Computer-Aided Manufacturing

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  - *Computer-Aided part programming*
- *Computer-Aided Part programming*
  - *CAD-CAM based part programming*

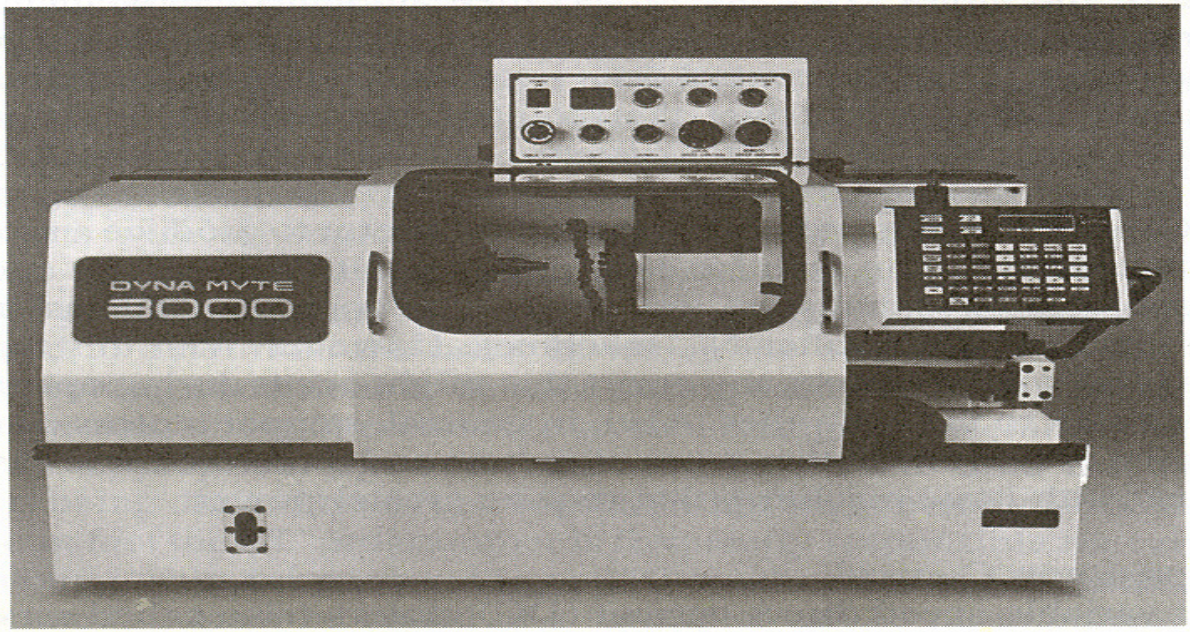
- Reference: Singh, N. (1996), "Systems approach to computer-integrated design and manufacturing", John Wiley & Sons.

Metal cutting machines

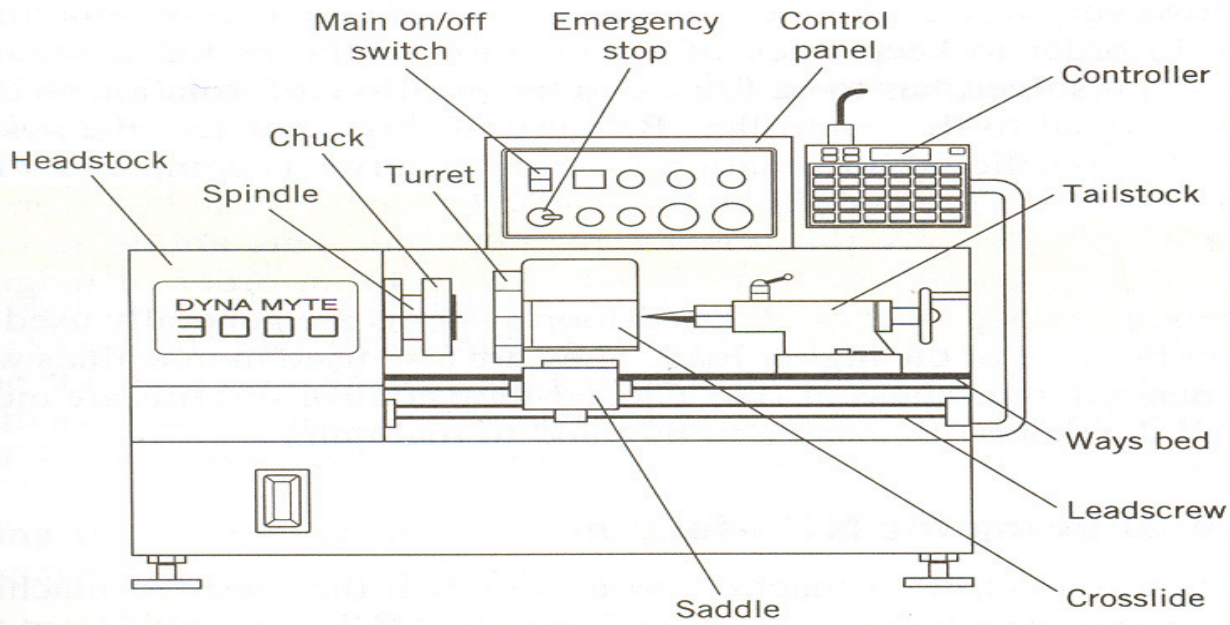
- Relative motion between cutting tool and work piece by forcing a sharp cutting edge into the work-piece.
- Problems:
  - Metals are very hard.
  - Motion between tool and work-piece should be at sufficiently high rate
- Temporary solution: Power driven machines (machine tools) are capable of generating high forces required, but to use a machine tool, we need to
  - Determine the location on the work-piece where machining is to be done.
  - Controlling the path followed during the motion of the tool or work-piece
  - Controlling the rate at which the path is traversed
  - Controlling the rate at which the path is traversed
- Further:
  - A highly skilled operator is required even for a simple job
  - Inconsistency in results
  - Much longer time, depend on knowledge and skill of operator.\ Very difficult to manufacture complex products
  - Low productivity

Numerically Controlled Machines

- Same technological capabilities as of conventional machines in terms of machining, but differ in control of machine functions.
- Elements of NC system
  - Part program
  - Machine control unit (MCU)
  - The machine tool
- Capabilities of Machine control unit (MCU) of a NC machine:
  - Positioning the tool
  - Turning the spindle ON/OFF
  - Setting cutting speeds/feed rates
  - Turning coolant ON/OFF
  - Direction and rate of slide motion, spindle rotation, etc.

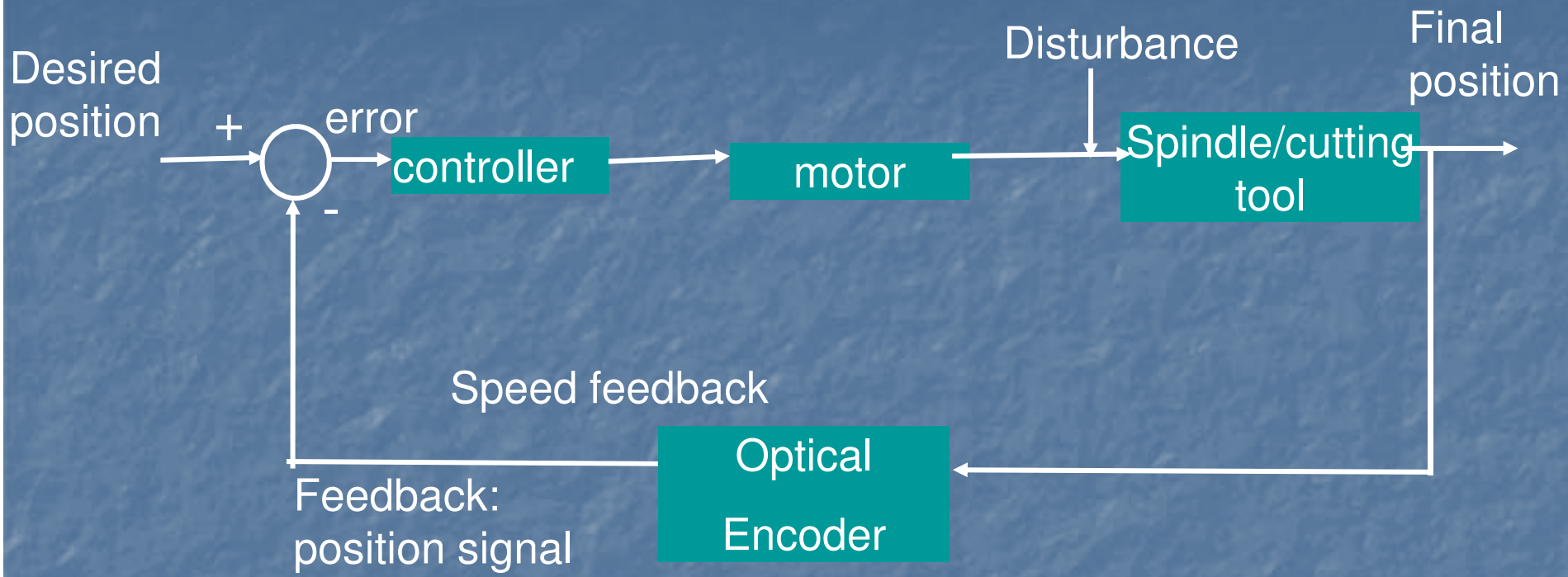


(a)



(b)

Control system in NC machine:



- Each motion is positioned by rotating motors by a desired amount
- The spindle/cutting tool is driven by DC/AC motors through reduction gear boxes
- Position of the motor is sensed using an encoder (e.g. resolution is 3500/revolution)
- Velocity of the motor is measured by a tacho-generator

Types of NC control systems

- Open-loop Control
  - Stepper motor is used, having a predefined amount of revolution.
  - Current pulses are send from MCU to individual motors.
  - Movement/rotation depends on number of pulses send.
  - Advantages:
    - Position is maintained just by keeping track of number of revolutions.
    - Can produce a movement of 1/1000th of an inch, for a single pulse.
    - Cheap and less complex.
    - Easy to maintain.
  - Drawback:
    - Assumption: Motor movement is precise, i.e. motor is moving the exact amount depending on the number of pulses.
    - No way to correct errors, because no feedback.
    - This control is not suitable for large machines requiring greater power because of limitation of stepper motor to generate high torque.

Types of NC control systems

- Closed-loop Control
  - Direct current (DC) motors are used.
  - Can generate high levels of torque.
  - Can be reversed.
  - Unlike stepper motors, it cannot achieve very precise movement.
  - Separate positions sensors are required.
  - Position information is fed back as a signal to the controller.
  - Major advantage: because of feed back and servo motors reversible feature, errors can be corrected, by comparing with target position.
  - Thus formed a closed loop.
  - Higher accuracy than open loop systems because of feed back.
  - Applications:
    - Larger NC machines because of higher loads.
    - For greater accuracy, any kind of load.
  - Expensive and complex.

Motion and coordinate system for NC machine

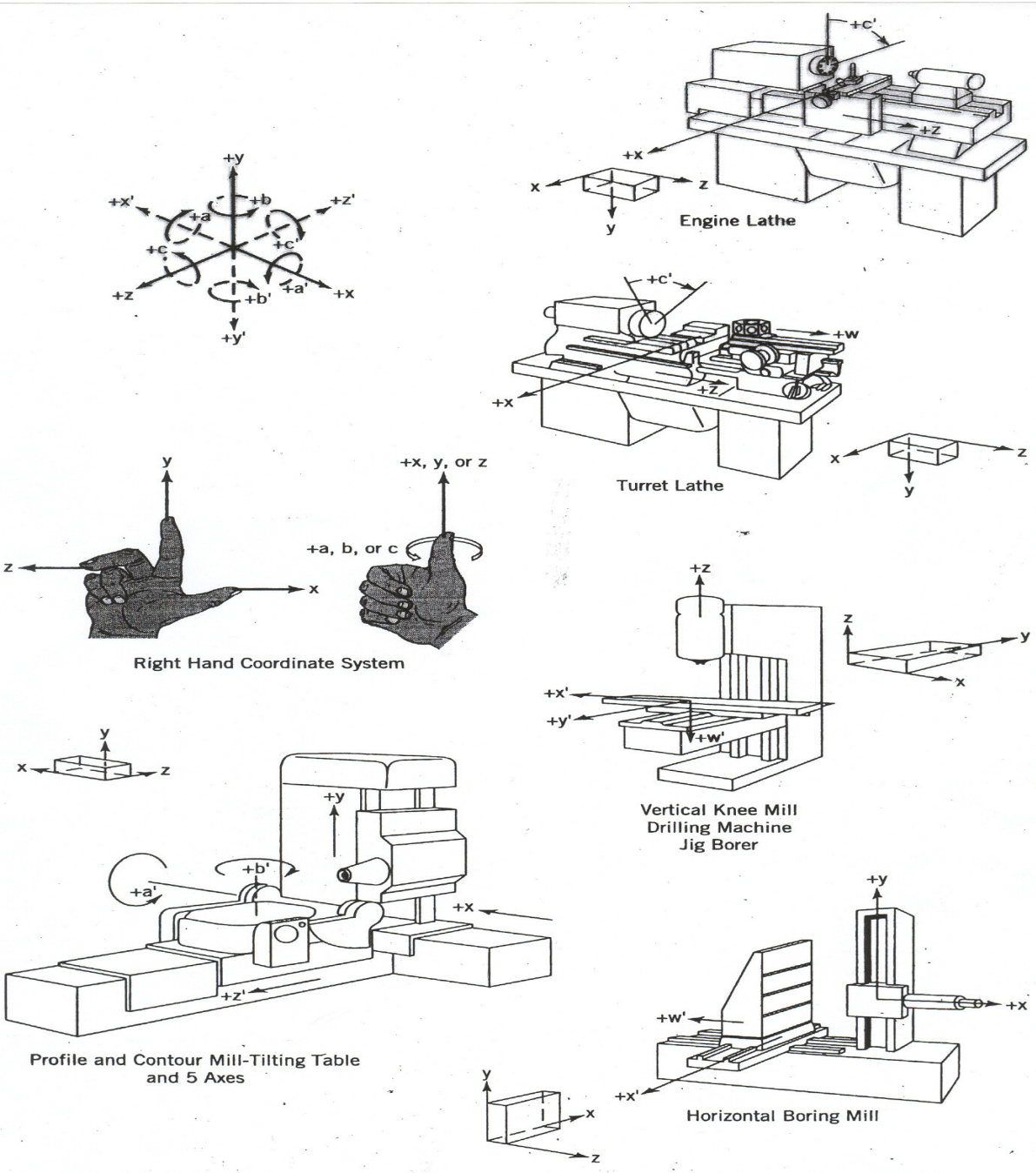


FIGURE 6.2 The right-handed Cartesian coordinate system and its application to some common machines. (*Source:* EIA Standard RS-267 B. Used with permission of the Electronic Industries Association.)

Z-axis: Always aligned with the spindle that imparts cutting power. This spindle might rotate the work-piece as in a lathe, it might rotate a tool as in a milling machine. It is perpendicular to work-holding surface if there is no such spindle. Positive motion in z axis tends to increase the separation between the work-piece and the tool

X axis: Positioning the moving element, parallel to the work-holding surface, horizontal (if possible).

On machines with rotating work-pieces, it is radial and parallel to the cross-slide

On machines with rotating tools,

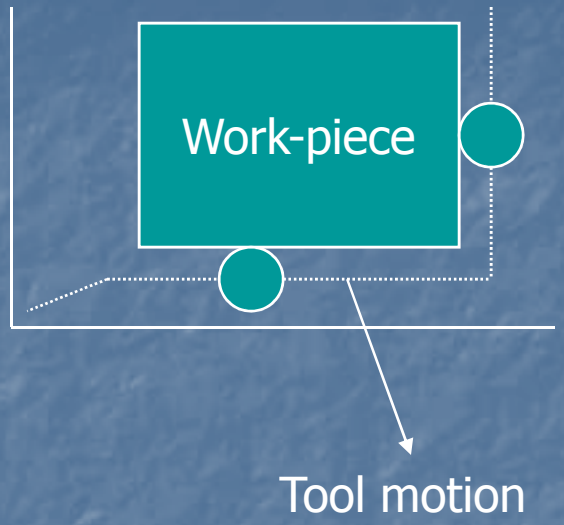
1. If the Z-axis is horizontal, the positive x motion is to the right when looking from the spindle to the work-piece.
2. If the z axis in vertical, the positive x axis is to the right when looking from the spindle to the column

On machines with non-rotating work-pieces and non-rotating tools, the x-axis is parallel to and directed toward the principal cutting direction

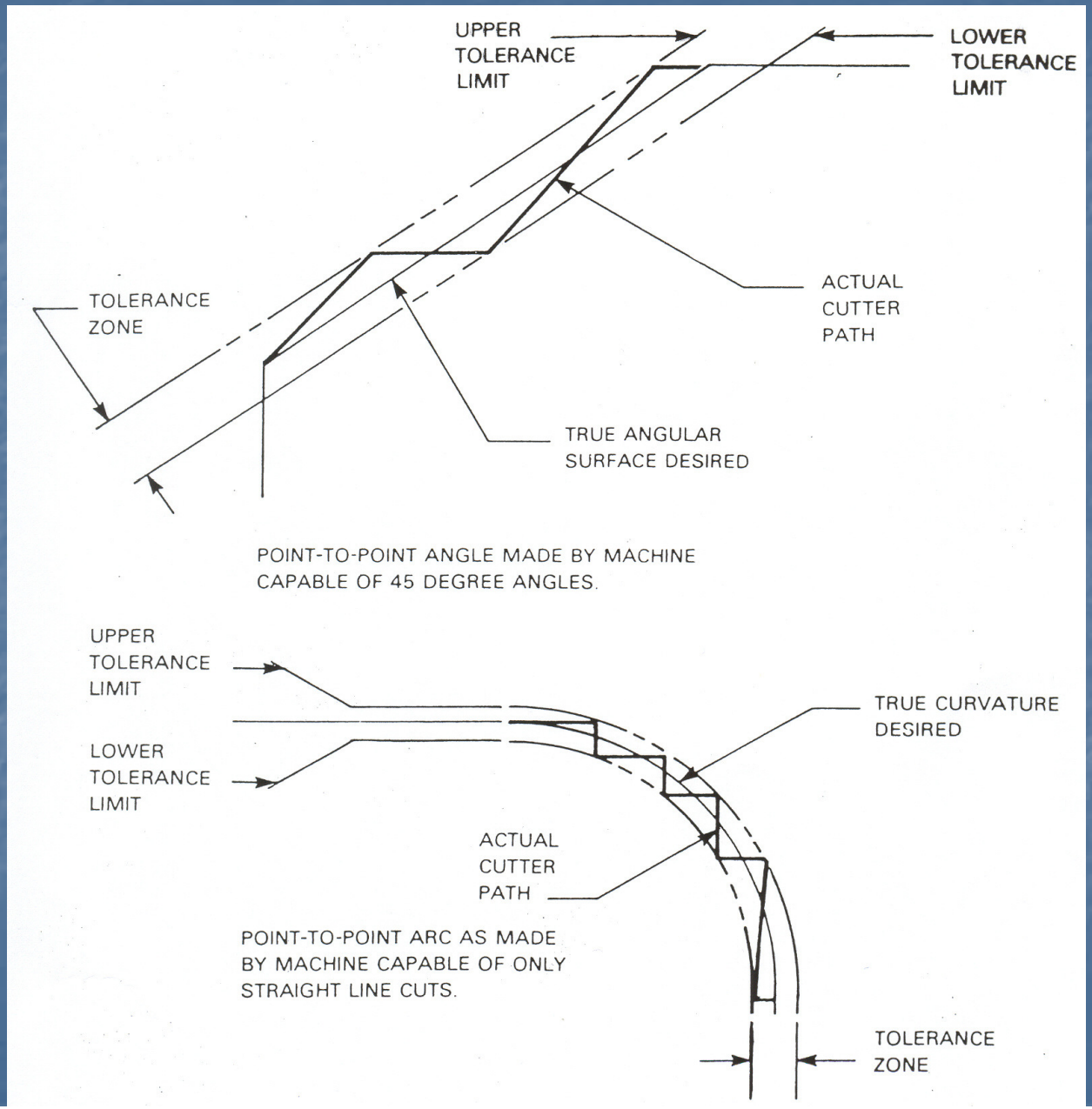
Y-axis: be in such a direction as to complete a right-handed Cartesian coordinate system

Motion control system

- Point to point
- Straight cut system
- Continuous path

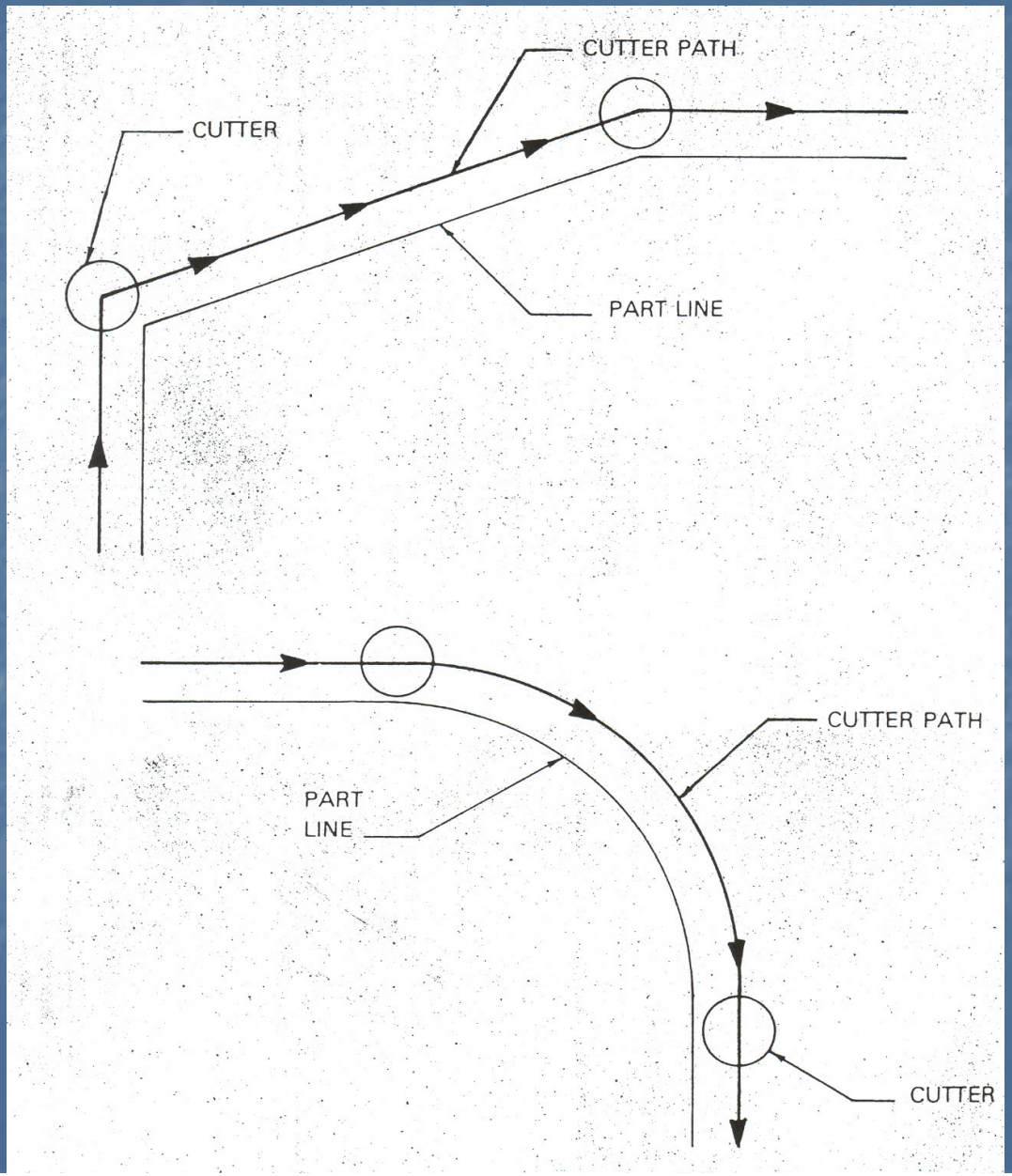


Point to Point angles and Arcs:



Continuous path angles and Arcs:

- Linear path interpolation
- Incremental path approximation
- Interpolation using circular or other equations



NC Part Programming

- Part Program is the program required to machine a specific part or component.
- Require intimate knowledge about the processes.
- NC part programmer should be a skill operator and good part programmer for maximum utilization of machine capabilities and available resources like jigs and fixtures, cutting tools, without violating the machine constraints.
- Assumed that it is the tool that undergoes the primary motion, for writing NC part program.
- Absolute positioning mode:
  - Target position of the tool is given relative to the origin point of the program.
- Incremental positioning mode
  - Target position for the tool is given relative to the current tool position

Structure of an NC part program

1. Fixed sequential format:

- Each statement consists of exactly the same number of words entered in a specified sequence,
- Each word consists of a fixed number of data characters
- Characters cannot be omitted and no extra characters can be included

```
0050 00 +0025400 +0012500 +0000000 0000 00
0060 01 +0025400 +0012500 −0010000 0500 08
0070 01 +0025400 +0012500 +0000000 0500 09
```

Tab sequential format:

- It is essential the same as fixed sequential format
- The difference is that each word within a statement is preceded by a TAB character
- The sequence of the words remains significant
- The spaces should not be used in the actual program.

```
0050 TAB 00 TAB +0025400 TAB +0012500 TAB TAB TAB
0060 TAB 01 TAB TAB TAB −0010000 TAB 0500 TAB 08
0070 TAB 00 TAB TAB TAB +0000000 TAB 0000 TAB 09
```

Word address format:

- A method of coding machine motion using ANSI format letter system.
- Ease to use
- Does not require all the words.
- Ignores spaces.

TABLE 6.1 **Commonly Used Word Addresses**

Address	*Meaning*
F	Feed rate command
G	Preparatory function
I	Circular interpolation: *x*-axis offset
J	Circular interpolation: *y*-axis offset
K	Circular interpolation: *z*-axis offset
M	Miscellaneous commands
N	Sequence number
R	Arc radius
S	Spindle speed
T	Tool number
X	*x*-axis data
Y	*y*-axis data
Z	*z*-axis data

```
N50 G00 X25400 Y12500 Z0 F0
N60 G01 Z-10000 F500 M08
N70 Z0 M09
```

Fundamentals of NC Programming:

- Preparatory function:
  - Necessary operation conditions
- Axis motion commands:
  - Control the amount of relative motion
- Feed and speed commands:
  - Control the cutting conditions
- Identification commands:
  - To identify specific entities in the program, such as cutting tools used
- Miscellaneous commands:
  - Controls various aspects of the machine's operation such as turning the spindle on and off and changing tools

```
N50 G00 X25400 Y12500 Z0 F0
N60 G01 Z-10000 F500 M08
N70 Z0 M09
```

Preparatory function:

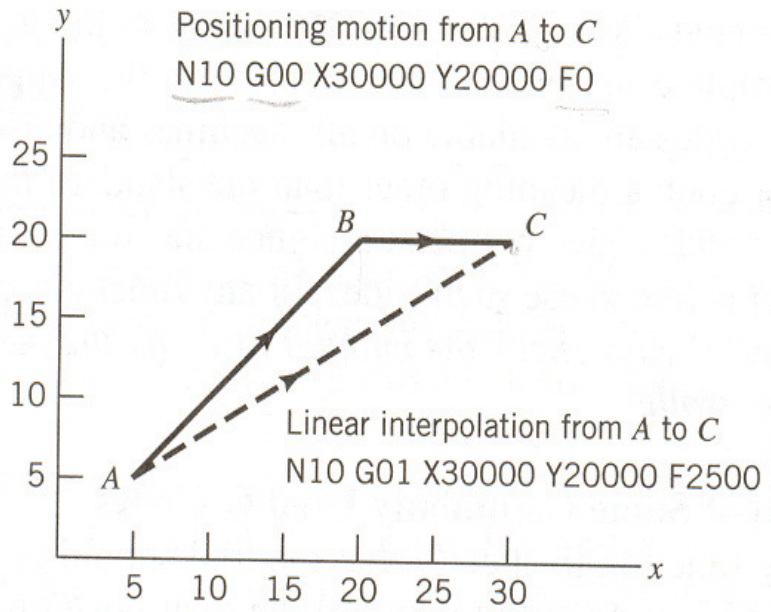


FIGURE 6.3 Positioning and linear interpolation for NC.

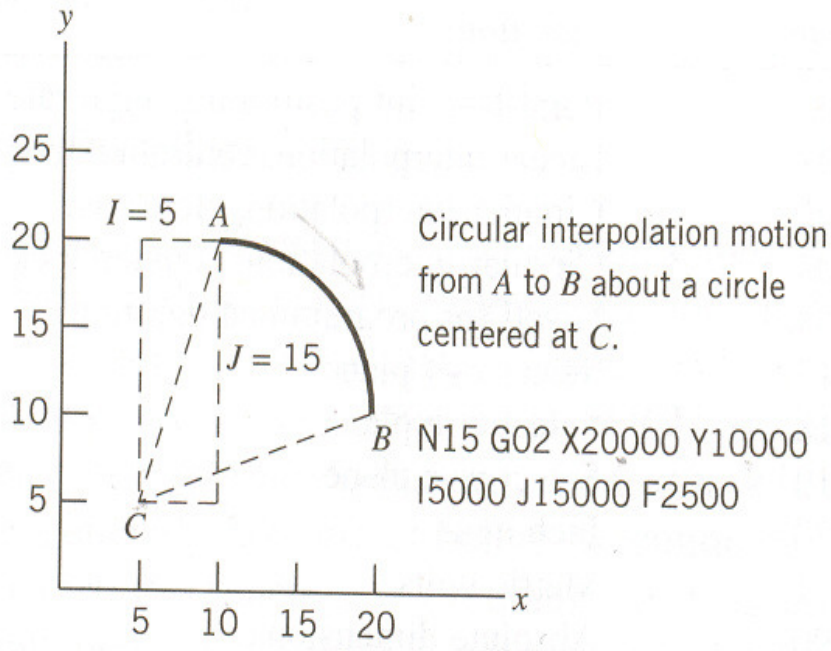


FIGURE 6.4 Circular interpolation for NC.

Preparatory function continue.. Canned cycles:

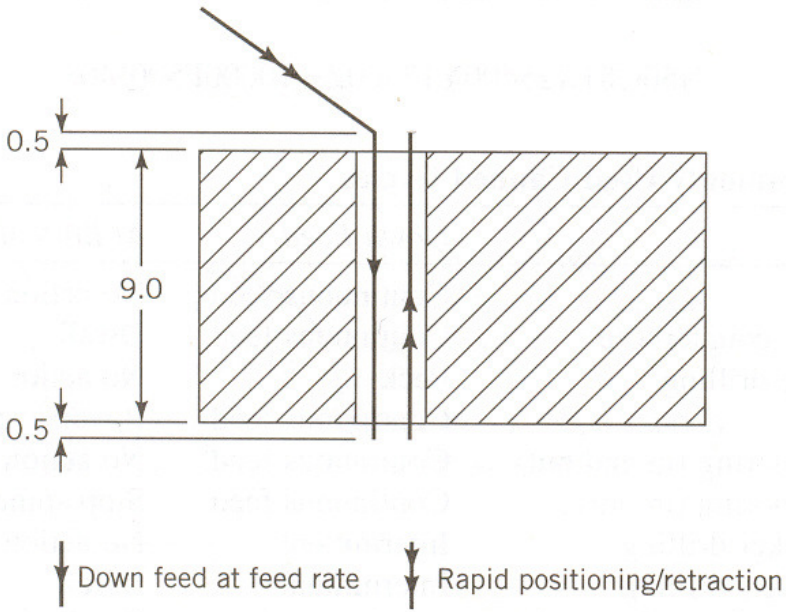


FIGURE 6.5 Drilling motion for Exhibits 6.1–6.4.

TABLE 6.3 **Commonly Used Canned Cycles**

Code	*Function*	*Down Feed*	*At Bottom*	*Retraction*
G81	Drilling	Continuous feed	No action	Rapid
G82	Spot face, counterbore	Continuous feed	Dwell	Rapid
G83	Deep hole drilling	Peck	No action	Rapid
G84	Tapping	Continuous feed	Reverse spindle	Feed rate
G85	Through boring (in and out)	Continuous feed	No action	Feed rate
G86	Through boring (in only)	Continuous feed	Stop spindle	Rapid
G87	Chip breaker drilling	Intermittent	No action	Rapid
G88	Chip breaker drilling	Intermittent	Dwell	Rapid
G89	Through boring with dwell	Continuous feed	Dwell	Feed rate

Example 1:

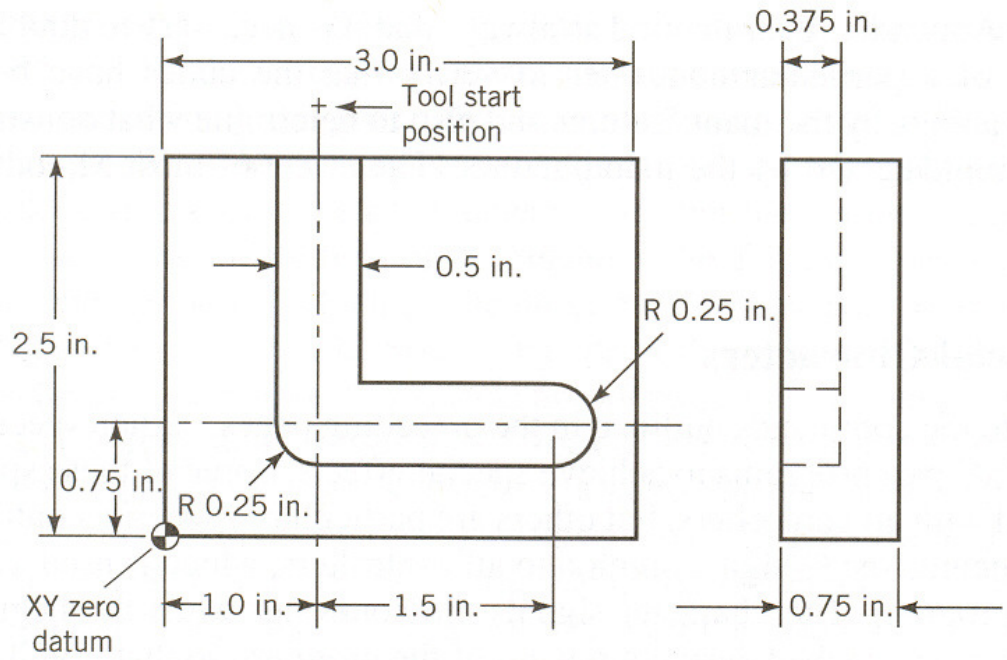


FIGURE 6.6 A slot milling example.

```
%
N005 G90 G70
N010 G97 G94 T01

N015 G00 X1000 Y3000 Z250 F0
N020 G01 Z-375 M03 S500 F10
N025 Y750
N030 X2500
N035 Z250
N040 X-1000 Y-1000 F0
N045 M30
```

Indicates start of program
Specifies absolute dimensions, inch units
Specifies units for speed and feed rate; loads first tool
Rapid positioning of tool to start point
Turns on spindle, feeds tool to required depth
Machines the vertical portion of the L
Machines the horizontal portion of the L
Retracts tool to 0.25 in above part surface
Moves to safe location at rapid rate
Turns off all machine functions

Example 2:

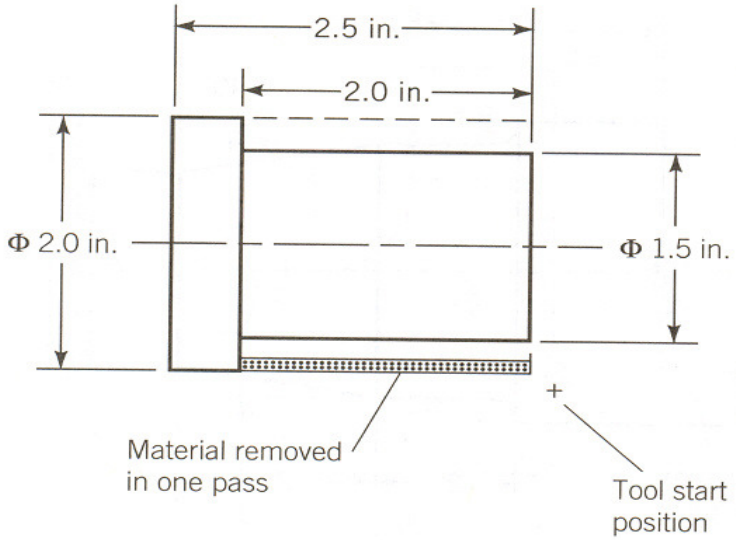


FIGURE 6.7 A simple turning example.

```
%
N005 G90 G70
N010 G98 G92 T01
N015 G00 X2200 Z2600 F0
N020 X1800 M03 S1200 F0

N025 G01 Z500 F12
N030 X1900
N035 G00 Z2600 F0
N040 X1600 F0
N045 G01 Z500 F12
N050 X1700
N050 G00 Z2600 F0
N060 X1500 F0
N065 G01 Z500 F12
N070 X2200
N075 G00 X5000 Z5000 F0
N080 M30
```

Indicates start of program
Specifies absolute programming, inch units
Specifies units for speed and feed rate, loads 1st tool
Rapid positioning of tool to tool start position
Position tool to remove 0.1 in. off part diameter, start spindle
Feed tool into workpiece
Retract tool (overlap previous cut)
Move tool clear of workpiece
Position tool to remove 0.1 in. off part diameter
Feed tool into workpiece
Retract tool (overlap previous cut)
Move tool clear of workpiece
Position tool to take finish cut
Feed tool into workpiece
Retract tool clear of the workpiece
Move to safe position
Turn off all machine functions

Loading the program

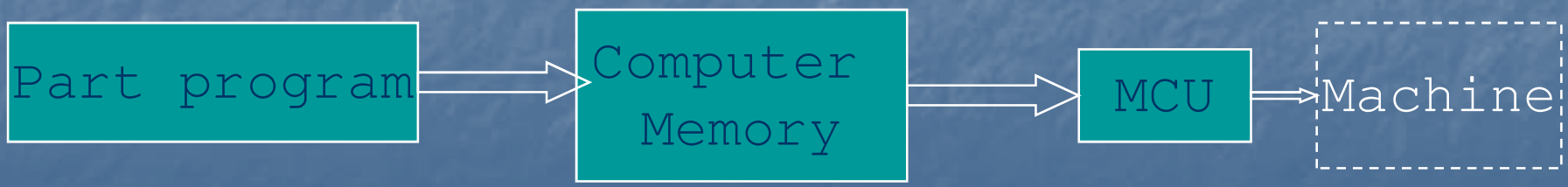
Conventional NC:

- *1-in.-wide punched paper tape*: for program storage and input to NC machines
- A binary-based representation code
- Two standard coding schemes: EIA & ASCII

Loading the program

Computer NC (CNC)

- Storage medium
- Display operational parameters, coordinate positions, etc.
- Keyboard for data entry and editing the program



Loading the program

Distributed Numerical Control (DNC)

- Each CNC machine has its own memory
- The local machine can run autonomously
- Central computer plays a supervisory role, monitoring the operations of machines, etc.

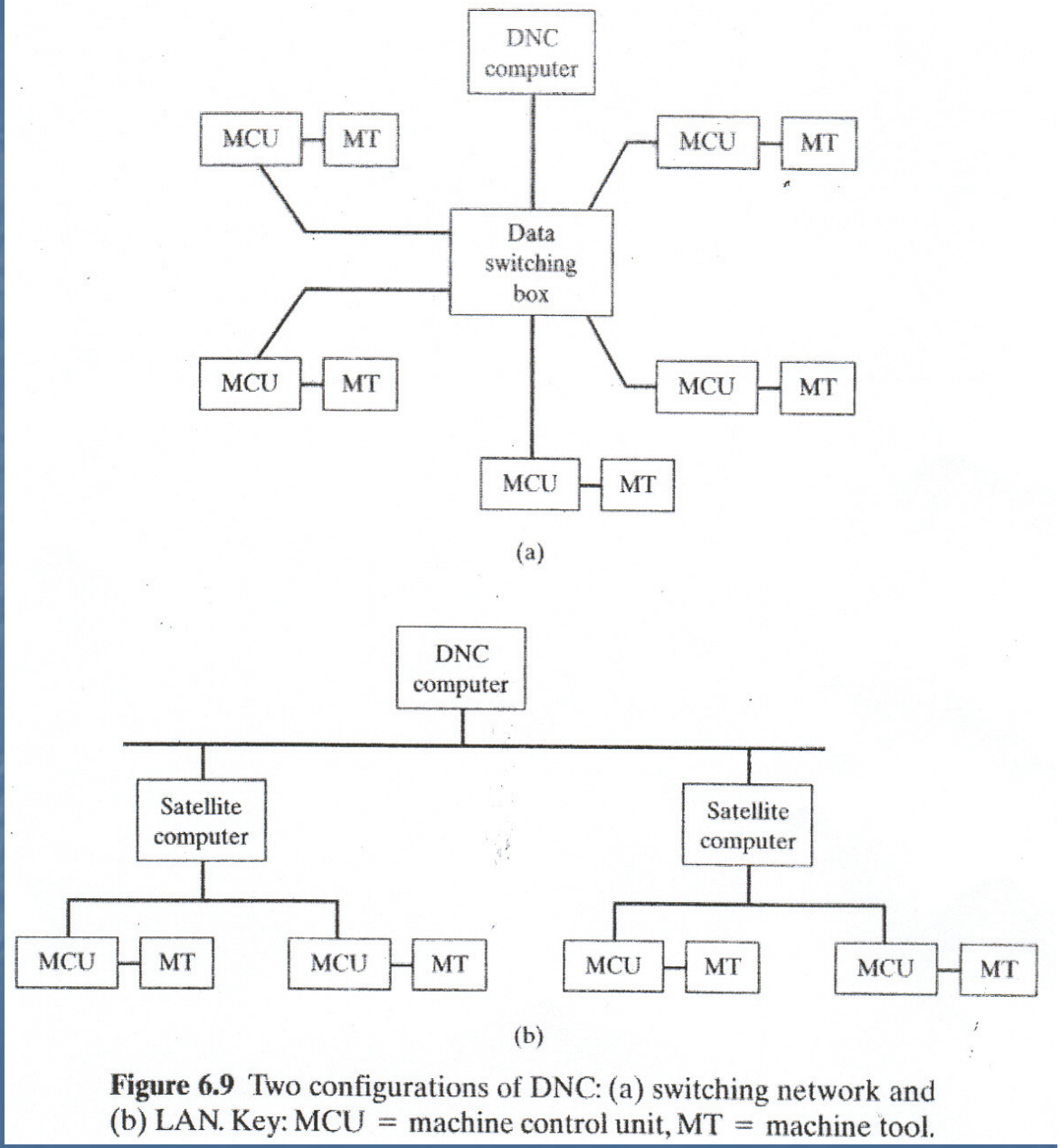
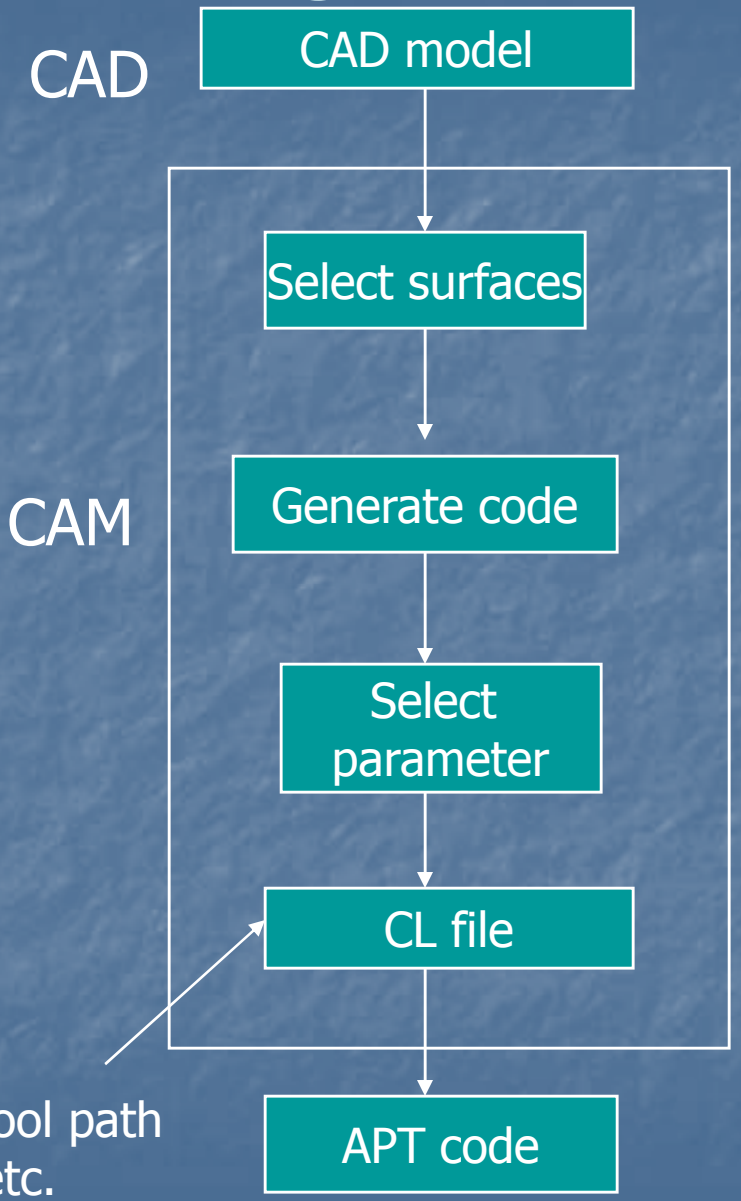


Figure 6.9 Two configurations of DNC: (a) switching network and (b) LAN. Key: MCU = machine control unit, MT = machine tool.

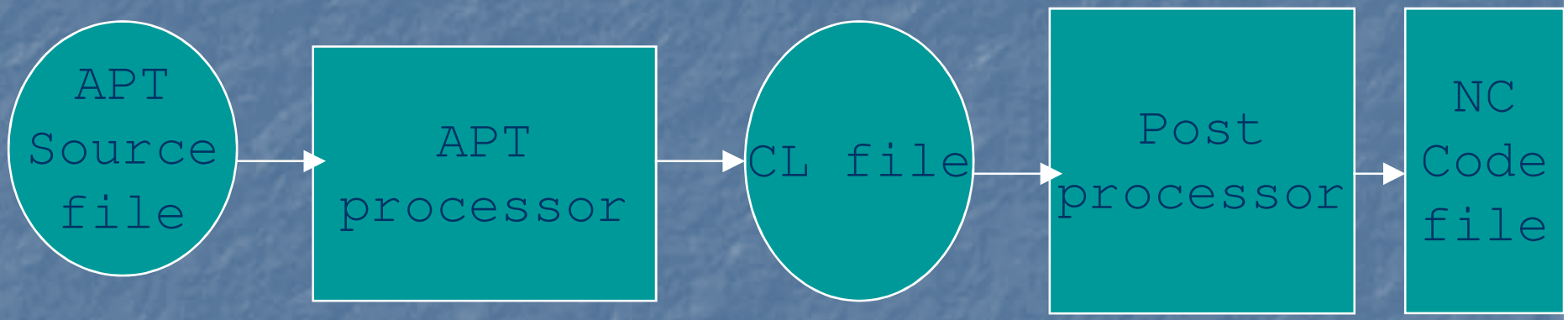
Computer-Aided Part Programming:

- Reduces the manual calculations
- To prove the program by path simulation, identify errors
- Set of events can be programmed with fewer commands, leading to shorter programs
- English-like structure of the programming systems makes it easier for programmers to learn
- Program preparation is simplified by use of English-like commands that are easy to understand and program. It reduces the likelihood of errors in the program.



Computer-Aided Part Programming:

Standard APT (Automatically programmed tools) language:



- APT source file: written by user
- APT processor checks the source file for errors in defined geometry, errors in required tool motions
- CL file means cutter location file
- Post processor converts CL data into final NC codes.

Computer-Aided Part Programming:

Post processing

- Convert the CL data into m/c tool coordinates.
- Check for speed, feed, movement limitations.
- Develop motion command using M&G codes.
- Process machine specific functions.
- Select acceleration, deceleration, etc.

CAD/CAM based Part Programming:

- Direct use the CAD database for geometric description of parts.
- Generate tool path information from the geometric model of the part in the CAD database.
- Post processor is still required.
- Commercial CAD/CAM systems with NC program generation: CATIA, CADAM, Pro/E.

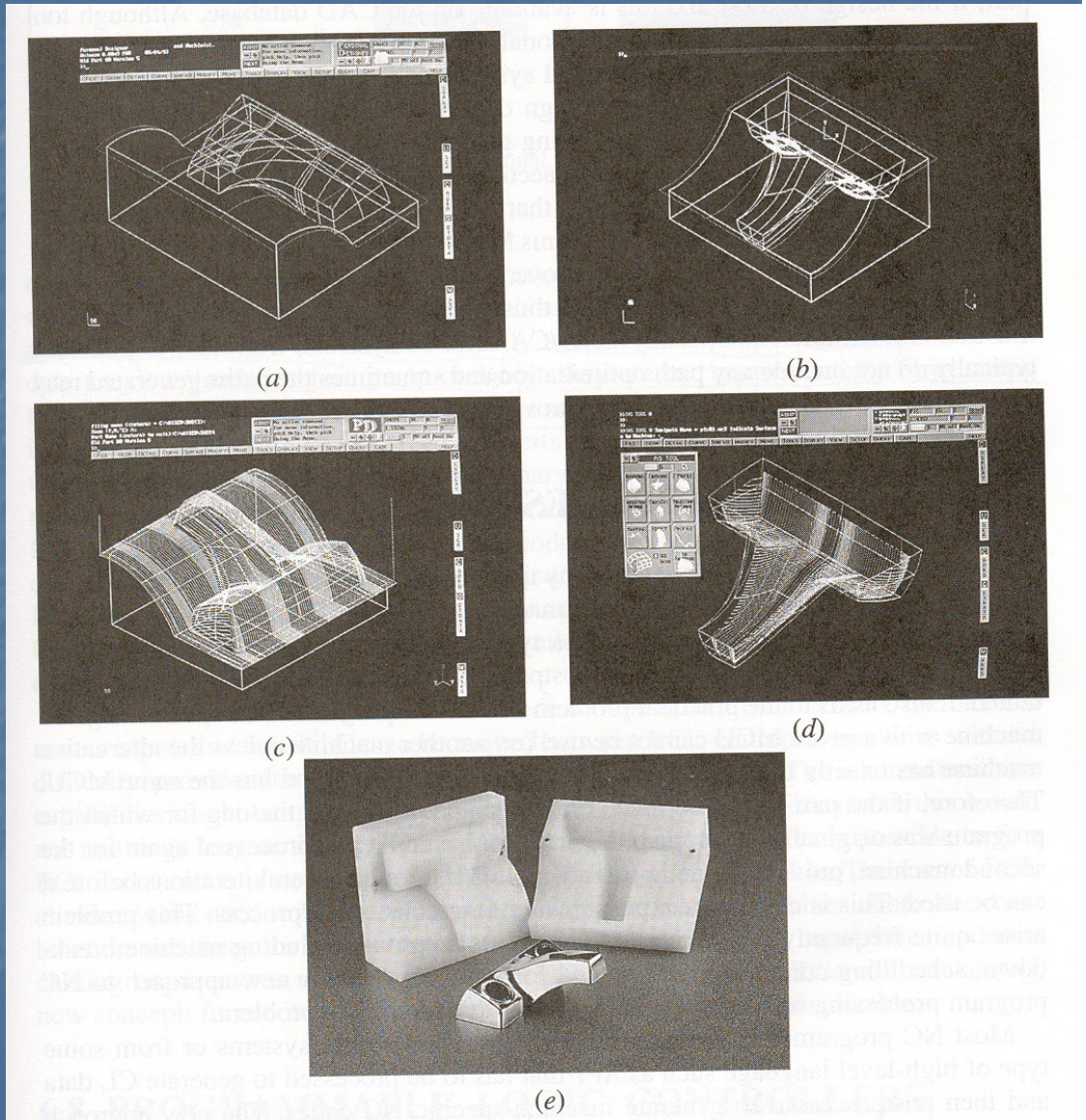


FIGURE 6.15 CAD/CAM-based NC program generation using Personal Machinist. (Used with permission of Computervision Corp.)