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CERTIFICATION COURSES

AUTOMATION IN PRODUCTION SYSTEMS AND MANAGEMENT

Fundamentals of NC Technology-II

PROF PRADIP KUMAR RAY

DEPARTMENT OF INDUSTRIAL AND SYSTEMS ENGINEERING

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Fundamentals of NC Technology-II

- **Lecture-1:** Distributed Numerical Control (DNC) and its Configuration
- **Lecture-2:** NC Part Programming-I (Manual, Computer-assisted)
- **Lecture-3:** NC Part Programming-II (CAD/CAM, MDI)
- **Lecture-4:** Interpolation and Part Programming
- **Lecture-5:** Numerical Examples

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Fundamentals of NC Technology-II

- ✓ **Distributed Numerical Control (DNC) and its Configuration**

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Distributed Numerical Control

- The first attempt to use a digital computer to drive the NC machine tool was called direct numerical control (DNC).
- This was in the late 1960s before the advent of CNC.
- DNC involved the control of a number of machine tools by a single (mainframe) computer through direct connection and in real time.
- Instead of using a punched tape reader to enter the part program into the MCU, the program was transmitted to the MCU directly from the computer, one block of instructions at a time. This mode of operation was referred to by the name behind the tape reader (BTR).

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Distributed Numerical Control

- The DNC computer provided instructions blocks to the machine tool on demand; when a machine needed control commands, they were communicated to it immediately.

- As each block was executed by the machine, the next block was transmitted. As far as the machine tool was concerned, the operation was no different from that of a conventional NC controller. In theory, DNC relieved the NC system of its least reliable components: the punched tape and tape reader.

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Distributed Numerical Control

- The general configuration of a DNC system is depicted in Figure 7.8.

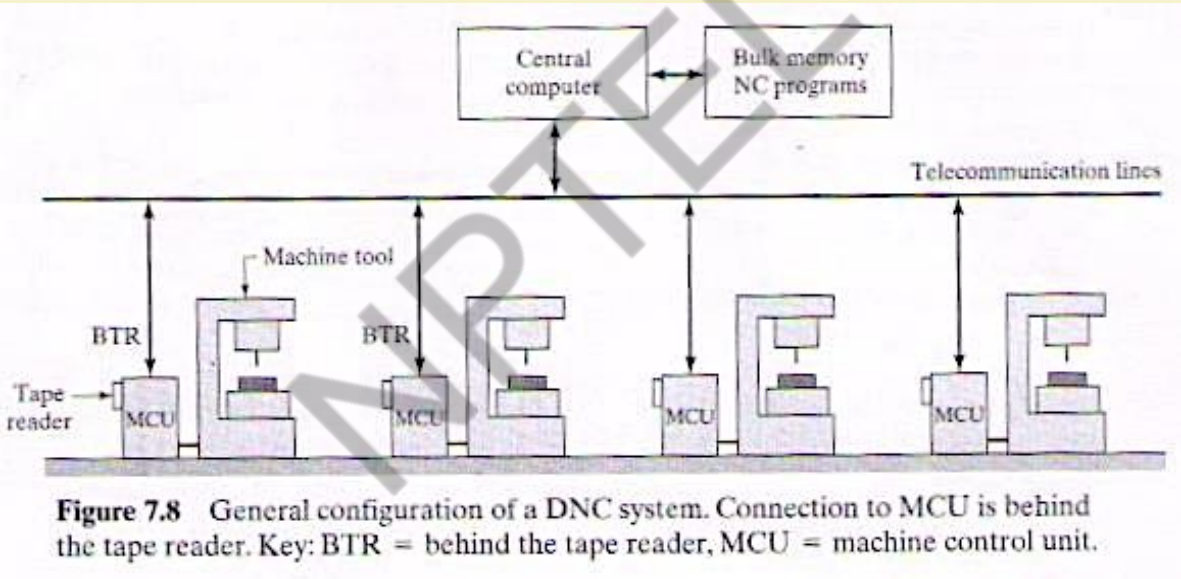

Figure 7.8 General configuration of a DNC system. Connection to MCU is behind the tape reader. Key: BTR = behind the tape reader, MCU = machine control unit.

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Distributed Numerical Control

- The system consisted of four components:
  1. Central computer,
  2. Bulk memory at the central computer site,
  3. Set of controlled machines, and
  4. Telecommunications lines to connect the machines to the central computer.
- In operation, the computer called the required part program from bulk memory and sent it (one block at a time) to the designated machine tool.

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Distributed Numerical Control

- In addition to transmitting data to the machines, the central computer also received data back from the machines to indicate operating performance in the shop (e.g., number of machining cycles completed, machine utilization, and breakdowns). A central objective of DNC was to achieve two-way communication between the machines and the central computer.
- As the number of CNC machine installations grew during the 1970s and 1980s, a new form of DNC emerged, called distributed numerical control (DNC).

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Distributed Numerical Control

- The central computer is connected to MCUs, which are themselves computers.
- This permits complete part programs, not one block at a time, to be sent to the machine tools.
- It also permits easier and less costly installation of the overall system, because the individual CNC machines can be put into service and distributed NC can be added later. Redundant computers improve system reliability compared with the original DNC.

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Distributed Numerical Control

- The new DNC permits two-way communication of data between the shop floor and the central computer, which was one of the important features included in the old DNC.
- Some of the data and information sets included in the two-way communication flow are itemized in Table 7.3

TABLE 7.3 Flow of Data and Information Between Central Computer and Machine Tools in DNC

Data and Information Downloaded from the Central Computer to Machine Tools and Shop Floor	*Data and Information Uploaded from the Machine Tools and Shop Floor to the Central Computer*
NC part programs	Piece counts
List of tools needed for job	Actual machining cycle times
Machine tool setup instructions	Tool life statistics
Machine operator instructions	Machine uptime and downtime statistics, from which machine utilization and reliability can be assessed
Machining cycle time for part program	Product quality data
Data about when program was last used	
Production schedule information	

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Distributed Numerical Control

- Distributed NC system can take on a variety of physical configurations, depending on the number of machine tools included, job complexity, security requirements, and equipment availability and preferences.

- There are several ways to configure a DNC system.

  a) Switching network and
  b) LAN.

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Distributed Numerical Control

- The switching network is the simplest DNC system to configure. It uses a data switching box to make a connection from the central computer to a given CNC machine for downloading part programs or uploading data.
- Transmission of programs to the MCU is accomplished through an Rs-232-C connection. Virtually all commercial MCUs include the Rs-232-C or compatible device as standard equipment.
- Use of a switching box limits the number of machines that can be included in the DNC system. The limits depends on factors such as part program complexity, frequency of service required to each machine, and capabilities of the central computer.

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Distributed Numerical Control

- The number of machines in the DNC system can be increased by employing a serial link RS-232-C multiplexer.
- Local area networks (LAN) have been used for DNC since the early 1980s.
- Various network structures are used in DNC systems, among which is the centralized structure illustrated in figure 7.9(b).

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Distributed Numerical Control

- The number of machines in the DNC system can be increased by employing a serial link RS-232-C multiplexer.
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- Various network structures are used in DNC systems, among which is the centralized structure illustrated in figure 7.9.

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Distributed Numerical Control

- In this arrangement, the computer system is organized as a hierarchy, with the central (host) computer coordinating several satellite computers that are each responsible for a number of CNC machines.
- Alternative LAN structures are possible, each with its relative advantages and disadvantages.
- Local area networks in different sections and departments of a plant are often interconnected in plant-wide and corporate-wide networks.

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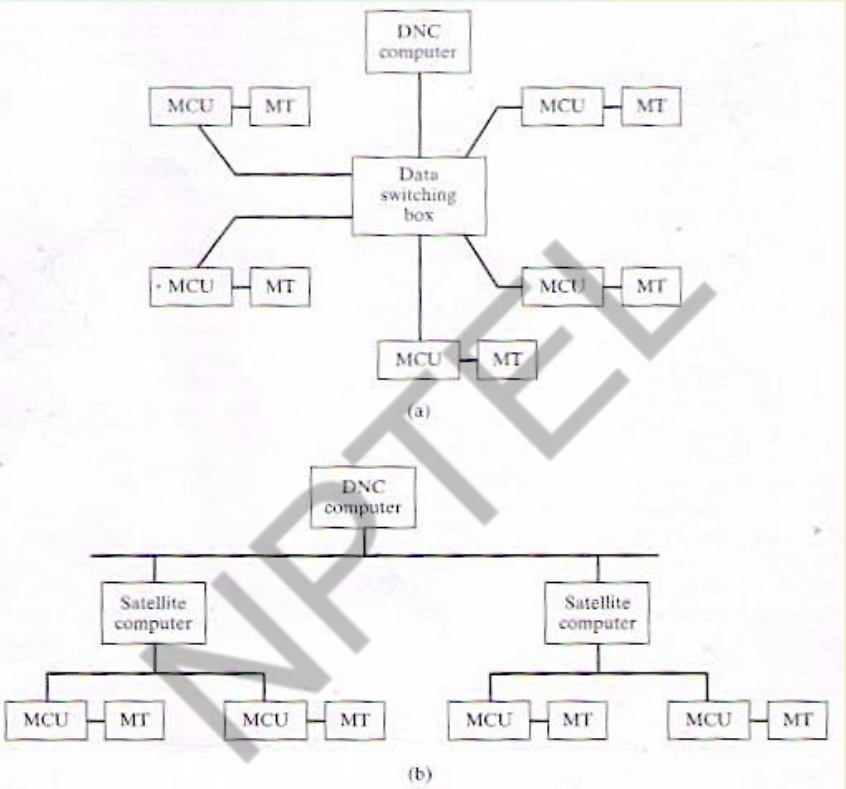

Figure 7.9 Two configurations of DNC: (a) switching network and (b) LAN. Key: MCU = machine control unit, MT = machine tool.

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List of Reference Textbooks

- Groover, M P, Automation, Production Systems, and Computer Integrated Manufacturing, Third Edition, Pearson Prentice Hall, Upper Saddle River.

- Groover, M P and Zimmers, E W Jr, CAD/CAM: Computer-aided Design and Manufacturing, Prentice-Hall of India Private Ltd.

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Fundamentals of NC Technology-II

- ✓ **NC Part Programming-I (Manual, Computer-assisted)**

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NC Part Programming

- NC part programming consists of planning and documenting the sequence of processing steps to be performed on an NC machine.
- The part programmer must have a knowledge of machining (or other processing technology for which the NC machine is designed), as well as geometry and trigonometry.
- Part programming can be accomplished using a variety of procedures ranging from highly manual to highly automated methods.

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NC Part Programming

- The methods are

    1. Manual part programming
    2. Computer-assisted part programming
    3. Part programming using CAD/CAM, and
    4. Manual data input

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Manual Part Programming

- In manual part programming, the programmer prepares the NC code using a low-level machine language.
- The coding system is based on binary numbers. This coding is the low-level machine language that can be understood by the MCU.
- When higher level languages are used, such as APT, the statements in the program are converted to this basic code.

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Manual Part Programming

- NC uses a combination of the binary and decimal number system, called the binary-coded decimal (BCD) system.

- In this coding scheme, each of the ten digits (0-9) in the decimal system is coded as a four-digit binary number, and these binary numbers are added in sequence as in the decimal number system.

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Manual Part Programming

- For example, the decimal value 1250 would be coded in BCD as follows:

Number Sequence	Binary Number	Decimal Value
First	0001	1000
Second	0010	200
Third	0101	50
Fourth	0000	0
Sum		1250

TABLE 7.4 Comparison of Binary and Decimal Numbers

Binary	Decimal	Binary	Decimal
0000	0	0101	5
0001	1	0110	6
0010	2	0111	7
0011	3	1000	8
0100	4	1001	9

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Manual Part Programming

- In addition to numerical values, the NC coding system must also provide for alphabetical characters and other symbols.
- Eight binary digits are used to represent all of the characters required for NC part programming.
- Out of a sequence of characters, a word is formed. A word specifies a detail about the operation, such as x-position, y-position, feed rate, or spindle speed.

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Manual Part Programming

- Out of a collection of words, a block is formed. A block is one complete NC instruction.

- For example, an instruction block for a two-axis NC milling machine would likely include the x- and y- coordinates to which the machine table should be moved, the type of motion to be performed (linear or circular interpolation), the rotational speed of the milling cutter, and the feed rate at which the milling operation should be performed.

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Manual Part Programming

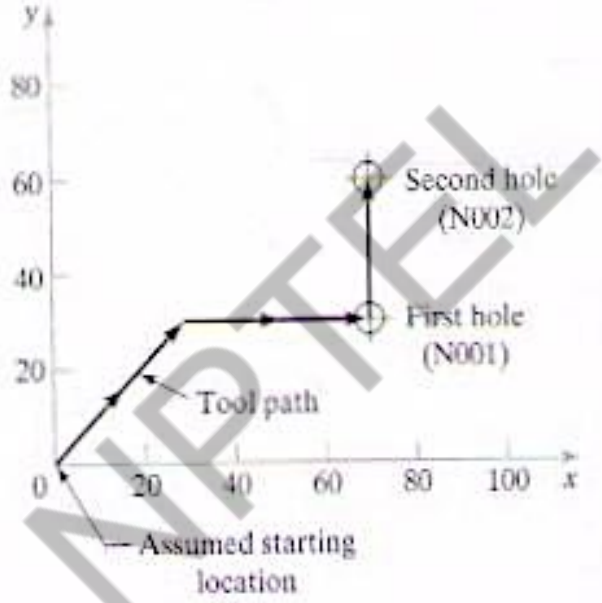

Figure 7.16 Drilling sequence for word address format example. Dimensions are in millimeters.

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Computer-Assisted Part Programming

- Manual part programming can be time consuming, tedious, and subject to errors for parts possessing complex geometries or requiring many machining operations.
- In these cases, and even for simpler jobs, it is advantageous to use computer-assisted part programming.
- A number of NC part programming language systems have been developed to accomplish many of the calculations that the programmer would otherwise have to do.

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Computer-Assisted Part Programming

- The program is written in English-like statements that are subsequently converted to the low-level machine language.

- Computer-assisted part programming saves time and results in a more accurate and efficient part programming. Using this programming arrangement, the various tasks are divided between the human part programmer and the computer.

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- Groover, M P and Zimmers, E W Jr, CAD/CAM: Computer-aided Design and Manufacturing, Prentice-Hall of India Private Ltd.

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- ✓ **NC Part Programming-II (CAD/CAM, MDI)**

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Computer-Assisted Part Programming

❑ The Part Programmer's Job

- In computer-assisted part programming, the machining instructions are written in English-like statements that are subsequently translated by the computer into the low-level machine code that can be interpreted and executed by the machine tool controller.

- The two main tasks of the programmer are
  1. Defining the geometry of the part and
  2. Specifying the tool path and operation sequence.

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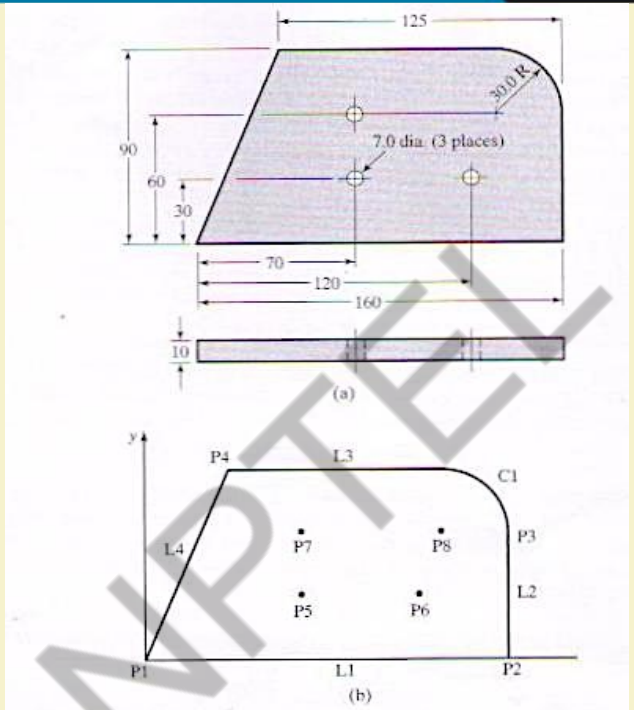

Figure 7.17 Sample part with geometry elements (points, lines, and circle) labeled for computer-assisted part programming.

APT, which stands for automatically programmed tooling

Computer-Assisted Part Programming

❑ Computer Tasks in Computer-Assisted Part Programming.

The computer's role in computer-assisted part programming consists of the following tasks, performed more or less in the sequence noted:

1. Input translation
2. Arithmetic and cutter offset computations
3. Editing, and
4. Post processing

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Computer-Assisted Part Programming

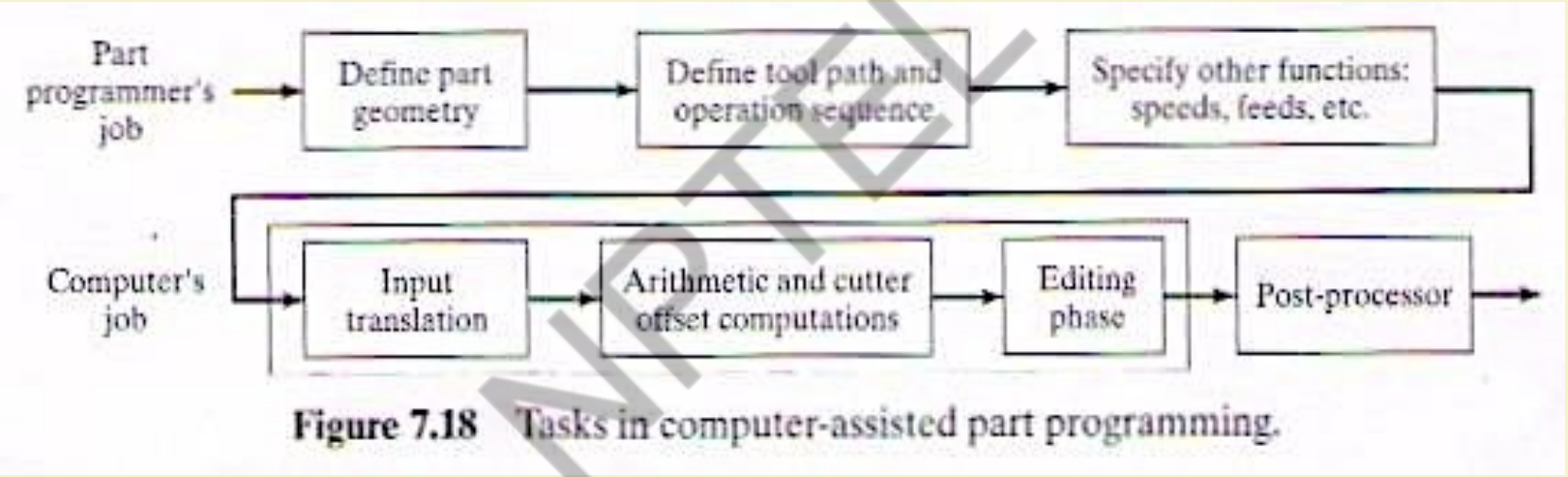

Figure 7.18 Tasks in computer-assisted part programming.

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NC Part Programming Using CAD/CAM

- A CAD/CAM system is a computer interactive graphics system equipped with software to accomplish certain tasks in design and manufacturing and to integrate the design and manufacturing functions.

Manual Data Input

- Manual and computer-assisted part programming require a relatively high degree of formal documentation and procedure.
- There is lead time required to write and validate the programs. CAD/CAM part programming automates a substantial portion of the procedure, but a significant commitment in equipment, software, and training is required.

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NC Part Programming Using CAD/CAM

- One method of simplifying the procedure is to have the machine operator perform the part programming task at the machine tool. This is called manual data input (abbreviated MDI) because the operator manually enters the part geometry data and motion commands directly into the MCU prior to running the job.
- MDI, also known as conversational programming, is perceived as a way for the small machine shop to introduce NC into its operations without needing to acquire special NC part programming equipment and hiring a part programmer.

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NC Part Programming Using CAD/CAM

- MDI permits the shop to make a minimal initial investment to begin the transition to modern CNC technology.
- The limitation, of manual data input is the risk of programming errors as jobs become more complicated. For this reason, MDI is usually applied for relatively simple parts.
- A minimum of training in NC part programming is required of the machine operator.
- The operator must have the ability to read an engineering drawing of the part and must be familiar with the machining process.

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NC Part Programming Using CAD/CAM

- An important caveat in the use of MDI is to make certain that the NC system does not become an expensive toy that stands idle while the operator is entering the programming instructions.
- Efficient use of the system requires that programming for the next part be accomplished while the current part is being machined.
- Most MDI systems permit these two functions to be performed simultaneously to reduce changeover time between jobs.

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- ✓ **Interpolation and Part Programming**

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Interpolation Methods

- One of the important aspects of contouring is interpolation.
- The paths that a contouring-type NC system is required to generate often consist of circular arcs and other smooth nonlinear shapes .
- Some of these shapes can be defined mathematically by relatively simple geometric formulas (e.g. the equation for a circle is $x^2+y^2=R^2$ where R = the radius of the circle and the center of the circle is at the origin., whereas others cannot be mathematically defined except by approximation.

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Interpolation Methods

- A fundamental problem in generating these shapes using NC equipment is that they are continuous, whereas NC is digital.
- To cut along a circular path, the circle must be divided into a series of straight line segments that approximate the curve.
- The tool is commanded to machine each line segment in succession so that the machined surface closely matches the desired shape.
- The maximum error between the nominal (desired) surface and the actual (machined) surface can be controlled by the lengths of the individual line segments.

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Numerical Control Interpolation Methods for Continuous Path Control

- If the programmer were required to specify the endpoints for each of the line segments, the programming task would be extremely arduous and fraught with errors . Also, the part program would be extremely long because of the large number of points.

- To ease the burden, interpolation routines have been developed that calculate the intermediate points to be followed by the cutter to generate a particular mathematically defined or approximated path.

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Numerical Control Interpolation Methods for Continuous Path Control

- A number of interpolation methods are available to deal with the various problems encountered in generating a smooth continuous path in contouring.
- They include
    1. Linear interpolation
    2. Circular interpolation
    3. Helical interpolation
    4. Parabolic interpolation, and
    5. Cubic interpolation.

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Numerical Control Interpolation Methods for Continuous Path Control

Linear Interpolation

- This is the most basic method and is used when a straight line path is to be generated in continuous path NC.
- Two-axis and three-axis linear interpolation routines are sometimes distinguished in practice, but conceptually they are the same.
- The programmer specifies the beginning point and end point of the straight line and the feed rate to be used along the straight line.
- The interpolator computes the feed rates for each of the two (or three) axes to achieve the specified feed rate.

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Numerical Control Interpolation Methods for Continuous Path Control

Circular Interpolation

- This method permits programming of a circular arc by specifying the following parameters: (1) the coordinates of the starting point, (2) the coordinates of the endpoint, (3) either the center or radius of the arc, and (4) the direction of the cutter along the arc.
- The generated tool path consists of a series of small straight line segments (see Figure 7.5) calculated by the interpolation module.

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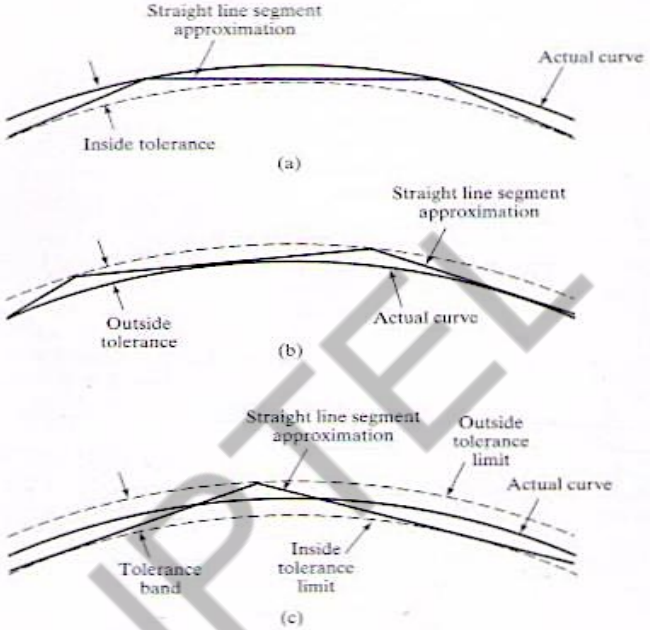

Figure 7.5 Approximation of a curved path in NC by a series of straight line segments. The accuracy of the approximation is controlled by the maximum deviation (called the tolerance) between the nominal (desired) curve and the straight line segments that are machined by the NC system. In (a) the tolerance is defined on only the inside of the nominal curve. In (b) the tolerance is defined on only the outside of the desired curve. In (c) the tolerance is defined on both the inside and outside of the desired curve.

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Numerical Control Interpolation Methods for Continuous Path Control

- The cutter is directed to move along each line segment one by one to generate the smooth circular path.

- A limitation of circular interpolation is that the plane in which the circular arc exists must be a plane defined by two axes of the NC system (x - y, x - z, or y - z).

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Numerical Control Interpolation Methods for Continuous Path Control

Helical Interpolation

- This method combines the circular interpolation scheme for two axes with linear movement of a third axis.
- This permits the definition of a helical path in three-dimensional space.
- Applications include the machining of large internal threads, either straight or tapered.

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Numerical Control Interpolation Methods for Continuous Path Control

Parabolic and cubic Interpolation

- These routines provide approximations of free-form curves using higher order equations.
- They generally require considerable computational power and are not as common as linear and circular interpolation.
- Most applications are in the aerospace and automotive industries for freeform designs that cannot accurately and conveniently be approximated by combining linear and circular interpolations.

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Numerical Control Interpolation Methods for Continuous Path Control

- The interpolation module in the MCU performs the calculations and directs the tool along the path.
- In CNC systems, the interpolator is generally accomplished by software.
- Linear and circular interpolators are almost always included in modern CNC systems, whereas helical interpolation is a common option.
- Parabolic and cubic interpolations are less common; they are only needed by machine shops that must produce complex surface contours.

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Numerical Control Interpolation Methods for Continuous Path Control

Absolute versus Incremental Positioning

- Another aspect of motion control is concerned with whether positions are defined relative to the origin of the coordinate system or relative to the previous location of the tool.
- The two cases are called absolute positioning and incremental positioning.
- In absolute positioning, the workhead locations are always defined with respect to the origin of the axis system.
- In incremental positioning, the next workhead position is defined relative to the present locations

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- Groover, M P. Automation, Production Systems, and Computer Integrated Manufacturing, Third Edition, Pearson Prentice Hall, Upper Saddle River

- Groover, M P. and Zimmers, E W Jr. CAD/CAM: Computer-aided Design and Manufacturing, Prentice-Hall of India Private Ltd.

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- ✓ **Applications of NC Technology-II**

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Manual Part Programming

- In manual part programming, the programmer prepares the NC code using a low level machine language based on binary numbers.
- In addition to numerical values, the NC coding system must also provide for alphabetical characters and other symbols.
- A **Word** specifies a detail about the operation, such as x-position, y-position, feed rate, or spindle speed.
- Out of a collection of words, a **block** is formed. A block is one complete NC instruction.
- It specifies the destination for the move, the speed and feed of the cutting operation, and other commands that determine explicitly what the machine tool will do.

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Manual Part Programming

- The organization of words within a block is known as a **block format**.
- For example, the two commands in word address format to perform the two drilling operations illustrated in Figure 7.15 are

N001 G00 X07000 Y03000 M03
N002 Y06000

- where N is the sequence number prefix, and X and Y are the prefixes for the x- and y- axes, respectively. G-words and M-words require some elaboration. G-words are called preparatory words.

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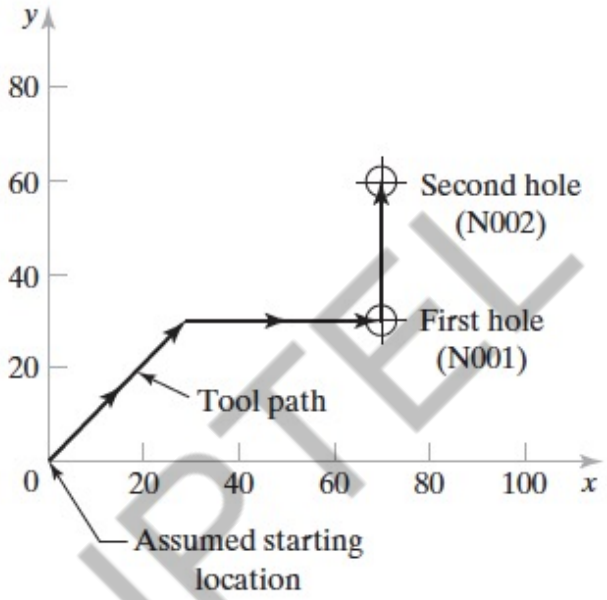

Figure 7.15 Drilling sequence for word address format example. Dimensions are in millimeters.

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Manual Part Programming

- Words in an instruction block are intended to convey all of the commands and data needed for the machine tool to execute the move defined in the block.
- The words required for one machine tool type may differ from those required for a different type; for example, turning requires a different set of commands than milling.
- The words in a block are usually given in the following order (although the word address format allows variations in the order):

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Manual Part Programming

- sequence number (N-word)
- preparatory word (G-word)
- coordinates (X-, Y-, Z-words for linear axes, A-, B-, C-words for rotational axes)
- feed rate (F-word)
- spindle speed (S-word)
- tool selection (T-word)
- miscellaneous command (M-word)

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Computer-Assisted Part Programming

- In computer-assisted part programming, the machining instructions are written in English-like statements that are subsequently translated by the computer into the low-level machine code that can be interpreted and executed by the machine tool controller.
- A few examples will be instructive here to show how geometric elements are defined. The sample part will be used to illustrate, with labels of geometry elements added in Figure 7.16(b).
- The statements are taken from APT, which stands for automatically programmed tooling.

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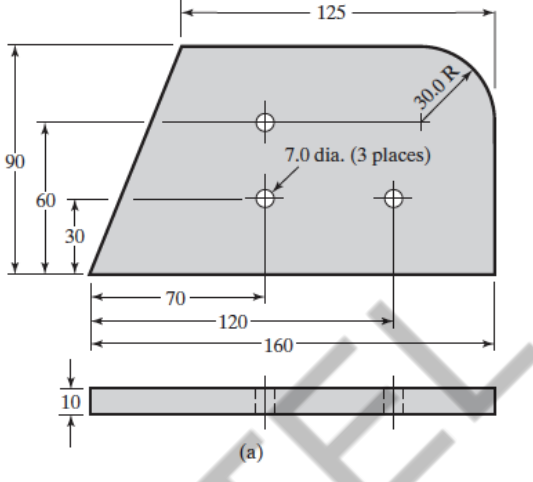

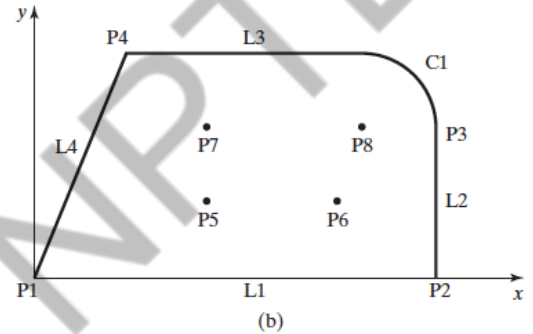

Figure 7.16 Sample part with geometry elements (points, lines, and circle) labeled for computer-assisted part programming.

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Computer-Assisted Part Programming

- The simplest geometric element is a point, and the simplest way to define a point is by means of its coordinates; for example,

P4 = POINT/35, 90, 0

- where the point is identified by a symbol (P4), and its coordinates are given in the order x, y, z in millimeters (x = 35 mm, y = 90 mm, and z = 0).
- A line can be defined by two points, as in the following:

L1 = LINE/P1, P2

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Computer-Assisted Part Programming

- where L1 is the line defined in the statement, and P1 and P2 are two previously defined points. And finally, a circle can be defined by its center location and radius,

C1 = CIRCLE/CENTER, P8, RADIUS, 30

- where C1 is the newly defined circle, with center at previously defined point P8 and radius = 30 mm. The APT language offers many alternative ways to define points, lines, circles, and other geometric elements.

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Computer-Assisted Part Programming

- After the part geometry has been defined, the part programmer must next specify the tool path that the cutter will follow to machine the part.

- The tool path consists of a sequence of connected line and arc segments, using the previously defined geometry elements to guide the cutter.

- A cut has just been finished along surface L1 in a counterclockwise direction around the part, and the tool is presently located at the intersection of surfaces L1 and L2.

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Some Common NC Modules for Automatic Programming of Machining Cycles

Module Type	Brief Description
Profile milling	Generates cutter path around the periphery of a part, usually two-dimensional contour where depth remains constant.
Pocket milling	Generates the tool path to machine a cavity, as in Figure 7.19(a). A series of cuts is usually required to complete the bottom of the cavity to the desired depth.
Engraving	Generates tool path to engrave (mill) alphanumeric characters and other symbols to specified font and size.

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Some Common NC Modules for Automatic Programming of Machining Cycles

Module Type	Brief Description
Contour turning	Generates tool path for a series of turning cuts to provide a defined contour on a rotational part, as in Figure 7.19(b).
Facing	Generates tool path for a series of facing cuts to remove excess stock from the end of a rotational part or to create a shoulder on the part by a series of facing operations, as in Figure 7.19(c).
Threading	Generates tool path for a series of threading cuts to cut external, internal, or tapered threads on a rotational part, as in Figure 7.19(d) for external threads.

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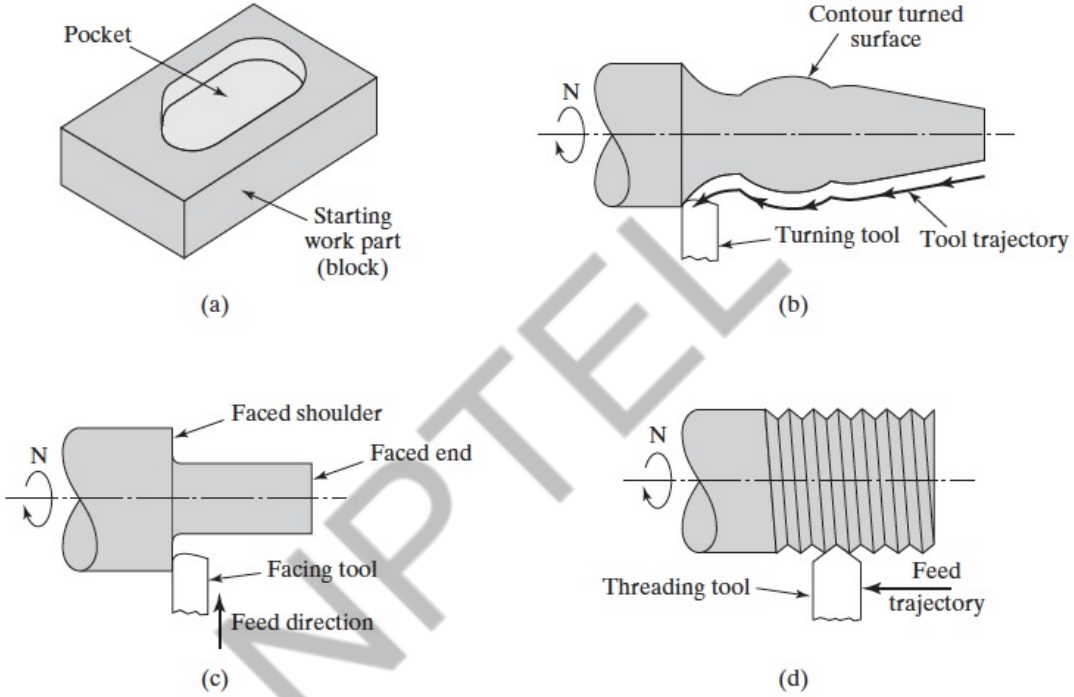

Figure 7.19 Examples of machining cycles available in automatic programming modules. (a) pocket milling, (b) contour turning, (c) facing and shoulder facing, and (d) threading (external).

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Typical Sequence of Steps in CNC Part Programming Using Mastercam for a Sequence of Milling and Drilling Operations

Step	Description
1	Develop a CAD model of the part to be machined using Mastercam, or import the CAD model from a compatible CAD package.
2	Orient the starting workpiece relative to the axis system of the machine.
3	Identify the workpiece material and specified grade (e.g., Aluminum 2024, for selection of cutting conditions).

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Typical Sequence of Steps in CNC Part Programming Using Mastercam for a Sequence of Milling and Drilling Operations

Step	Description
4	Select the operation to be performed (e.g., drilling, pocket milling, contouring) and the surface to be machined.
5	Select the cutting tool (e.g., 0.250-in drill) from the tool library.
6	Enter applicable cutting parameters such as hole depth.

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Typical Sequence of Steps in CNC Part Programming Using Mastercam for a Sequence of Milling and Drilling Operations

Step	Description
7	Repeat steps 4 through 6 for each additional machining operation to be performed on the part.
8	Select appropriate post-processor to generate the part program in word address format for the machine tool on which the machining job will be accomplished.
9	Verify the part program by animated simulation of the sequence of machining operations to be performed on the part.

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List of Reference Textbooks

- Groover, M P. Automation, Production Systems, and Computer Integrated Manufacturing, Third Edition, Pearson Prentice Hall, Upper Saddle River

- Groover, M P. and Zimmers, E W Jr. CAD/CAM: Computer-aided Design and Manufacturing, Prentice-Hall of India Private Ltd.

- Singh, N. Systems Approach to Computer-integrated Design and Manufacturing, Wiley

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Thank You!!

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