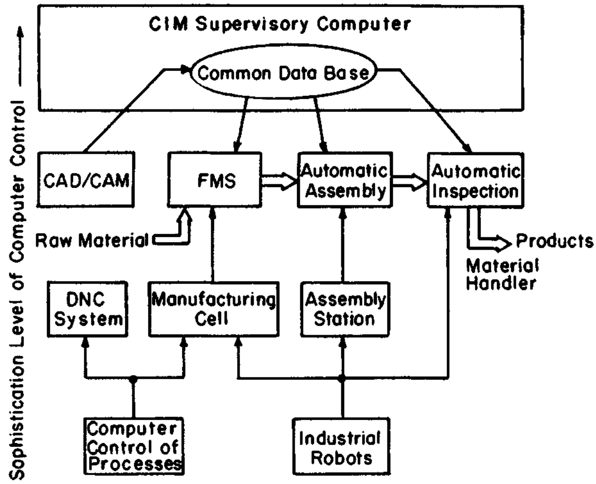

Fig. 37.9 Hierarchical computer control in manufacturing.

dinates the movements of several machines and robots working in concert. The computer receives "completion of job" signals from the machines and issues instructions to the robot to unload the machines and change their tools. The software includes strategies for handling machine breakdowns, tool wear, and other special situations.

The operation of several manufacturing cells can be coordinated by a central computer in conjunction with an automated material-handling system. This is the next level of control in the hierarchical structure and is known as a *flexible manufacturing system* (FMS). The FMS receives incoming workpieces and processes them into finished parts, completely under computer control.

The parts fabricated in the FMS are then routed on a transfer system to automatic assembly stations, where they are assembled into subassemblies or final product. These assembly stations can also incorporate robots for performing assembly operations. The subassemblies and final product may also be tested at automatic inspection stations.

As shown in Fig. 37.9, FMS, automatic assembly, and automatic inspection are integrated with CAD/CAM systems to minimize production lead time. These four functions are coordinated by means of the highest level of control in the hierarchical structure-computer-integrated-manufacturing (CIM) systems. The level of control is often called *supervisory computer control.*

The increase in productivity associated with CIM systems will not come from a speedup of machining operations, but rather from minimizing the direct labor employed in the plant. Substantial savings will also be realized from reduced inventories, with reductions in the range of 80–90%.

37.5.2 CNC and DNC Systems

The distinguishing feature of a CNC system is a dedicated computer, usually a microcomputer, associated with a single machine tool, such as a milling machine or a lathe. Programming the machine tools is managed through punched or magnetic tape, or directly from a keyboard.

DNC is another step beyond CNC, in that a number of CNC machines, ranging from a few to as many as 100, are connected directly to a remote computer. NC programs are downloaded directly to the CNC machine, which then processes a prescribed number of parts.

37.5.3 The Manufacturing Cell

The concept of a manufacturing cell is based on the notion of cellular manufacturing, wherein a group of machines served by one or more robots manufactures one part or one part family. Figure 37.10 depicts a typical manufacturing cell consisting of a CNC lathe, a CNC milling machine, a CNC drill, open conveyor to bring workparts into the cell, another to remove completed parts from the cell, and a robot to serve all these components. Each manufacturing cell is self-contained and self-regulating. The cell is usually made up of 10 or fewer machines. Those cells that are not completely automated are usually staffed with fewer personnel than machines, with each operator trained to handle several machines or processes.

37.5.4 Flexible Manufacturing Systems

Flexible manufacturing systems (FMS) combine many different automation technologies into a single production system. These include NC and CNC machine tools, automatic material handling between

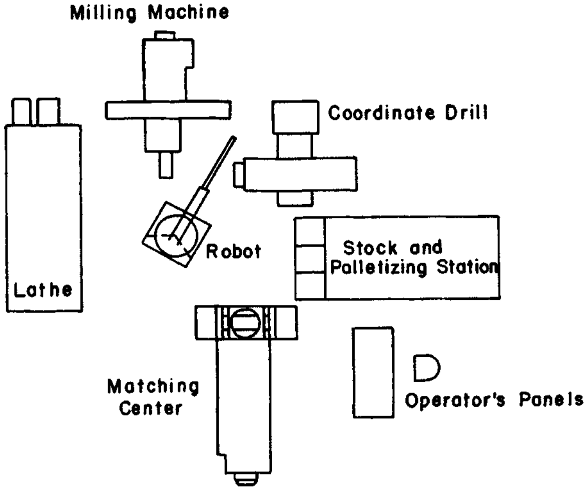

Fig. 37.10 A typical manufacturing cell.

machines, computer control over the operation of the material handling system and machine tools, and group technology principles. Unlike the manufacturing cell, which is typically dedicated to the production of a single parts family, the FMS is capable of processing a variety of part types simultaneously under NC control at the various workstations.

Human labor is used to perform the following functions to support the operation of the FMS:

- Load raw workparts into the system
- Unload finished workparts from the system
- Change tools and tool settings
- Equipment maintenance and repair

Robots can be used to replace human labor in certain areas of these functions, particularly those involving material or tool handling. Figure 37.11 illustrates a sample FMS layout.

37.6 GROUP TECHNOLOGY

Group technology is a manufacturing philosophy in which similar parts are identified and grouped together to take advantage of similarities in design and/or manufacture. Similar parts are grouped into part families. For example, a factory that produces as many as 10,000 different part numbers can group most of these parts into as few as 50 distinct part families. Since the processing of each family would be similar, the production of part families in dedicated manufacturing cells facilitates workflow. Thus, group technology results in efficiencies in both product design and process design.

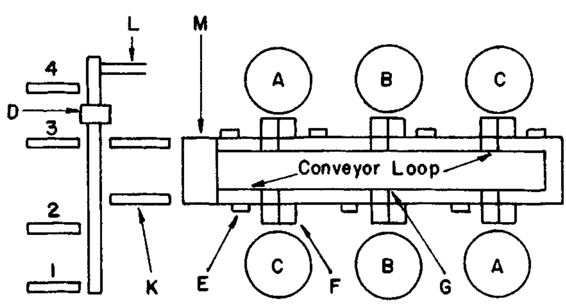

Fig. 37.11 A flexible manufacturing system.

37.6.1 Part Family Formation

The key to gaining efficiency in group-technology-based manufacturing is the formation of part families. A part family is a collection of parts that are similar either due to geometric features such as size and shape or because similar processing steps are required in their manufacture. Parts within a family are different, but are sufficiently similar in their design attributes (geometric size and shape) and/or manufacturing attributes (the sequence of processing steps required to make the part) to justify their identification as members of the same part family.

The biggest problem in initiating a group-technology-based manufacturing system is that of grouping parts into families. Three methods for accomplishing this grouping are

1. *Visual inspection.* This method involves looking at the part, a photograph, or a drawing and placing the part in a group with similar parts. It is generally regarded as the most time-consuming and least accurate of the available methods.
2. *Parts classification and coding.* This method involves examining the individual design and/or manufacturing attributes of each part, assigning a code number to the part on the basis of these attributes, and grouping similar code numbers into families. This is the most commonly used procedure for forming part families.
3. *Production flow analysis.* This method makes use of the information contained on the routing sheets describing the sequence of processing steps involved in producing the part, rather than part drawings. Workparts with similar or identical processing sequences are grouped into a part family.

37.6.2 Parts Classification and Coding

As previously stated, parts classification and coding is the most frequently applied method for forming part families. Such a system is useful in both design and manufacture. In particular, parts coding and classification, and the resulting coding system, provide a basis for interfacing CAD and CAM in CIM systems. Parts classification systems fall into one of three categories:

1. Systems based on part design attributes:
   Basic external shape
   Basic internal shape
   Length/diameter ratio
   Material type
   Part function
   Major dimensions
   Minor dimensions
   Tolerances
   Surface finish
2. Systems based on part manufacturing attributes:
   Primary process
   Minor processes
   Major dimensions
   Length/diameter ratio
   Surface finish
   Machine tool
   Operation sequence
   Production time
   Batch size
   Annual production requirement
   Fixtures needed
   Cutting tools
3. Systems based on a combination of design and manufacturing attributes.

The part code consists of a sequence of numerical digits that identify the part's design and manufacturing attributes. There are two basic structures for organizing this sequence of digits:

1. Hierarchical structures in which the interpretation of each succeeding digit depends on the value of the immediately preceding digit
2. Chain structures in which the interpretation of each digit in the sequence is position-wise fixed

The Opitz system is perhaps the best known coding system used in parts classification and coding. The code structure is

12345 6789 ABCD

The first nine digits constitute the basic code that conveys both design and manufacturing data. The first five digits, 12345, are called the *form code* and give the primary design attributes of the part. The next four digits, 6789, constitute the *supplementary code* and indicate some of the manufacturing attributes of the part. The next four digits, ABCD, are called the *secondary code* and are used to indicate the production operations of type and sequence. Figure 37.12 gives the basic structure for the Opitz coding system. Note that digit 1 establishes two primary categories of parts, rotational and non-rotational, among nine separate part classes.

The MICLASS (Metal Institute Classification System) was developed by the Netherlands Organization for Applied Scientific Research to help automate and standardize a number of design, manufacturing, and management functions. MICLASS codes range from 12 to 30 digits, with the first 12 constituting a universal code that can be applied to any part. The remaining 18 digits can be made specific to any company or industry. The organization of the first 12 digits is as follows:

1st digit	main shape
2nd and 3rd digits	shape elements
4th digit	position of shape elements
5th and 6th digits	main dimensions
7th digit	dimension ratio
8th digit	auxiliary dimension
9th and 10th digits	tolerance codes
11th and 12th digits	material codes

MICLASS allows computer-interactive parts coding, in which the user responds to a series of questions asked by the computer. The number of questions asked depends on the complexity of the part and ranges from as few as 7 to more than 30, with an average of about 15.

37.6.3 Production Flow Analysis

Production flow analysis (PFA) is a method for identifying part families and associated grouping of machine tools. PFA is used to analyze the operations sequence of machine routing for the parts produced in a shop. It groups parts that have similar sequences and routings into a part family. PFA then establishes machine cells for the producing part families. The PFA procedure consists of the following steps:

1. Data collection is the gathering of part numbers and machine routings for each part produced in the shop
2. Sorting process routings into "packs" according to similarity
3. Constructing a PFA chart, such as depicted in Fig. 37.13, that shows the process sequence (in terms of machine code numbers) for each pack (denoted by a letter)
4. Analysis of the PFA chart in an attempt to identify similar packs. This is done by rearranging the data on the original PFA chart into a new pattern that groups packs having similar sequences. Figure 37.14 shows the rearranged PFA chart. The machines grouped together within the blocks in this figure form logical machine cells for producing the resulting part family

37.6.4 Types of Machine Cell Designs

The organization of machines into cells, whether based on parts classification and coding or PFA, follows one of three general patterns:

1. Single-machine cell
2. Group-machine layout
3. Flow-line cell layout

The single-machine pattern can be used for workparts whose attributes allow them to be produced using a single process. For example, a family composed of 40 different machine bolts can be produced on a single turret lathe.

The group-machine layout was illustrated in Fig. 37.13. The cell contains the necessary grouping of machine tools and fixtures for processing all parts in a given family, but material handling between machines is not fixed. The flow-line cell design likewise contains all machine tools and fixtures needed to produce a family of parts, but these are arranged in a fixed sequence with conveyors providing the flow of parts through the cell.

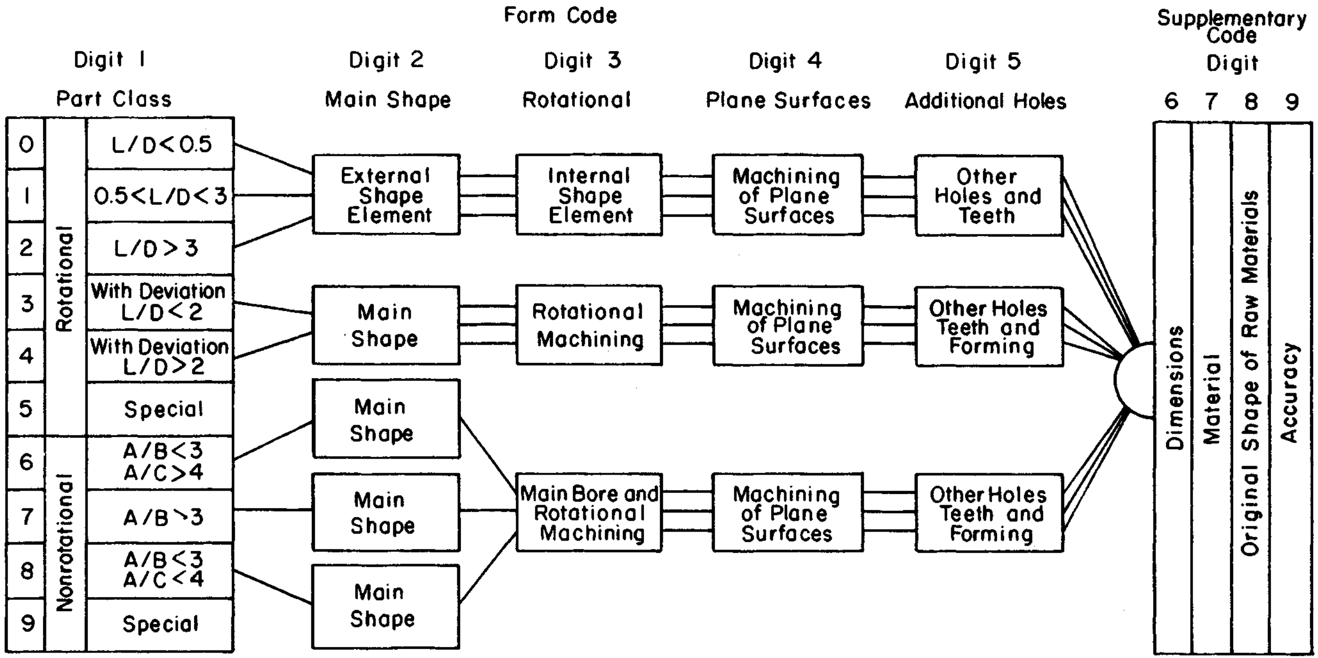

Fig. 37.12 Opitz parts classification and coding system.

Machine \ Part No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Lathe	x	x		x	x		x	x	x		x	x		x	x		x	x	x	x
Milling Mach. I	x	x	x		x	x	x		x		x		x	x		x				x
Milling Mach. II			x	x				x		x		x	x		x		x	x	x	
Drilling Mach.	x	x	x	x		x	x	x		x	x	x	x	x		x	x	x		x
Grinding Mach.	x	x	x	x		x			x			x	x		x			x		x

Fig. 37.13 PFA chart.

Machine \ Part No.	1	2	20	7	11	14	9	5	4	18	12	8	17	15	19	3	13	6	16	10
Lathe	x	x	x	x	x	x	x	x												
Milling Mach. I	x	x	x	x	x	x	x	x												
Drilling Mach.	x	x	x	x	x	x														
Grinding Mach.	x	x	x				x													
Lathe									x	x	x	x	x	x	x					
Milling Mach. II									x	x	x	x	x	x	x					
Drilling Mach.									x	x	x	x	x							
Grinding Mach.									x	x	x			x						
Milling Mach. I																x	x	x	x	
Milling Mach. II																x	x			x
Drilling Mach.																x	x	x	x	x
Grilling Mach.																x	x	x		

Fig. 37.14 Rearranged PFA chart.

37.6.5 Computer-Aided Process Planning

Computer-aided process planning (CAPP) involves the use of a computer to automatically generate the operation sequence (routing sheet) based on information about the workpart. CAPP systems require some form of classification and coding system, together with standard process plans for specific part families. The flow of information in a CAPP system is initiated by having the user enter the part code for the workpart to be processed. The CAPP program then searches the part family matrix file to determine if a match exists. If so, the standard machine routing and the standard operation sequence are extracted from the computer file. If no such match exists, the user must then search the file for similar code numbers and manually prepare machine routings and operation sequences for dissimilar segments. Once this process has been completed, the new information becomes part of the master file so that the CAPP system generates an ever-growing data file.

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