Numerical Control (NC) and The A(4) Level of Automation

Chapter 40

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40.1 Introduction

- Numeric Control (NC) and Computer Numeric Control (CNC) are means by which machine centers are used to produce repeatable machining process.
- Two types are used:
  - Fixed Automation using mechanical cam
  - Flexible Automation using G Code
- The control programs use either
  - Closed loop control using feedback
  - Or Open loop control

NC Machines

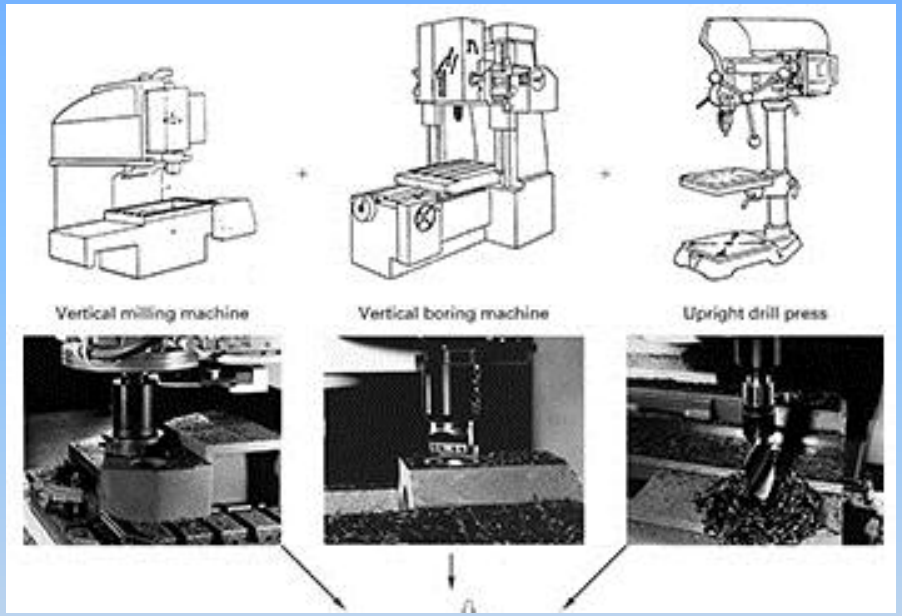
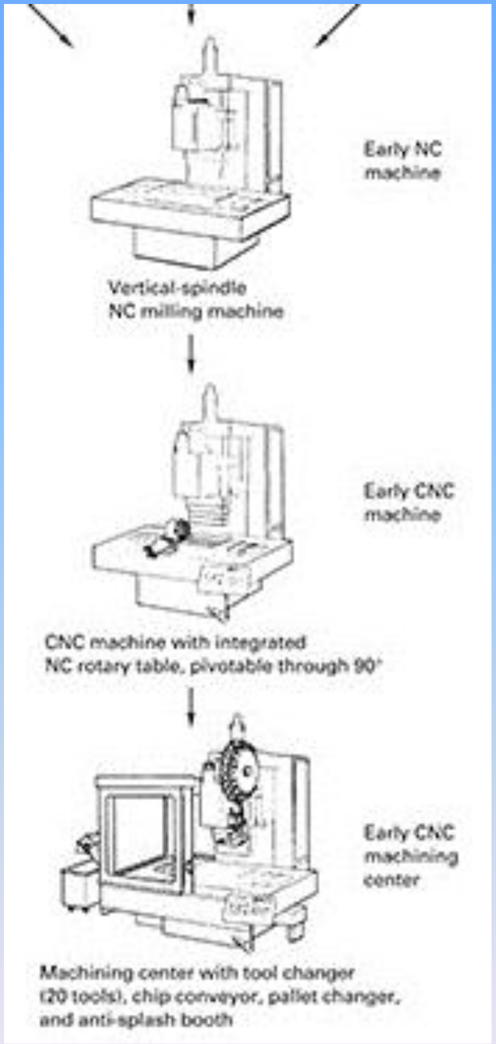


FIGURE 26-1 Early NC machine tools were controlled by paper tape. Soon onboard computers were added, followed by tool changers and pallet changers.



Open Loop versus Closed Loop

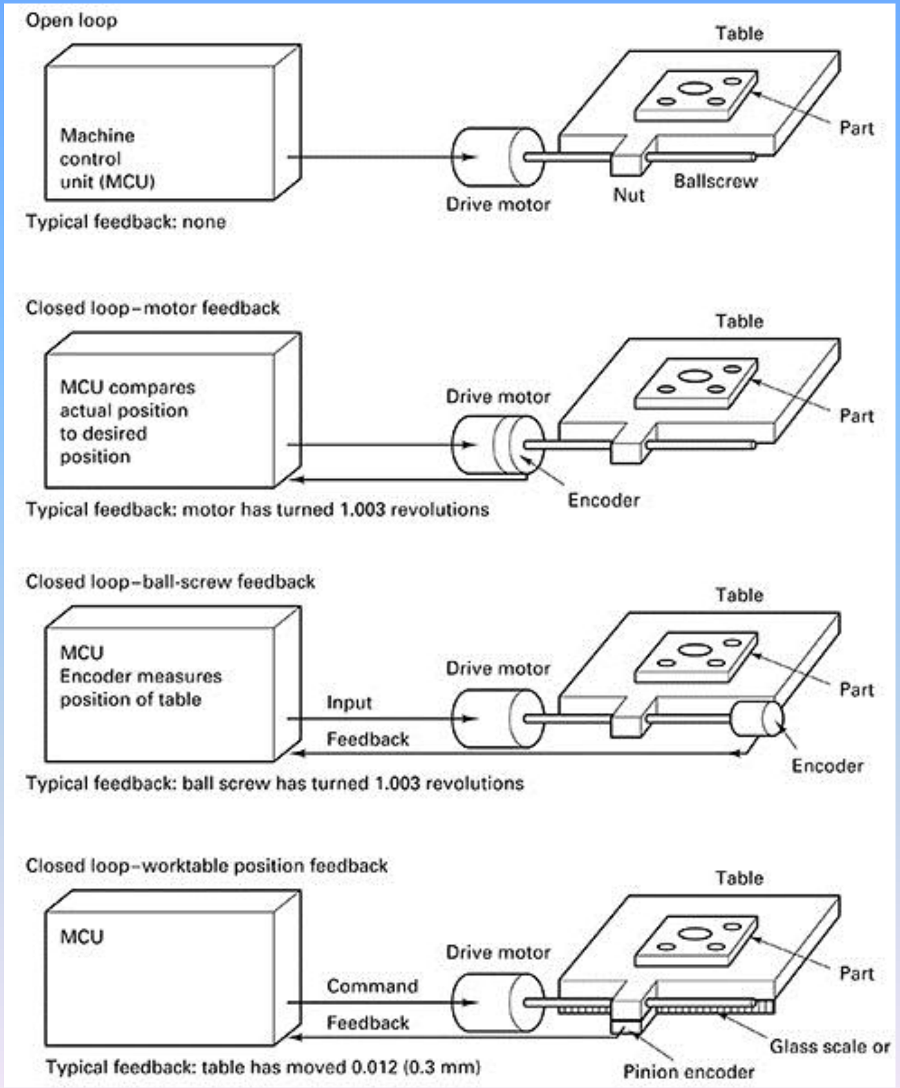
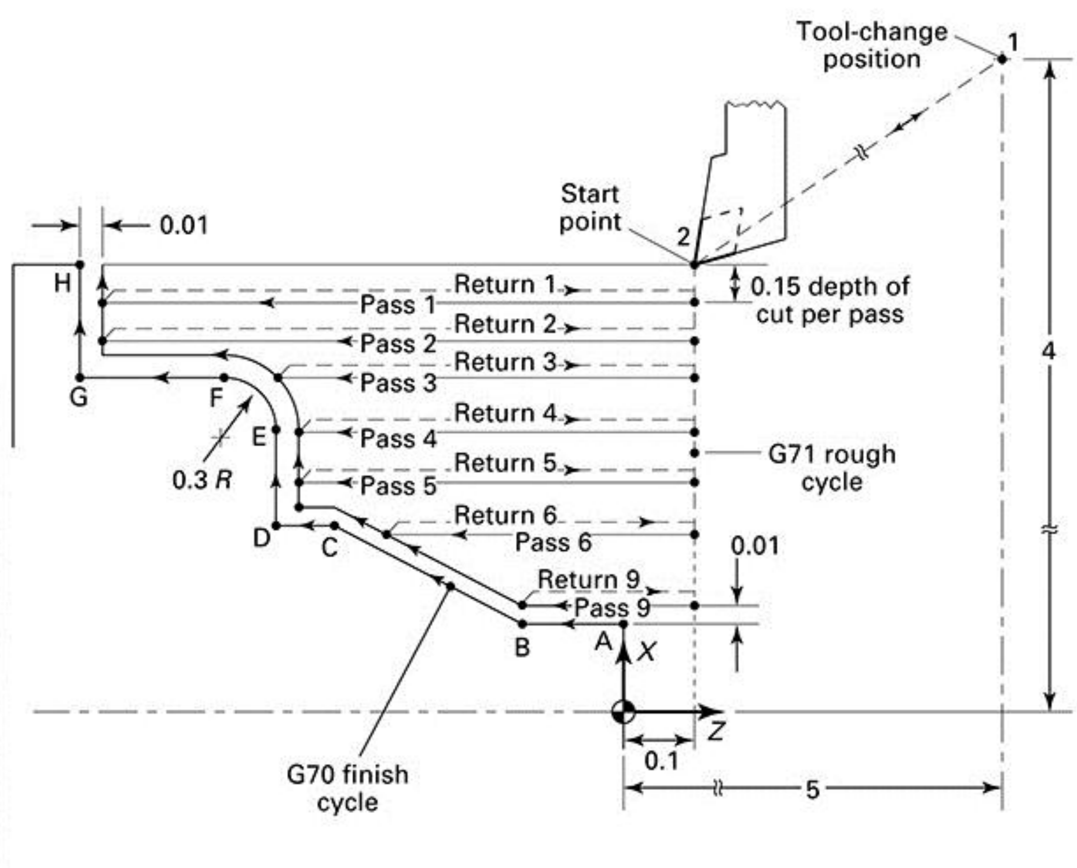


FIGURE 26-2 Open-loop NC versus three position control schemes for NC and CNC machine to

Example of G Code

FIGURE 26-3 The tool paths necessary to rough and finish turn a part in a CNC lathe are computer generated using G codes.

Point	X (in.) diameter	Z (in.)
2	4.5	0.1
A	1.8	0
B	1.8	–0.9
C	2.6	–2.6
D	2.6	–2.9
E	3.1	–2.9
F	3.7	–3.2
G	3.7	–3.8
H	4.5	–3.8



History of NC

- Machine Centers have been in development over the last 60 years, with significant support from the USAF
- NC has impacted tool design, requiring tools with greater strength and higher temperature resistance
- New NC coding software has removed the earlier need for highly trained programmers, broadening the use of NC to most manufacturing facilities
- Today, a majority of the machines use Distributed Numeric Control, eliminating the need for paper tapes and large onboard processors

Machine Center

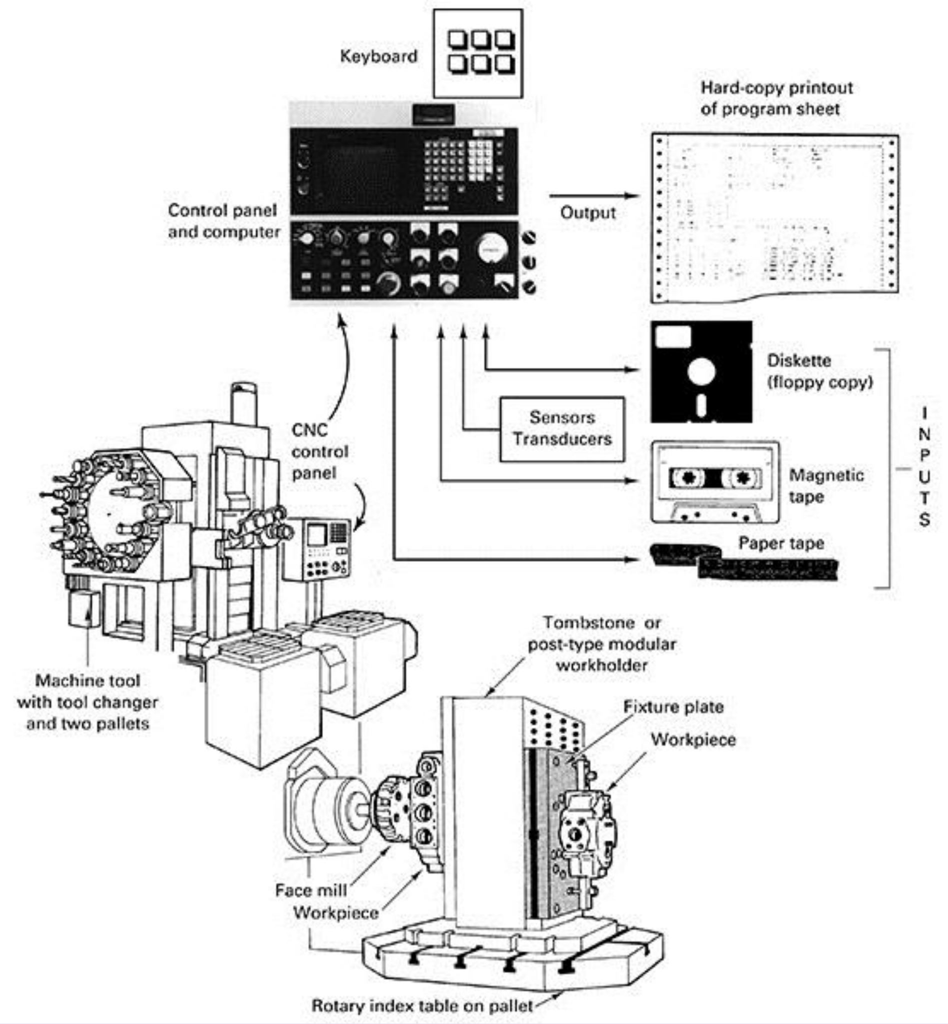


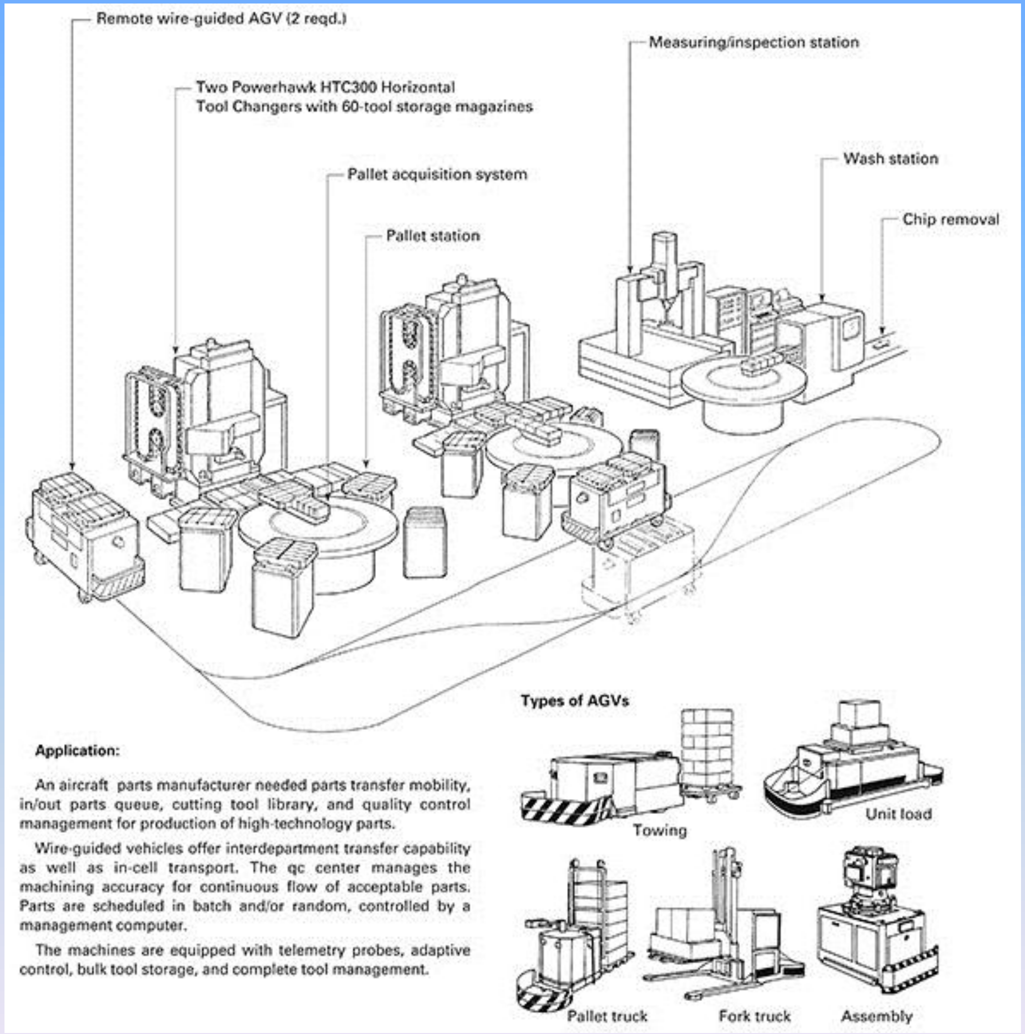
FIGURE 26-4 Horizontal machining center with four-axis control (*X, Y, Z, R* table) receives inputs to the control panel from many sources.

Flexible Manufacturing Systems (FMS)

- FMS enables products to take random paths through the machines
- The system used automated conveyors and NC machines to move parts through a shop, accounting for the variability of machine time for different parts.
- As a part reaches a machine, the appropriate code and tools are used for the part, the central system schedules the parts/machines based on production rate needs.

FMS Diagram

FIGURE 26-5 An example of a sophisticated FMS developed for machining aircraft parts. A wire-guided cart called an AGV (automated guided vehicle) is used to transport pallets from the unload/load station to the machines



FMS Features

TABLE 26-1 Common Features of Flexible Manufacturing Systems

Pallet changers
Multiple machine tools: NC or CNC
Automated material handling system (to deliver parts to machines)
Computer control for system: DNC
Multiple parts: Medium-sized lots (200–10,000) with families of parts
Random sequencing of parts to machines (optional)
Automatic tool changing
Inprocess inspection
Parts washing (optional)
Automated storage and retrieval (optional, to deliver parts to system)

Examples of FMS

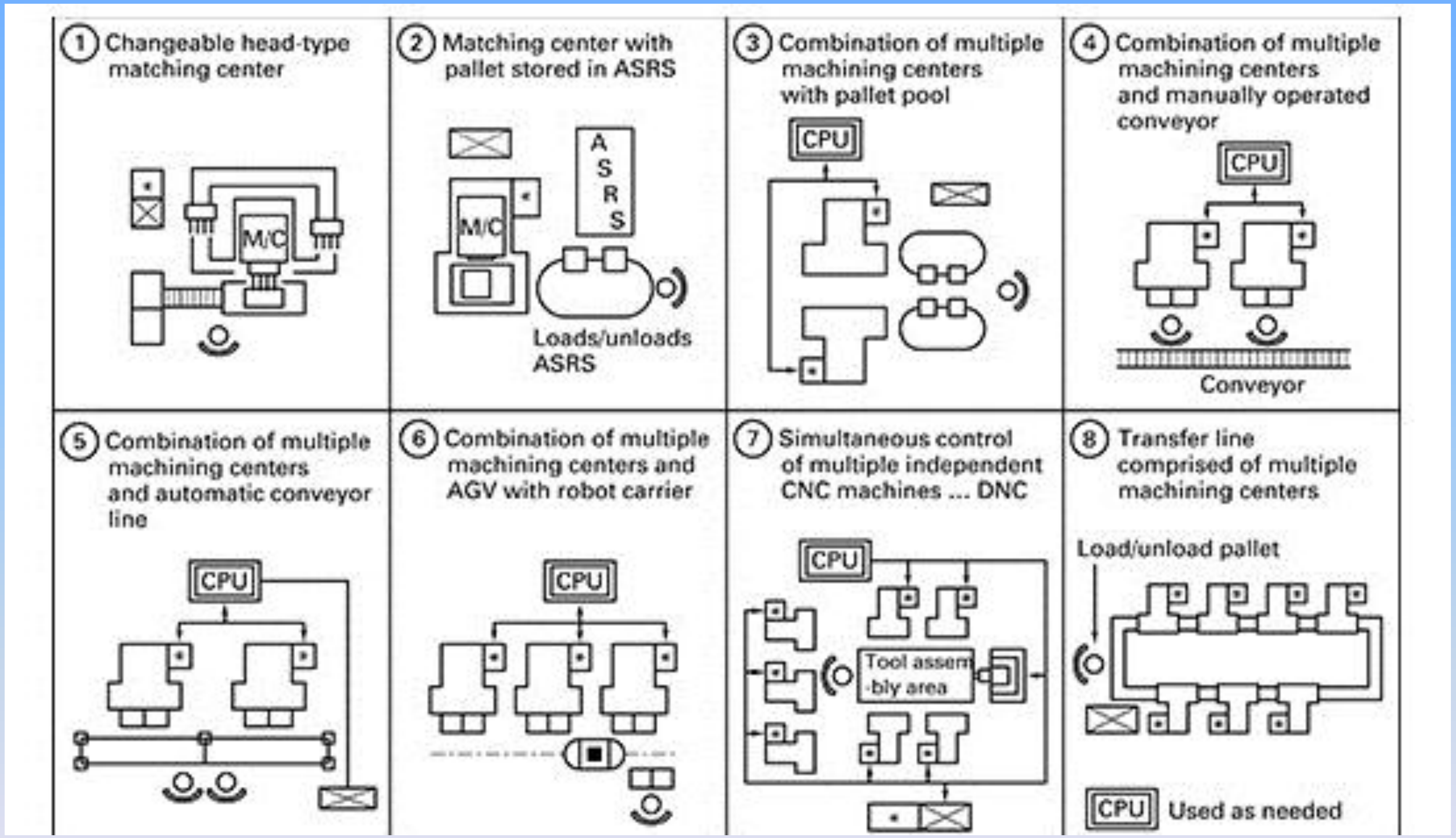


FIGURE 26-6 Examples of machining centers—FMC and FMS designs.

Examples of FMS

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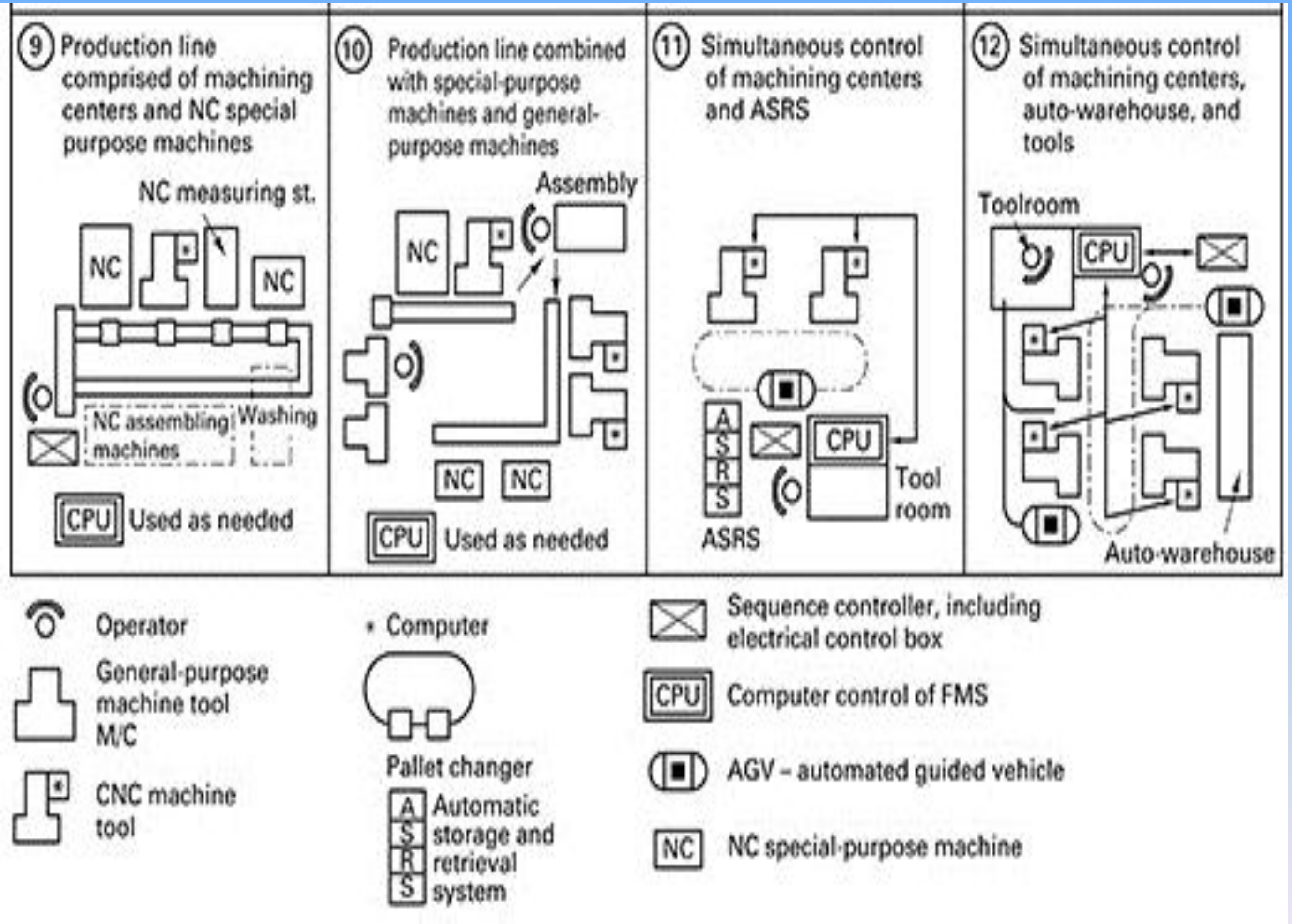
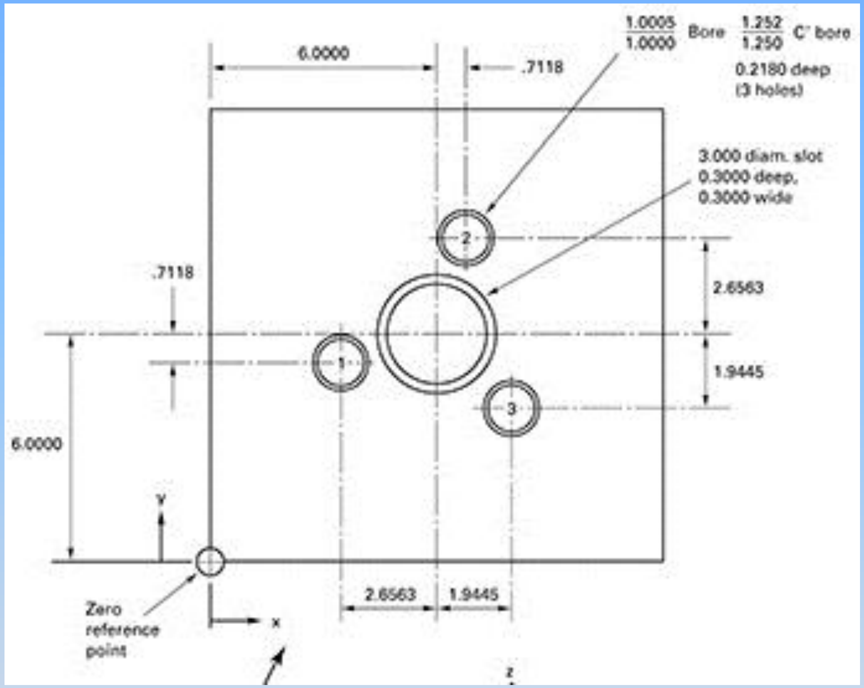


40.2 Basic Principles of Numerical Control

- NC uses processing language to control the movement of the cutting tool, workpiece or both
- NC machines can duplicate parts with repeatability and accuracy improved over conventional machining.
- NC greatly increases the productivity of a single shop
- Setup and fixturing can be made more universal, decreasing setup time, increasing production rates.
- Greater accuracy and precision does not necessarily translate into higher cost

Motion Control in NC Machines



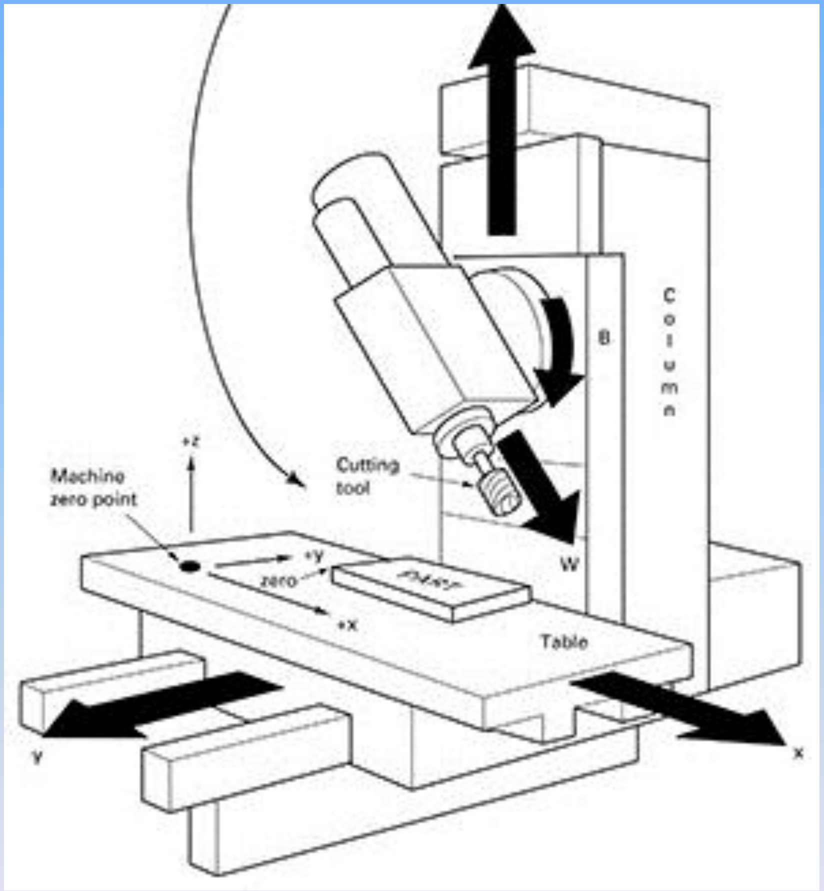


FIGURE 26-7 The part (above) to be machined on the NC machine (below) has a zero reference point. The machine also has a zero reference point.

How CNC Machines Work

- CNC use two forms of control
  - 1. Point to Point: which is typically open loop control
  - 2. Contouring: which is typically closed loop control
- CNC machines typically have a Machine Control Unit (MCU) on board that takes input from the data processing unit (DPU) and control-loop unit (CLU) to move the position of each axis and direction of feed, to produce the final product.

CNC Motion Control

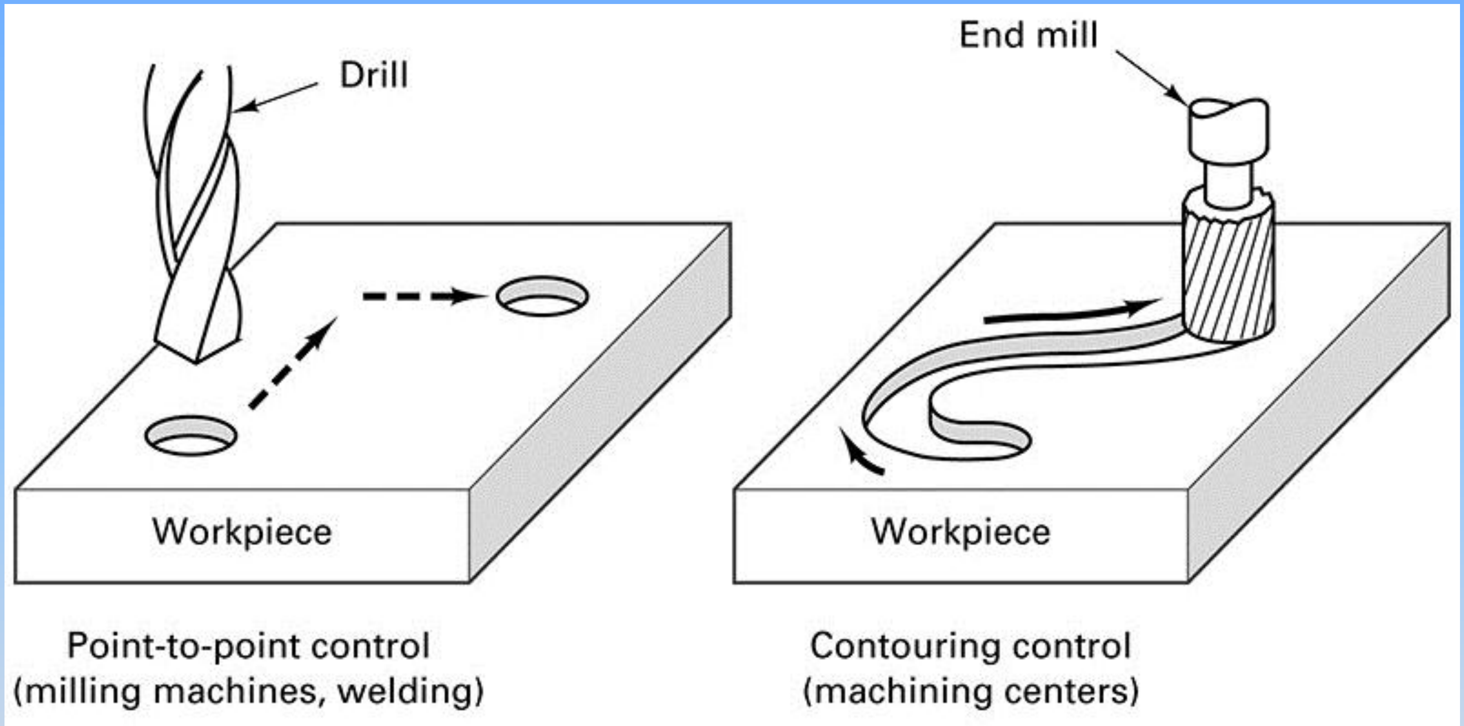
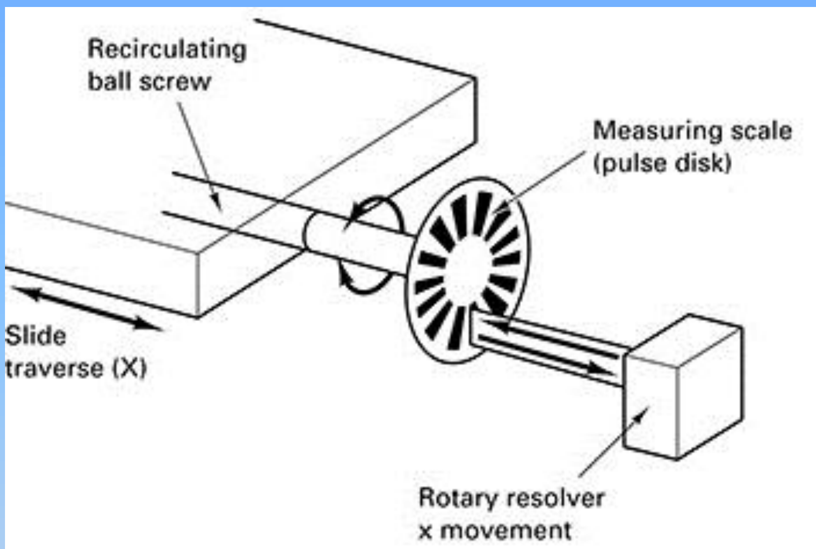


FIGURE 26-8 NC and CNC systems are subdivided into two basic categories: point-to-point controls or contouring controls.

Control Schematic for CNC



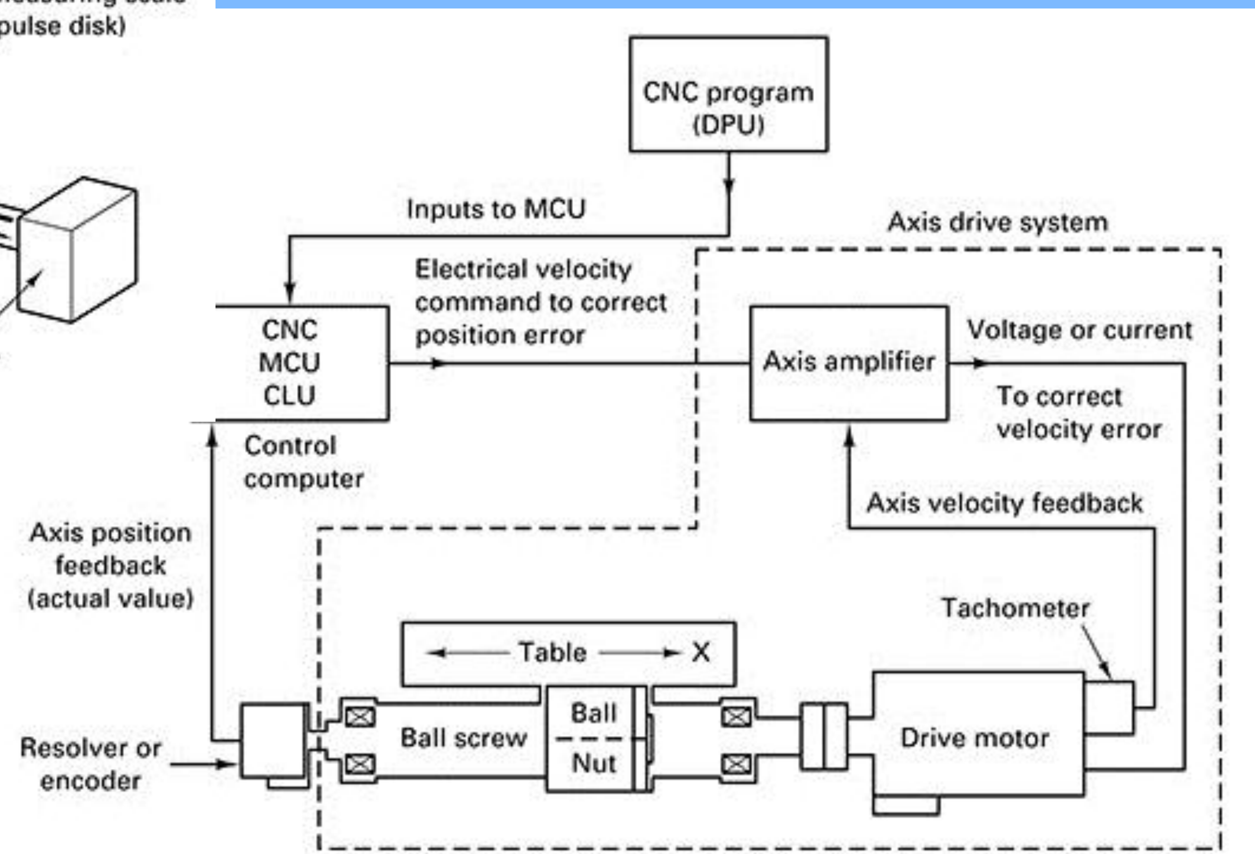


FIGURE 26-9 The table of the CNC machine (above) is translated with a ball screw mechanism, and its location is detected with a resolver. The schematic below shows how the table is located with respect to the spindle axis of the machine tool

Motion Control

- NC machines use electric motor drives with position feedback provided by transducers.
- Older system used DC motors with analog transducers
- Newer system use AC servomotors, or stepper motors with optical encoders for better accuracy, reliability, lower power consumption and performance to weight ratios.
- Recirculating ball screws drives or linear accelerators help improve accuracy by removing backlash in the drive systems
- Canned program routines are used when repeated common features are used in the part designs

Ball Screw Details

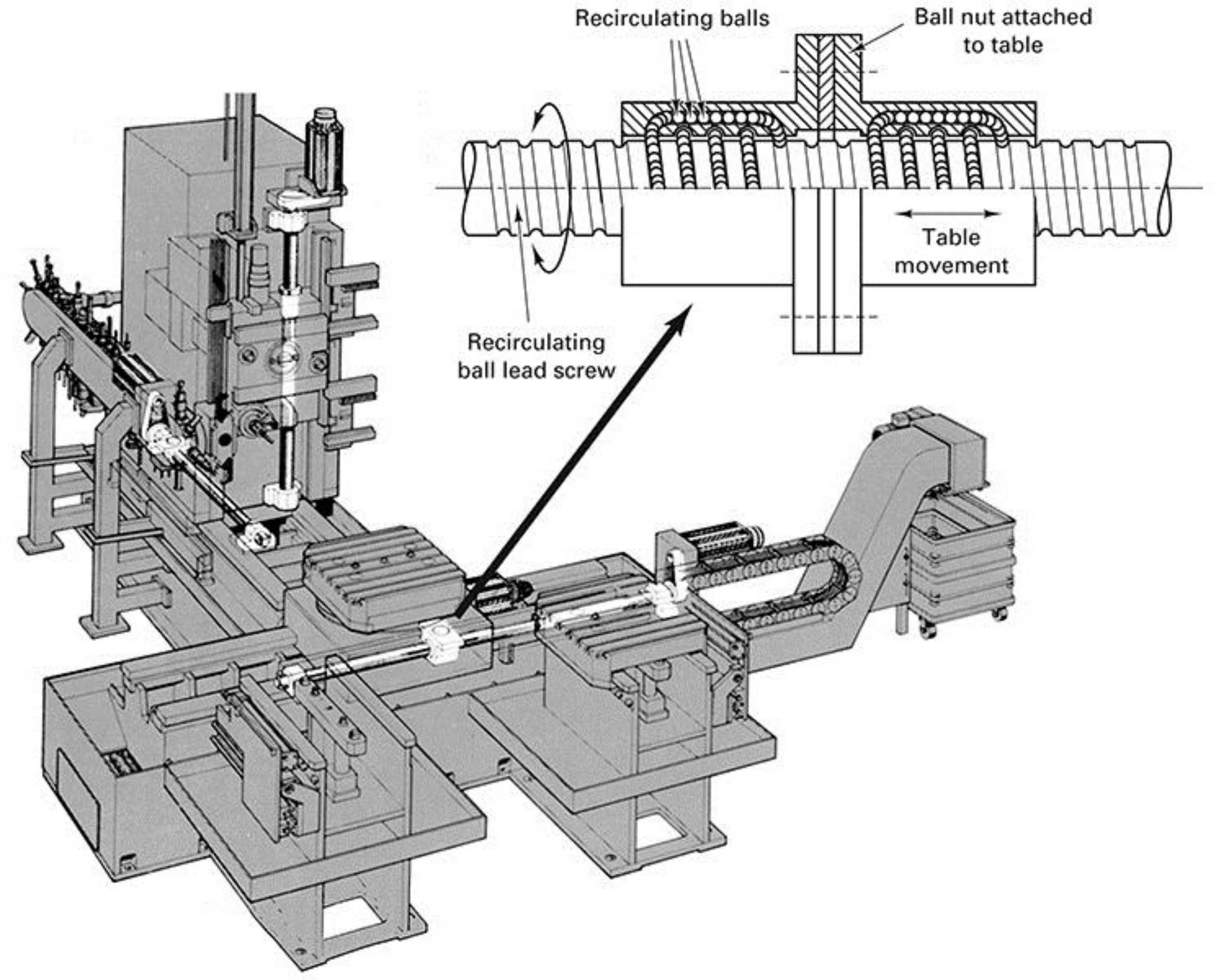
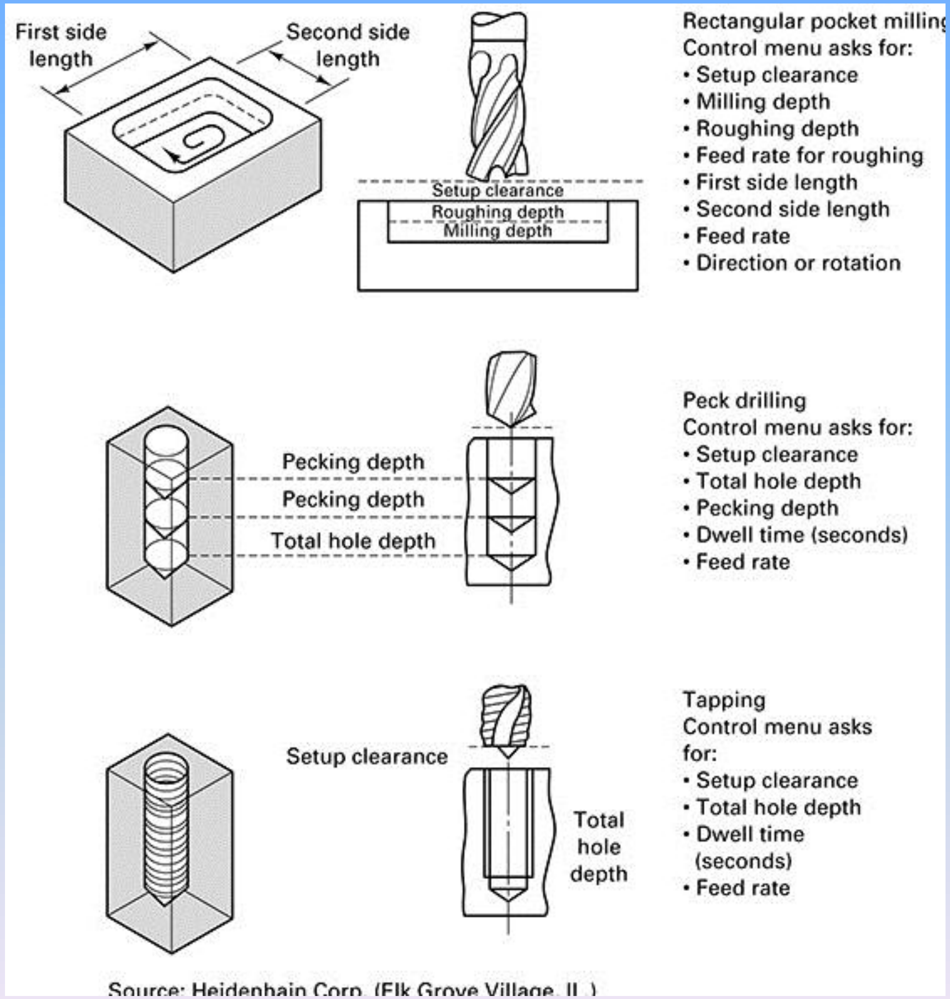


FIGURE 26-10 The ball lead screw shown in detail provides great accuracy and position to NC and CNC machine tools.

Canned Routines

FIGURE 26-11 Canned or preprogrammed machining routines greatly simplify programming CNC machines. *(Courtesy of Heidenkain Corporation, Elk Grove Village, ILL.)*



Tool Dimensioning

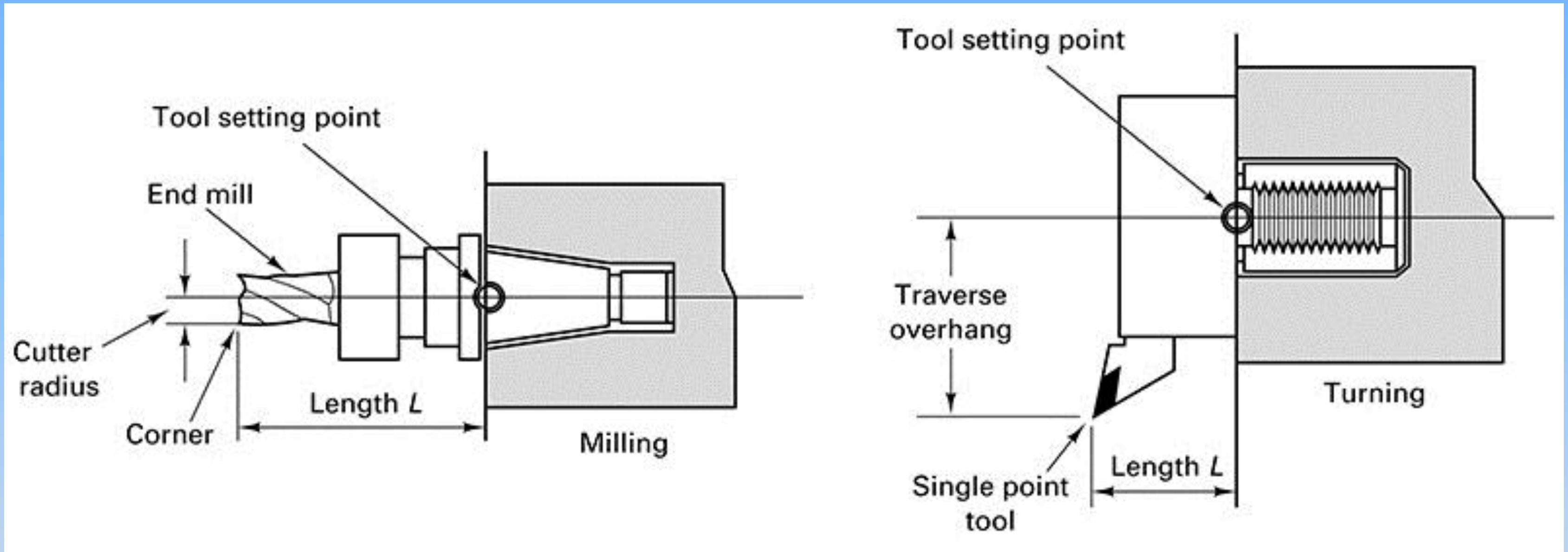


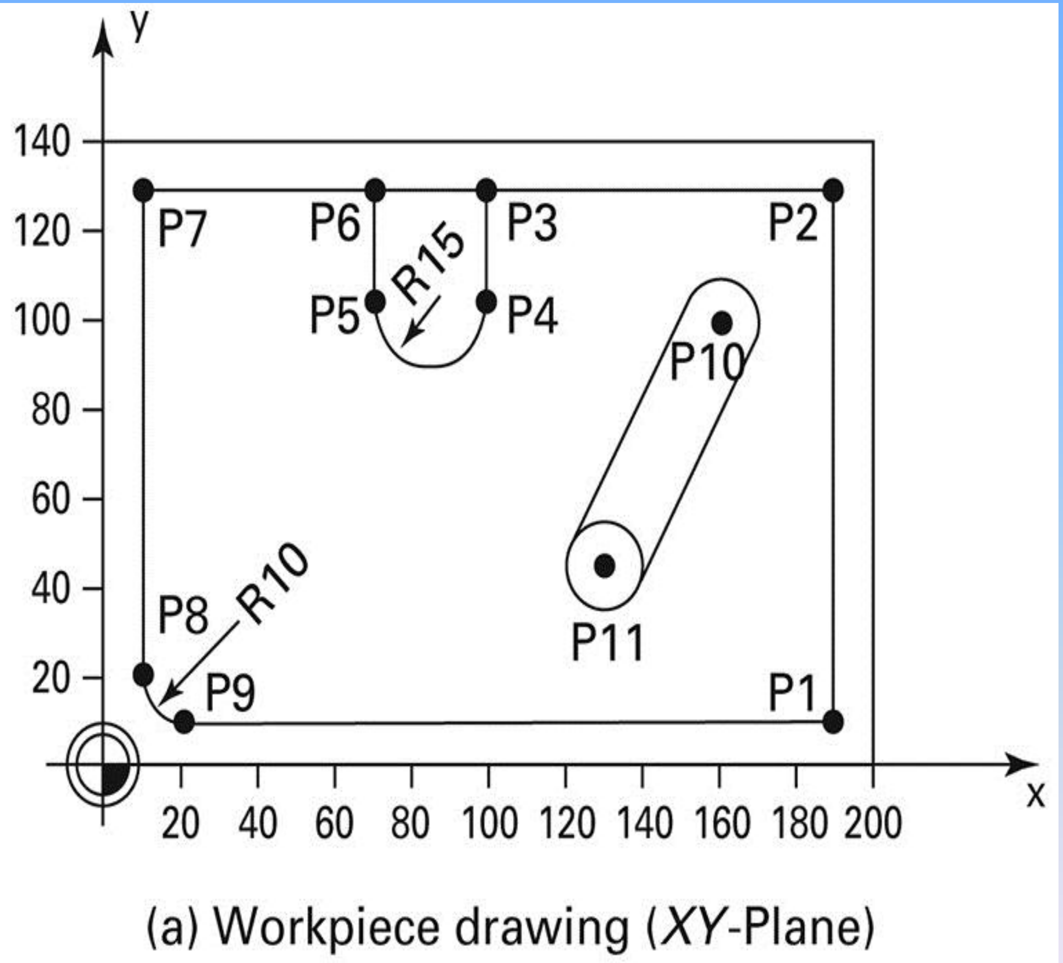
FIGURE 26-12 The location of the corner of the end mill (left) or the tip of a single-point tool (right) must be known with respect to the tool setting points so that tool dimensions are accurately set.

Part Programming

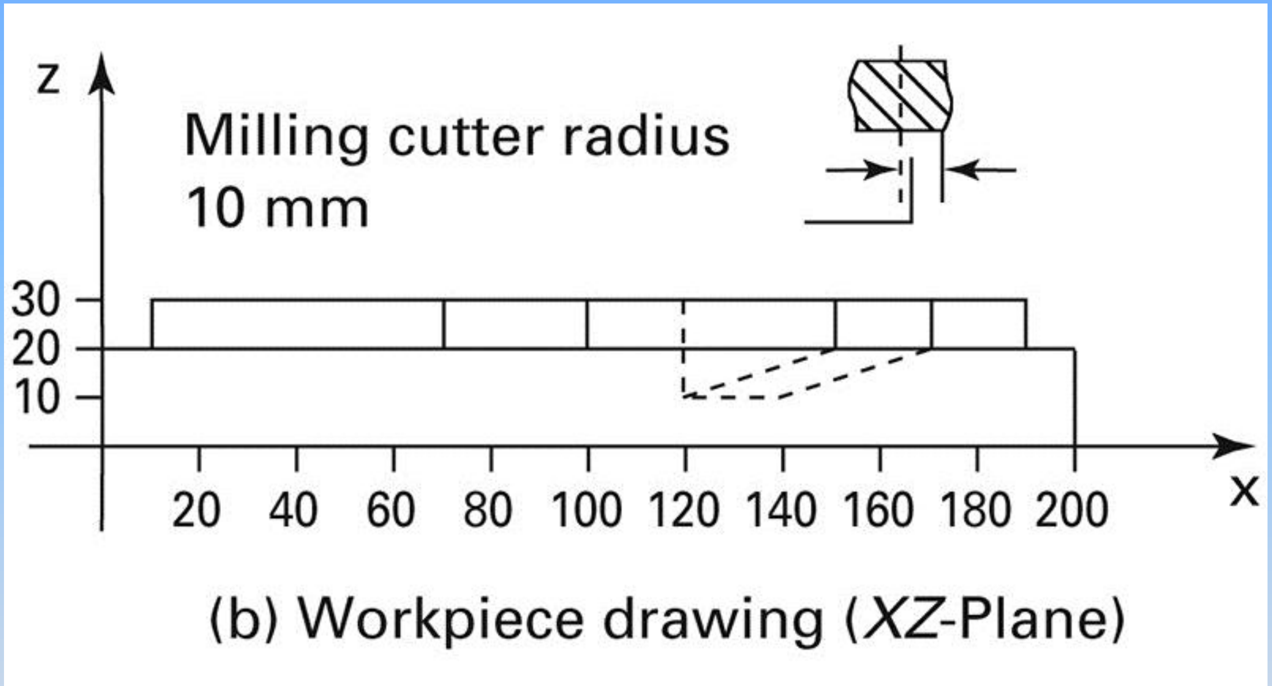
- NC coding uses a common language.
- Programmers must first establish a reference or zero point.
- Next the part is programmed, defining each step necessary to produce the part.
- Each step defines the x, y, and z location, plus the spindle speed, feed speed, and tool changes from the previous step.
- Following coding, the code is verified, typically by computer simulation
- Finally the code is fed into the machine, either by tape or computer interface

Example of Part Programming

FIGURE 26-13 Example of programming a part in a vertical-spindle NC machine.



Example of Part Programming



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Example of Part Programming

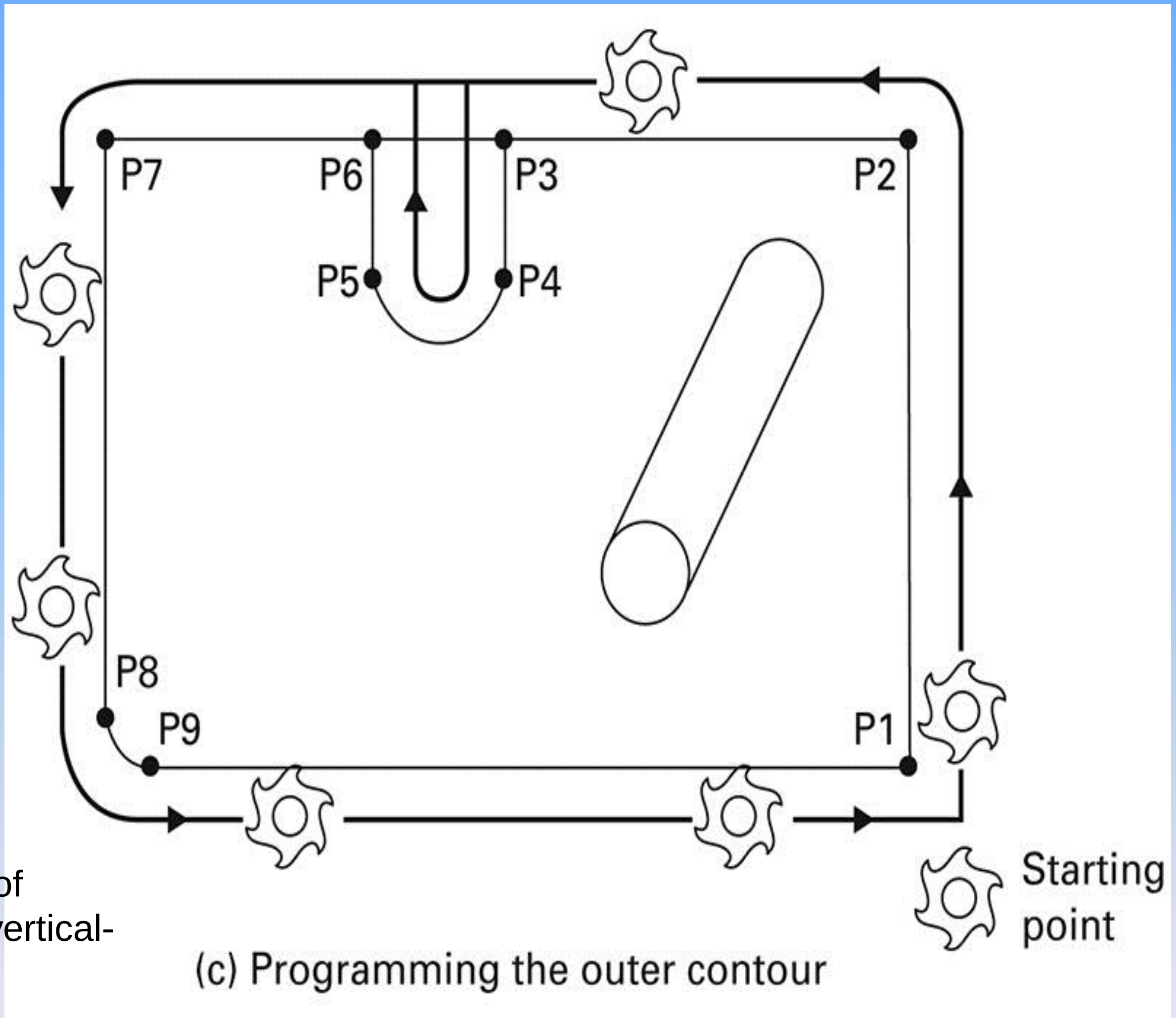

FIGURE 26-13 Example of programming a part in a vertical-spindle NC machine.

Example of Part Programming

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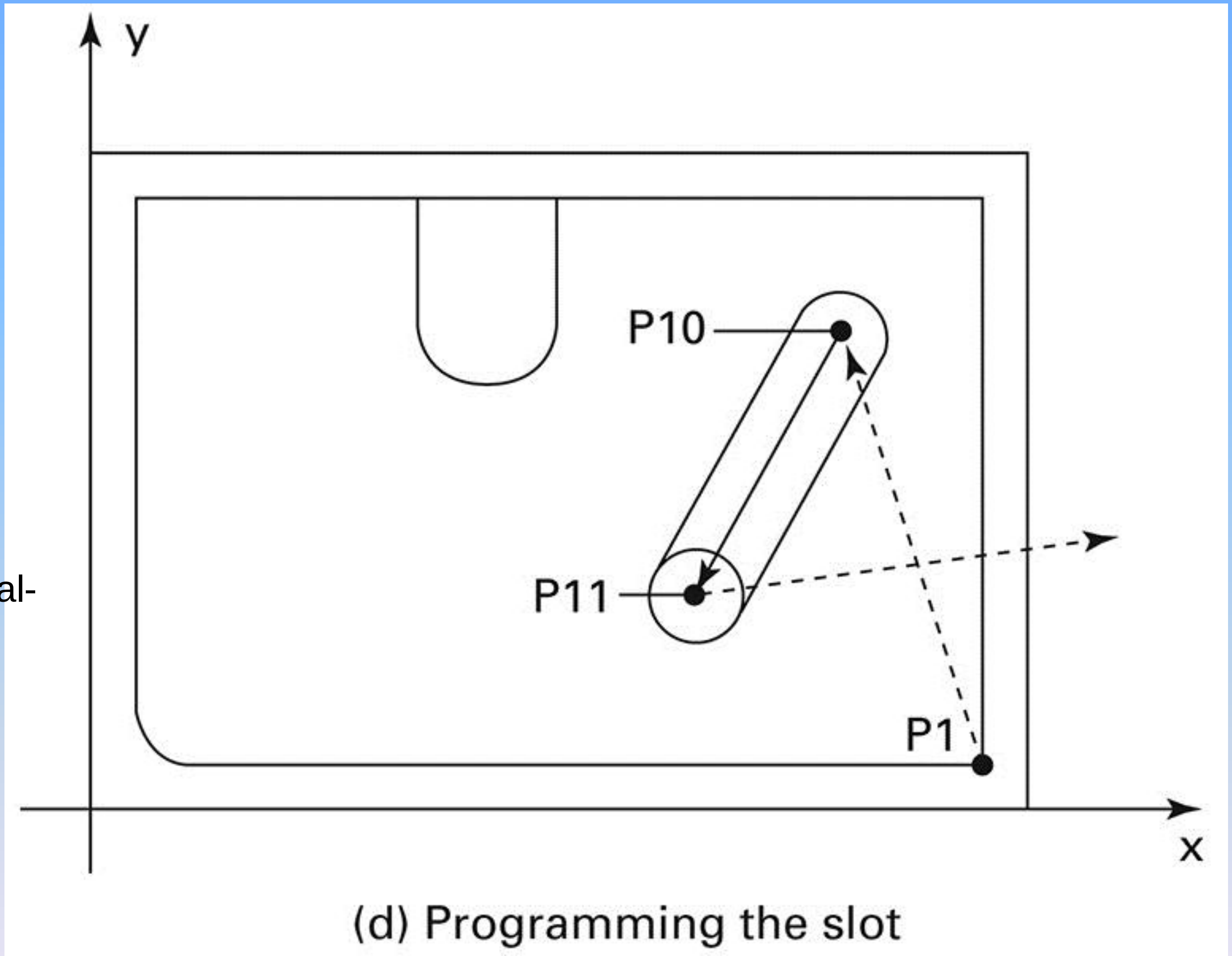


Example Code for Part in Figure 26-13

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
x	190	190	100	100	70	70	10	10	20	160	130
y	10	130	130	105	105	130	130	20	10	100	45
z	20	20	20	20	20	20	20	20	20	20	10

- G01 Y130 F200 — Straight line from starting point to P2
- G01 X100 — Straight line from P2 to P3
- G01 X105 F150 — Straight line from P3 to P4
- G02 X70 Y105 R15 — Radial arc, clockwise, with 15 radius
- G01 Y130 F200 — Straight line from P5 to P6
- G01 X10 — Straight line from P6 to P7
- G01 Y20 — Straight line from P7 to P8
- G03 X20 Y10 R10 F150 — Radial arc, counterclockwise with 10 radius
- G01 X190 F200 — Straight line from P9 to P1
- G00 X160 X100 — Rapid traverse to point P10
- G01 Z20 F150 — Down feed at point P10
- G01 X130 Y45 Z10 — Straight line from P10 to P11
- G01 Z35 F200 — Retraction from workpiece
- G00 X300 Y300 — Rapid traverse away from workpiece

NC Program Language

TABLE 26-2 Definitions of Common NC Words

NC Word	Use
N	*Sequence number:* identifies the block of information
G	*Preparatory function:* requests different control functions, including preprogrammed machining routines
X, Y, Z, B	*Dimensional coordinate data:* linear and angular motion commands for the axis of the machine
F	*Feed function:* sets feed rate for this operation
S	*Speed function:* sets cutting speed for this operation
T	*Tool function:* tells the machine the location of the tool in the tool holder or tool turret
M	*Miscellaneous function:* turns coolant on or off, opens spindle, reverses spindle, tool change, etc.
EOB	*End of block:* indicates to the MCU that a full block of information has been transmitted and the block can be executed

Cutter Offset

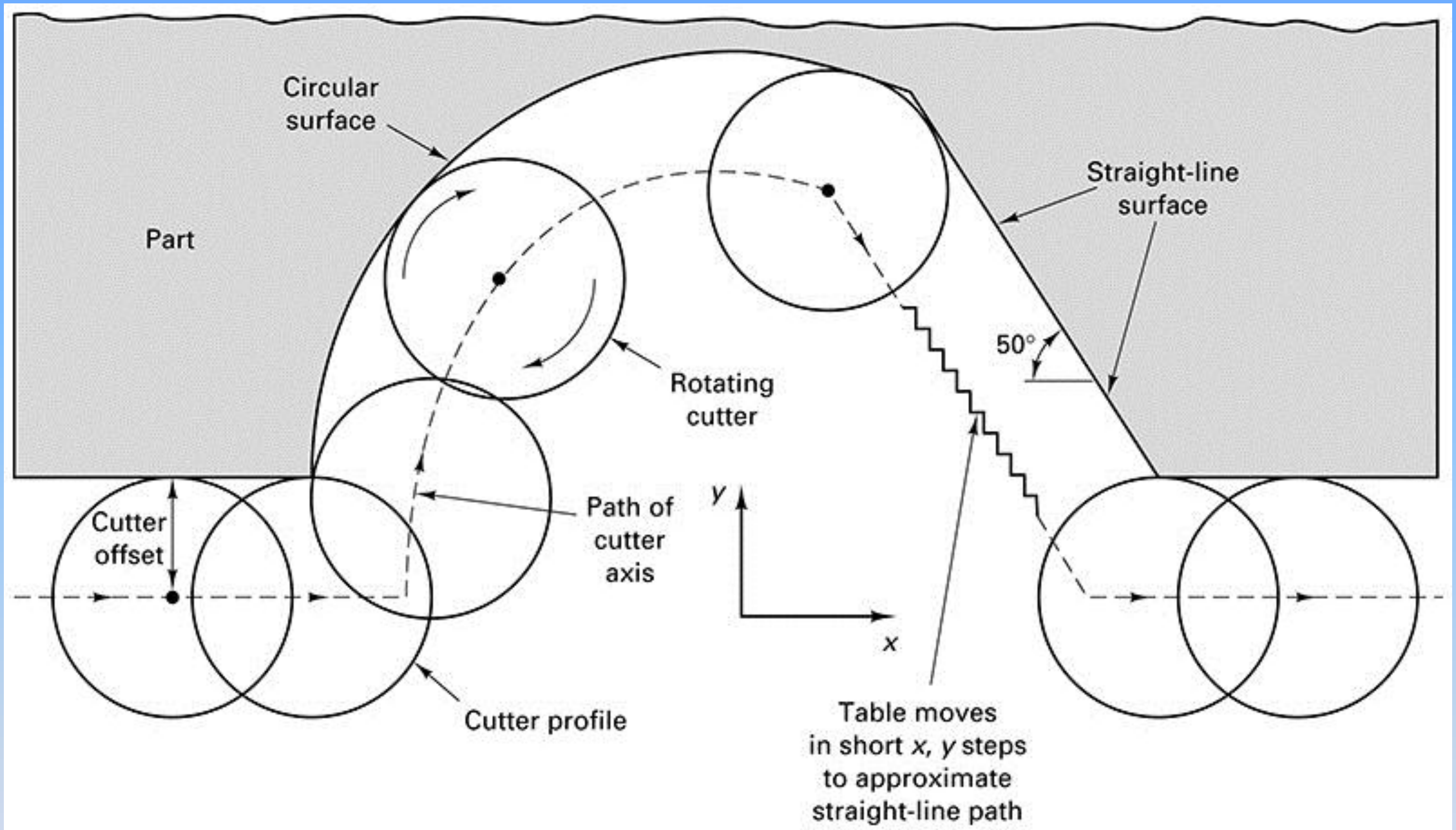


FIGURE 26-14 Two classic problems in NC programming are the determination of cutter offset and interpolation of cutter parts.

40.3 Machine Center Features and Trends

- MC's range from simple 2 axis systems to large multi-axis systems.
- System features can be very simple to systems that include automated tool change and workpiece transfer
- MC system are not limited to milling, but include:
  - Turning centers
  - Punching and Blanking centers
  - EDM centers
  - Laser centers
  - Water jet centers
  - Flame cutting centers

Large Multi-axis MC

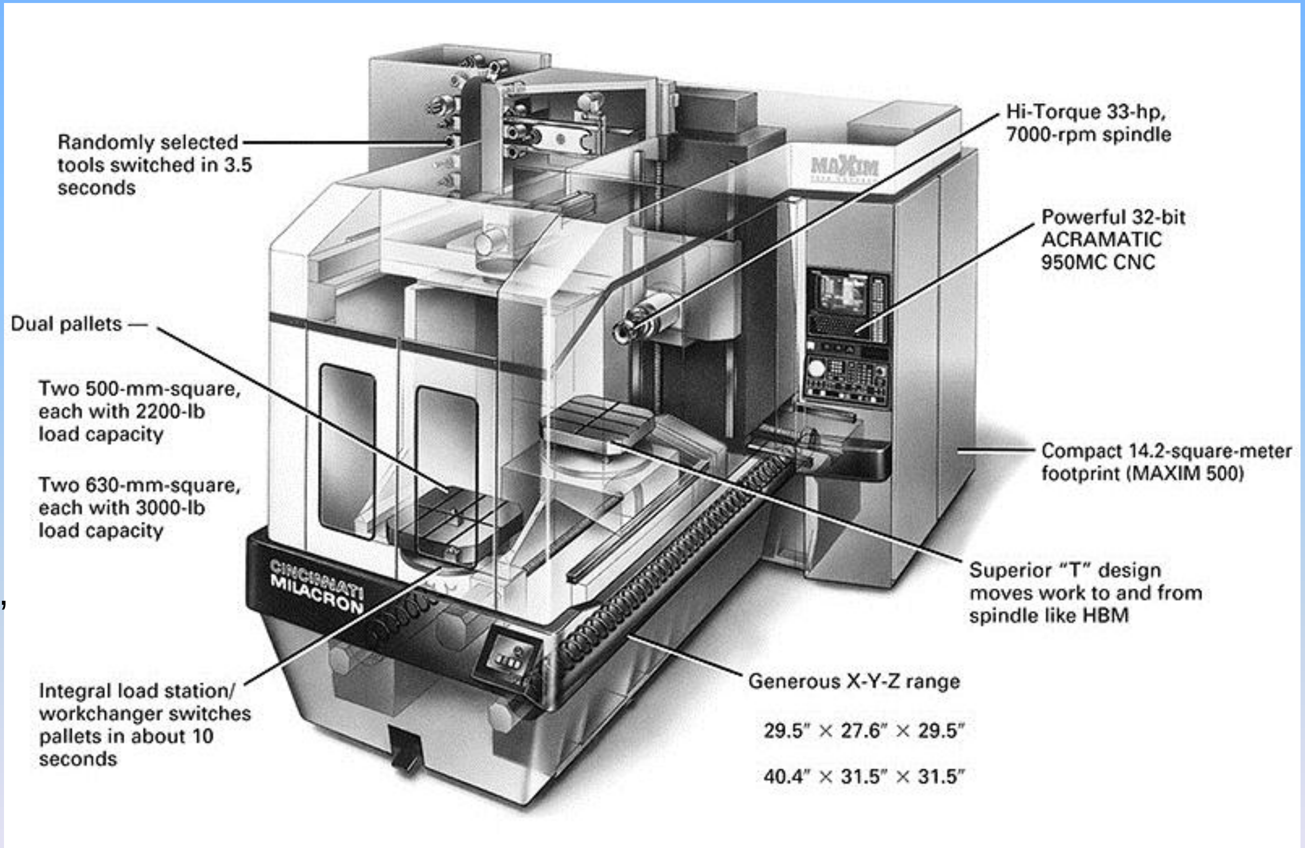
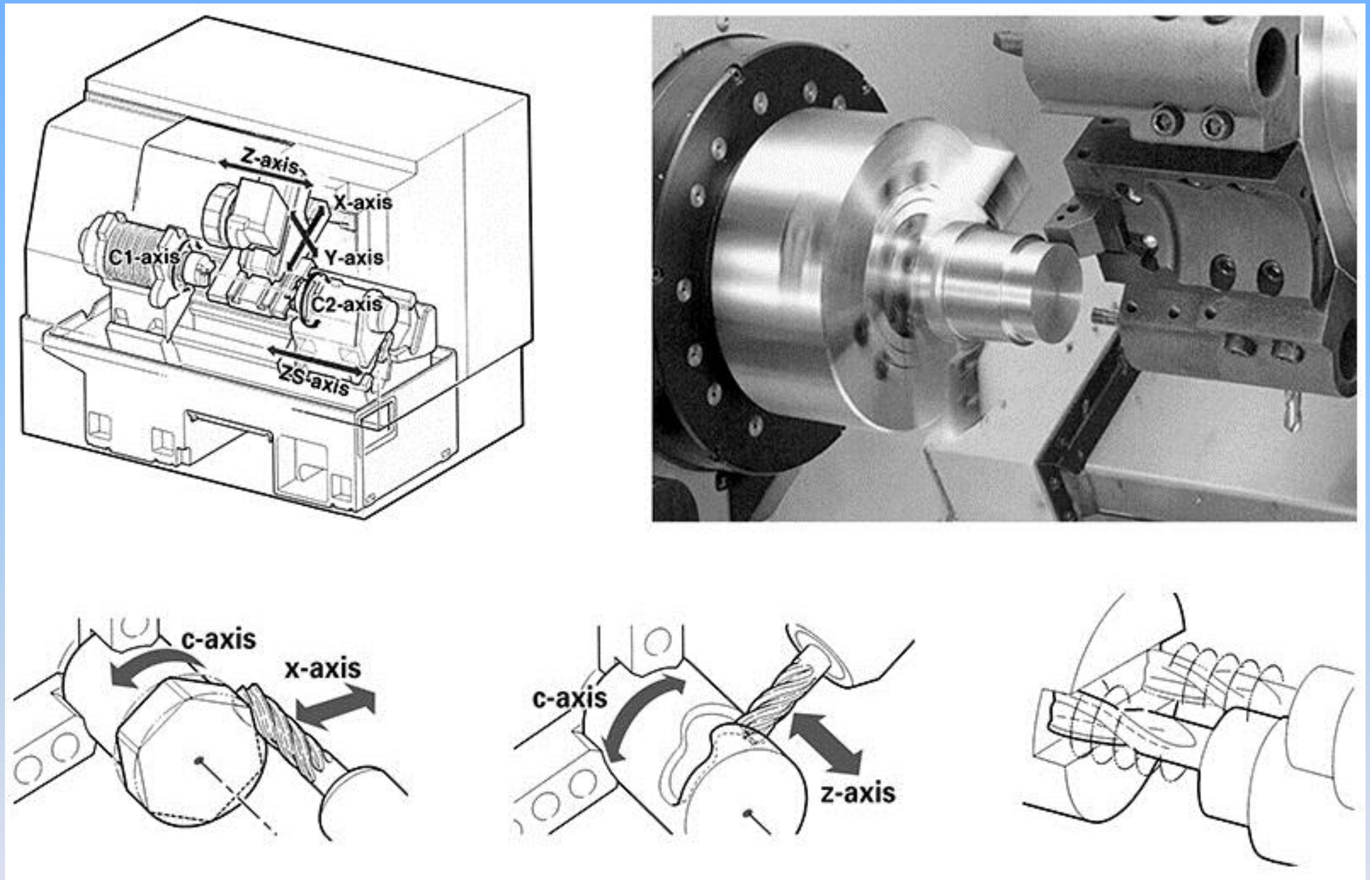


FIGURE 26-15 Modern machining centers will typically have horizontal spindles with rpms up to 15,000, dual pallets, and cutting-tool magazines holding 40 to 100 tools.

Turning Center

FIGURE 26-16 This CNC turning center has a multiple-axis capability with two spindles and a 12-tool turret with X, Y, and Z control as well as axis control of the spindles.



Process Accurcy

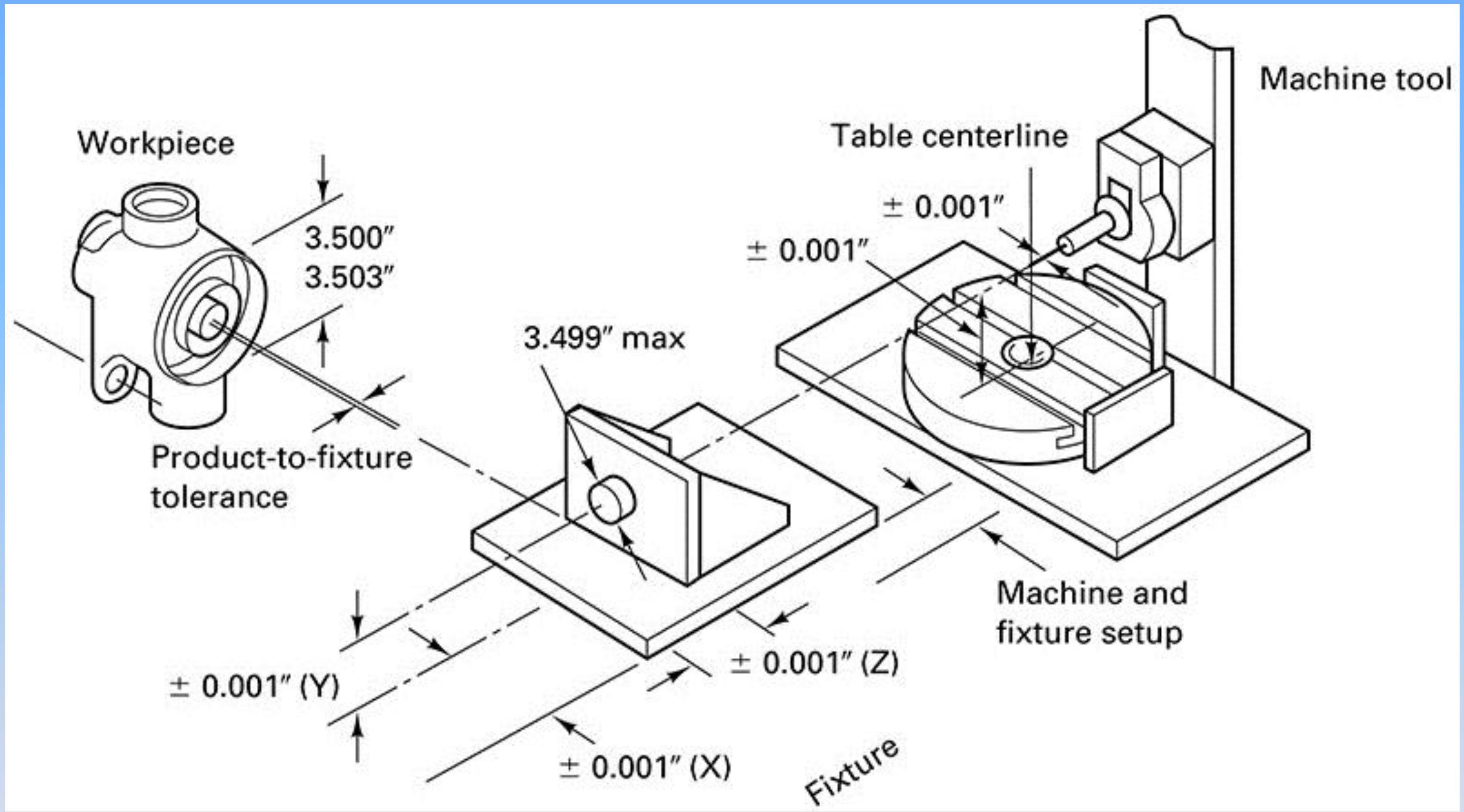
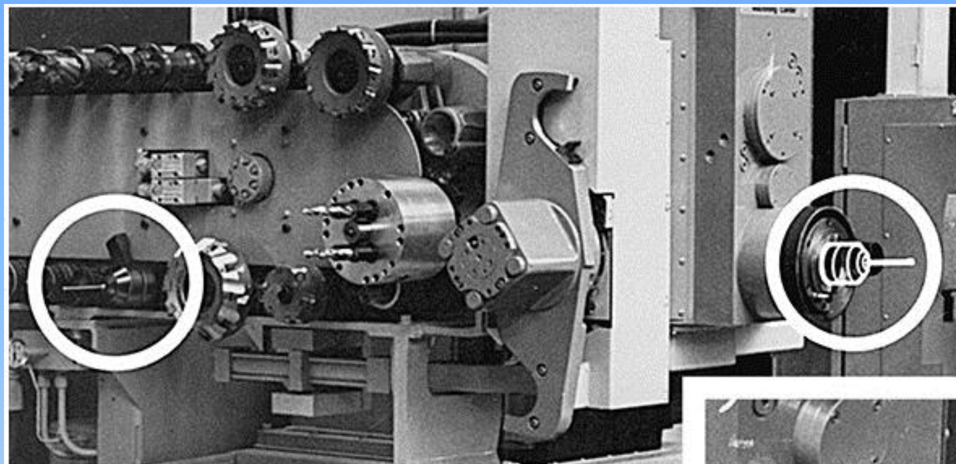


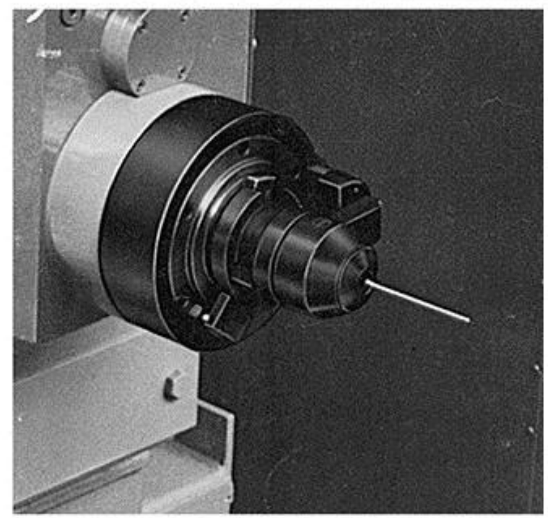
FIGURE 26-17 Process capability in NC machines is affected by many factors.

Probes



(a)

FIGURE 26-18 (a) Probe carried in the tool changer can be mounted in the spindle (b) for checking the location of part features accurately.

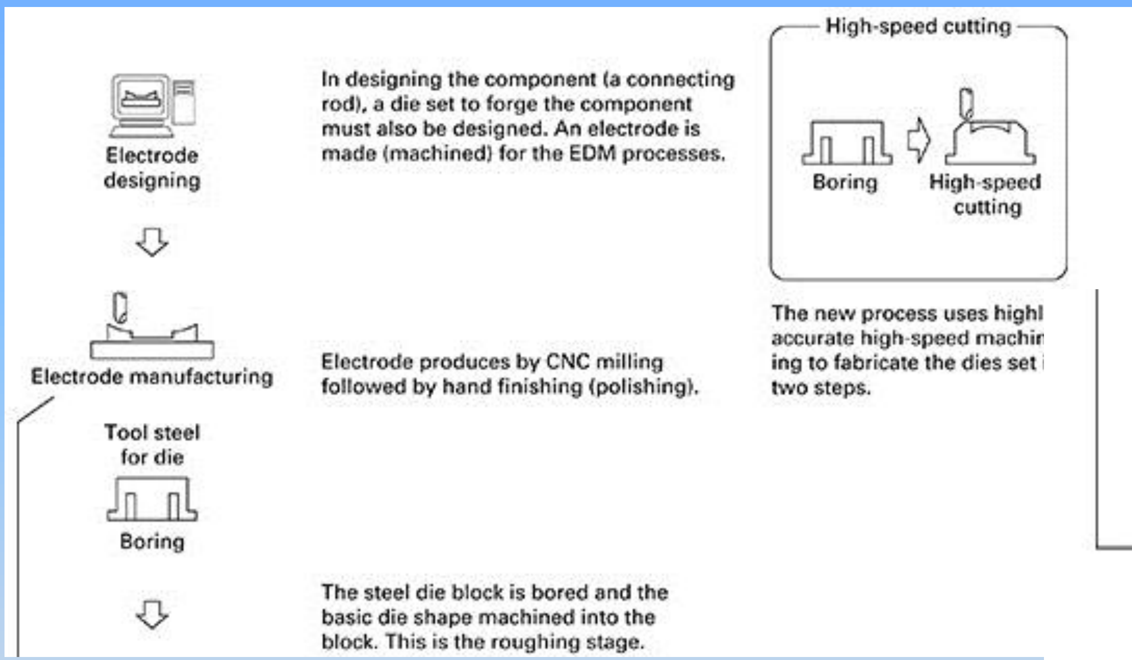


(b)

40.4 Ultra-High-Speed Machining Centers (UHSMCs)

- UHSMCs are used to rapidly produce dies
- They include exceptionally high spindle speeds and material removal rates
- They utilize ceramic ball bearings to improve spindle stiffness and spindle speeds.

UHSMC versus Traditional Die Manufacturing



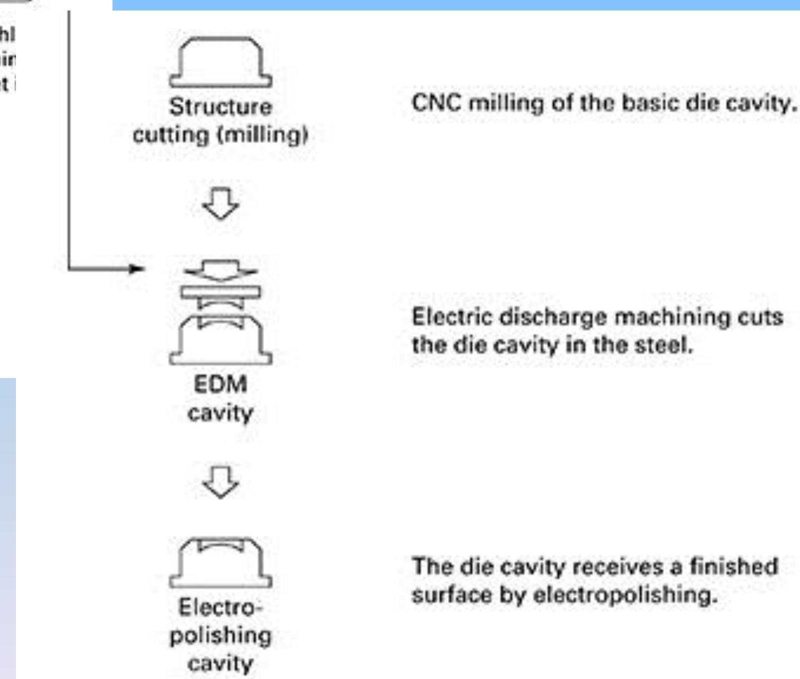


FIGURE 26-19 The process to manufacture dies for forging processes is shown on the left. Using ultra-high-speed machining centers reduces the sequence to two steps.

UHSMC Trends

FIGURE 26-20 Ultra-high-speed machining centers (UHSMCs) are being developed with ceramic ball
bearings in the spindles, synchronized ball screws on the *X*-axis to reduce distortion (due to inertia) in the moving components. *("Development of Ultra High Speed Machining Center",* Toyota Technical Review, *vol. 49, No. 1, September 1999.)*