CHAPTER 16

COMPUTER INTEGRATED MANUFACTURING

Computer integrated manufacturing (CIM) describes the integration of *computer aided design* (CAD) and *computer aided manufacturing* (CAM). In the early 1960s, Ivan Sutherland developed the SKETCHPAD system, a milestone of research achievement in computer graphics. The evolution of computer graphics has since resulted in the development of CAD. On the other hand, CAM was inspired by *numerical control* (NC) machines which were first introduced in the early 1950's. The communication between CAD and CAM systems became possible by reuse of the product model designed in CAD systems in CAM systems.

16.1 COMPUTER INTEGRATED MANUFACTURING

Computer integrated manufacturing (CIM) is a general term used to describe the computerized integration of the conventionally isolated functions of manufacturing, such as product design, planning, production, distribution, and management. It essentially needs large scale integrated communication system and extensive database. For this, functions of various elements of a manufacturing system are treated by subsystems such that the output of a subsystem serves as the input to another subsystem. Organizationally, the subsystems can be broadly grouped into two sets of functions:

1. *Business Planning* Forecasting, scheduling, material requirement planning, invoicing and accounting.

2. *Business Execution* Production and process control, material handling, testing and inspection.

Improved product quality and increased flexibility in use of capital are the two broad benefits of using CIM. Additionally, CIM offers the following benefits:

1. Responsiveness to short product life cycles and dynamics of global competition.

2. Process control resulting in consistent product quality and uniformity.

3. Control on production, scheduling, and management of the total manufacturing operations.

4. Improved productivity by optimum utilization of resources.

16.2 COMPUTER AIDED DESIGN

Computer aided design (CAD) systems describe software systems capable of creating, modifying, and analyzing an engineering design. This involves computers to aid in the process of product design and development.

CAD originated from early *computer graphic systems*, and evolved with the development of interactive computer graphics and geometric modeling. The development of SKETCHPAD system at MIT in 1963 by Dr. Ivan Sutherland was the turning point in the development of CAD systems. SKETCHPAD was the first system that allowed a designer to interact with a computer graphically by drawing on a cathode ray tube (CRT) monitor with a light pen.

In the early 1970s CAD systems were little more than drafting software used to create 2D drawings, limited to simple geometry, such as lines, circular arcs and ellipse arcs. Therefore, they were often referred to as *computer aided drafting*. Advances in programing and computer hardware, notably, solid modeling in the 1970s, made the CAD applications more versatile. CAD further evolved with the development of *geometric modeling* based on the mathematical description of geometry, from simple two-dimensional (2D) drafting to three-dimensional (3D) wire frame, to 3D surfaces, and now 3D solid modeling. *Geometric modeling* enables creation of new geometric models from the inbuilt blocks available in the system, moving the images around on the screen, zooming in on a certain feature, and so on. CAD systems are now being extensively used throughout the engineering processes from conceptual design and detailed engineering, to strength, dynamic analysis of components and assembly planning.

Computer aided design is a faster and more accurate method of engineering design than the conventional methods. This has become possible through the following benefits offered by CAD systems:

1. Increased design productivity.
2. Increased available geometric forms.
3. Improved quality of the design.
4. Improved communication documentation.
5. Creation of manufacturing data base.
6. Design standardization.

16.3 COMPUTER AIDED MANUFACTURING

Computer aided manufacturing (CAM) describes use of the computers and computer technology to assist in all phases of manufacturing, including process and production planning scheduling, manufacture, quality control, and management. Historically, CAM technology was sparked by the invention of NC machine tools that were developed to manufacture complex shapes in an accurate and repeatable manner. NC machines are directed by part programs following industrial data standard, RS274D, known as ISO 6983, internationally. The standard defines a set of M and G codes which specify a sequence of cutting tool movements as well as the direction of rotation, speed of travel and various auxiliary functions, such as coolant flow.

The first generation of CAM emerged when Automatically Programed Tool (APT) was developed to help control NC machines at the Massachusetts Institute of Technology (MIT) in the 1950s. APT is a universal programing language for NC machines and has been widely adopted in industry. APT provides a convenient way to define geometry elements and generate cutter locations for NC programs by computers. APT was created before graphical interfaces were available, so it relies on text to specify the geometry and tool paths needed to machine a part. This poses a significant potential for errors in defining comprehensive geometries and tool positioning commands. This problem was overcome by introduction of graphics-based CAM in 1980s, allowing part geometry to be described in the form of points, lines, arcs, and so on, rather than requiring a translation to a text-oriented notation.

16.4 INTEGRATION OF CAD AND CAM SYSTEMS

In initial stages, the development of CAD systems had little effect on CAM development due to the different capabilities and file formats used by drawings and NC programs. The result was that a lot of CAM programing time was spent in redefining the part geometry, which had already been defined in CAD. The realization of this fact led to the appearance of the first integrated CAD/CAM systems by enabling CAM systems to work with the geometric model created by the CAD system itself. This was evident with decreased time to market dynamics, lower development and design cost and the ability to rapidly translate ideas into models.

Present day CAD/CAM systems, such as Unigraphics, Pro/E, IDEAS, CATIA, have many modules packed together and are running on their own proprietary databases. These systems have both CAD and CAM capabilities and the geometric data from CAD can be used in the CAM module without conversion on the same interface. This allows information transfer from the design stage to the planning stage without re-entering the data manually on part geometry. The CAD database is directly processed by CAM for operating and controlling the production machinery and material handling equipment as well as for performing automated testing and inspection for product quality.

16.5 NUMERICAL CONTROL

Numerical control (NC) of machine tools is a method of automation in which functions of machine tools are controlled by programs using letters, numbers and symbols. These programs contain precise instructions about the manufacturing procedure as well as the movements. NC machines are suitable for jobs with complex part geometry or mathematically defined contours and requiring high accuracy and repeatability, such as airfoils, turbine blades. NC is most appropriate for small or medium lot sizes, ranging from one unit upto several hundred units, and also where there are frequent changes in the product design. An important application of NC is seen in the form of inspection machines, known as *coordinate measuring machines* (CMM), and in controlling robots.

16.5.1 NC Machine Tools

The most prominent feature of NC machine tool is that a variety of machining operations are performed on the same machining center, thus eliminating the non-productive waiting time when such operations are performed on different machines. In addition to this, the provision of automatic tool changing, indexing of tables, and several pallets add to the productivity of the machining centers.

16.5.2 Principle of Operation

An NC system consists of three basic components [Fig. 16.1]:

1. Part Program *Part program* is the set of detailed step-by-step commands that direct the action of the processing equipment. It requires basic information in three categories: part geometry, process information (e.g. cutting process parameters, spindle speed, feed rate) and technology details (e.g. cutting tool, cutting tool selection, etc.). Part programs are written keeping in view of the codes and symbols understood by the machine control unit.

2. Machine Control Unit *Machine control unit*[1], abbreviated as MCU, performs various controlling functions under the instructions contained in part program. In modern NC technology, MCU is a microcomputer and related to control hardware that stores the part program of instructions and executes it by converting each command into mechanical actions of the processing equipment, one command at a time. The MCU hardware also includes components to interface with the processing equipment and feed-back control elements.

3. Processing Unit The processing unit performs the actual productive work in defined processing steps according to the directions given by the MCU, which is driven by the instructions contained in the part program.

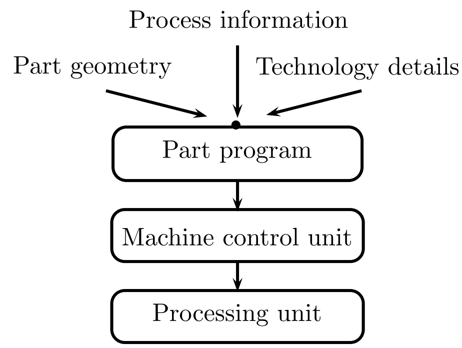

Figure 16.1 Elements of NC systems.

NC machines are designed to be highly automatic and capable of combining several operations in one setup that formerly required several machines. They are designed to reduce the time consumed by the non-cutting elements in the operation cycle, such as changing tools, loading and unloading the work part. A *machining center* is a machine tool capable of performing multiple machining operations on a single workpiece in one setup.

16.5.3 Coordinate Systems

Programs of NC processing equipment need a definite axis system to specify the position of the work head w.r.t. the work part. NC systems employ two types of axis systems, one for flat and prismatic work parts and the other for rotational parts. Both systems are based on Cartesian coordinate system.

16.5.4 Motion Control Systems

Different types of movement of the work head are accomplished by the motion control system. Once the motion is completed, some processing action is accomplished by the work head at the location. The motion control systems for NC can be broadly divided into two types:

1. Positioning Systems *Positioning system*, also called point-to-point mode, moves the work table to a programed location irrespective of the path

[1] Because the MCU is a computer, the term computer numerical control (CNC) is used to distinguish this type of NC from its technological predecessors that were based entirely on hard-wired electronics.

following between two points. This system offers capability of motion in all three axes, one at a time, that is, machining can be performed at a time along single axis only. This mode is useful for drilling and punching machines [Fig. 16.2].

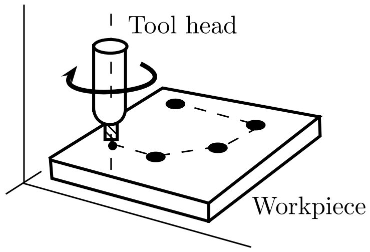

Figure 16.2 Positioning system.

Reference point for motion control can be defined in two ways:

(a) Absolute Positioning In *absolute positioning*, the work head positions are defined relative to the origin of the coordinate system.

(b) Incremental Positioning In *incremental positioning*, the next work head position is defined relative to the present location.

2. Continuous Path Systems Continuous path systems are capable of continuous simultaneous control of the motion in two or more axes. This enables control of the tool trajectory relative to the work part for the purpose of generating two-dimensional curves, surfaces, or three-dimensional contours in the work part. Continuous path systems can be grouped into three sets:

(a) Straight Line Mode In *straight line mode*, the machine performs continuous motion in each axis direction. This mode is suitable for straight line milling operations [Fig. 16.3].

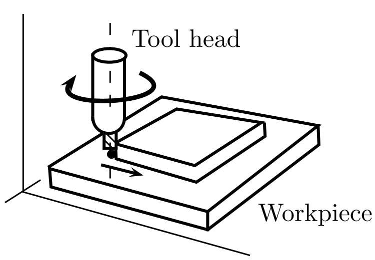

Figure 16.3 Straight line mode.

(b) Two-Axis Contouring Two-axis *contouring* offers simultaneous motion capability in any of the two axis. Any 3D profile to be machined can be completed using the concept of 2.5D mode [Fig. 16.4].

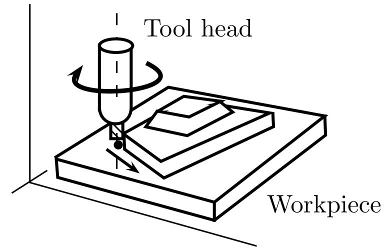

Figure 16.4 Two-axis contouring.

(c) Three-Axis Contouring Three-axis contouring is the highest form of control which gives capability of simultaneous three or more axes motion. This is useful for machining of complex 3D profiles encountered in industrial practice [Fig. 16.5].

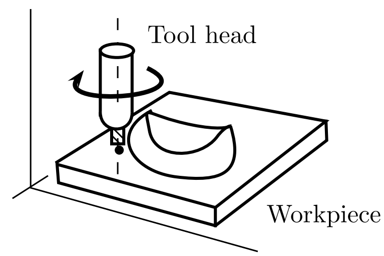

Figure 16.5 Three-axis contouring.

16.5.5 NC Positioning Systems

An NC positioning system converts the coordinate axis values in the NC part program into relative positions of the tool and work-part during processing. This controls the position of work table by means of a rotating lead-screw driven by a stepper motor or servomotor. For each revolution of the lead screw, the work table moves a distance equal to pitch of the lead screw. In turn, the velocity of the work table (feed rate) is determined by the pitch and rotational speed of the lead screw [Fig. 16.6].

The following are the two types of positioning systems:

1. Open Loop Positioning System An *open loop positioning systems* operates without verifying that the actual position achieved in the move is the same as the desired position [Fig. 16.6]. A stepper motor is driven by a series of electrical pulses, which are generated by the MCU in an NC system. Each pulse causes the motor to rotate a fraction of one revolution called *step angle*, denoted by α.

Consider an open loop positioning system in which the stepper motor has n_s number of step

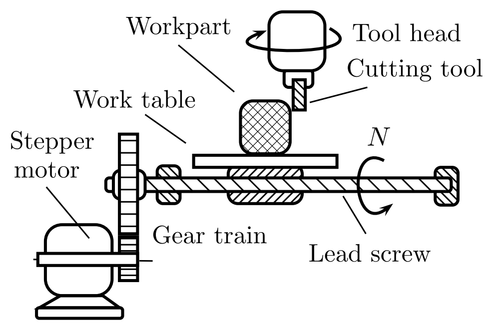

Figure 16.6 NC Positioning system.

angles of equal value α ($= 360/n_s$ degrees) and lead screw has a pitch (p). Transfer of angular rotation of the stepper motor to lead screw is reduced through a gear train having a gear ratio ($r_g > 1$) (defined as the number of turns of the motor for each single turn of the lead screw). The angle turned by the motor shaft (θ_m) for number of pulses n_p would be given by

$$\theta_m = n_p \alpha$$

The angle turned by lead screw (θ_l) for n_p pulses is given by

$$\theta_l = \frac{\theta_m}{r_g} = \frac{n_p \alpha}{r_g}$$

Linear movement of the work table for n_p pulses is determined as

$$x = p \times \frac{\theta_l}{360} = \frac{p n_p \alpha}{360 r_g}$$

Thus, the number of pulses required for movement x are given by

$$n_p = \frac{360 x r_g}{p\alpha}$$

Angular speed N (rpm) of the lead screw for pulse train frequency f_p (Hz) is given by

$$\frac{N}{60} r_g = \frac{f_p}{n_s}$$

$$N = \frac{60 f_p}{n_s r_g}$$

The table speed (v) can be determined as

$$v = Np = \frac{60 f_p p}{n_s r_g}$$

2. Closed Loop Positioning System A *closed loop system* functions same as the open loop positioning system but with an additional feature of feedback measurements to ensure that the work table is moved to the desired position. For this, an *optical encoder* is used as feed sensor. The additional feature of optical encoder is treated in reverse manner to that for pulses in the stepper motor.

   Closed loop systems are desired for machines that perform continuous path operations, such as milling, turning, in which there are significant forces resisting the forward motion of the cutting tool.

16.5.6 Manual NC Part Programming

NC part programing is used for preparing the sequence of instructions for part processing. Part programs are fed to the NC machine control unit (MCU) using an input medium. The instructions on part programs can be grouped into four sets: geometric instructions (movement between tool head and part head), processing instructions (cutting speed, feed, tools, cutting fluids, etc.), travel instructions (positioning and movement interpolation), and switching instructions (tool changes, coolant supplies, etc.). Part programing can be done manually, computer assisted or using CAD/CAM, and by manual data input.

In manual NC part programing, NC codes are written using a low-level machine language. The instructions include a combination of binary and decimal number systems, called the *binary coded decimal* (BCD) system, alphabetical characters, and other symbols.

A word is formed out of a sequence of those characters which specifies a detail about the operation, such as coordinate position, feed rate, spindle speed. A *block* is a collection of words which specifies a complete NC instruction. The organization of words within a block is known as a *block format*, which is usually in the sequence shown in Fig. 16.7.

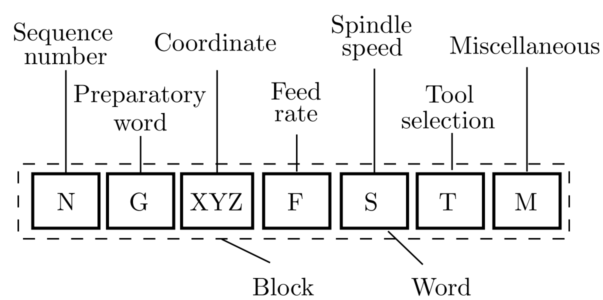

Figure 16.7 Block format of part programs.

Block of a part program starts with a sequence number N, having minimum three digits (e.g. N001, N023). Preparatory word G is followed by two numerical digit information, G00 to G99. It prepares the MCU for the instructions and data contained in the block. For example, block format N010 G00 X7.0 Y2.0 I5.0 J2.0 can be decoded as G00 prepares the controller for a point-to-point rapid transverse move between the previous point (5, 4) and the end point defined in the current command (7, 2).

16.5.7 Merits of NC

The numerical control offers the following advantages over conventional manufacturing:

1. *Non-Productive Time* NC cannot optimize the metal cutting process itself but can reduce the proportion of time when the machine is not cutting the metal. Thus, NC minimizes the non-productive time, and parts are produced in less time, therefore it is likely to be less expensive. This indirectly saves labor cost also.
2. *Accuracy and Repeatability* Automation and absence of interrelated human factors make the NC products more accurate, even for small batches. Thus, NC maintains consistent quality of the products for the entire batch.
3. *Quality* Consistent quality in the entire batch also reduces the inspection time. Even with use of inspection probes in advanced CNC machines, the measurement function also becomes a part of the program.
4. *Jigs and Fixtures* NC eliminates the need of expensive jigs and fixtures, depending upon the part geometry. The number of setups can usually be reduced significantly using NC.
5. *Part Geometry* Complex profiles can be programed in NC, hence eliminating the need for special form tools.
6. *Machining Center* A single CNC machine center can perform a variety of machining operations, thus eliminating the need for different types of machines.
7. *Machining Time and Cost* Machining time and costs are more accurately calculated and analyzed based on the part program itself.
8. *Human Factors* NC machines can be utilized continuously, ad hence eliminates the effect of operator fatigue in machining time. A single operator can look after two or three NC automatic machines simultaneously. No operator is required in NC except in setting up of the tools and the work, therefore, results in less scrap due to operator errors.
9. *Drafting* Automated drafting machines serve as one of the output devices for a CAD/CAM system.

16.5.8 Demerits of NC

The following are the basic demerits of NC:

1. *High Cost of NC Machines* The cost of an NC machine and cutting tools is five to ten times higher than conventional machines. Thus, NC machines require very high initial investment.
2. *Sophisticated Technology* NC machines use complex and sophisticated technology, thus require skilled staff with specialized training for both software and hardware. Part programers need to be trained to write instructions in desired languages for machines on the shop floor and also be acquainted with the manufacturing process.
3. *Preventive Maintenance* Breakdowns of NC systems are costly and can be time consuming due to their complexity. Their preventive maintenance is essential.
4. *Need of Programing* NC systems are based on programing which requires time and fluency.
5. *Design Requirements* The production time spent by the NC machine cutting metal is significantly greater than that with manually operated machines. This causes certain components, such as the spindle speed, drive gears and feed screws to wear more rapidly.

16.6 GROUP TECHNOLOGY

Group technology (GT) is a manufacturing philosophy in which similar parts are identified and grouped together into *part families* to take advantage of their similarity in manufacturing and design. The similar characteristics of parts in each family facilitates use of similar processing and results in manufacturing efficiencies, that is, reduction in setup time, lower in-process inventories, better scheduling, improved tool control, and use of standardized process plans.

Part family is a collection of parts which are similar either because of geometric shape and size or because similar processing steps are required in their manufacture. The concept of part family is central to design retrieval systems and most current computer-aided process planning schemes. This helps in organizing the layout to specialize in the manufacture of a particular part family. However, the biggest difficulty in changing over to group technology from a traditional production layout is the problem of grouping parts into part families.