Chapter 1

Introduction to CNC

CHAPTER OBJECTIVES

After studying this chapter, the student should have knowledge of the following:

- The evolution of CNC
- The process of CNC
- The flow of CNC processing
- The objectives of CNC

INTRODUCTION

Computer numerical control (CNC) is the process of manufacturing machined parts. Production is controlled and allocated by a computerized controller. The controller uses motors to drive each axis of a machine tool and actually regulates the direction, speed, and length of time each motor rotates. A programmed path is loaded into the machine's computer by the operator and then executed. The program consists of numeric point data in conjuction with specialized machine control commands and function codes. Numerical control (NC) is the original term given to this technology and is still often used interchangeably with CNC.

NC technology has been one of manufacturing's major developments in the past 50 years. It not only resulted in the development of new techniques and the achievement of higher production levels, but it also helped increase product quality and stabilize manufacturing costs.

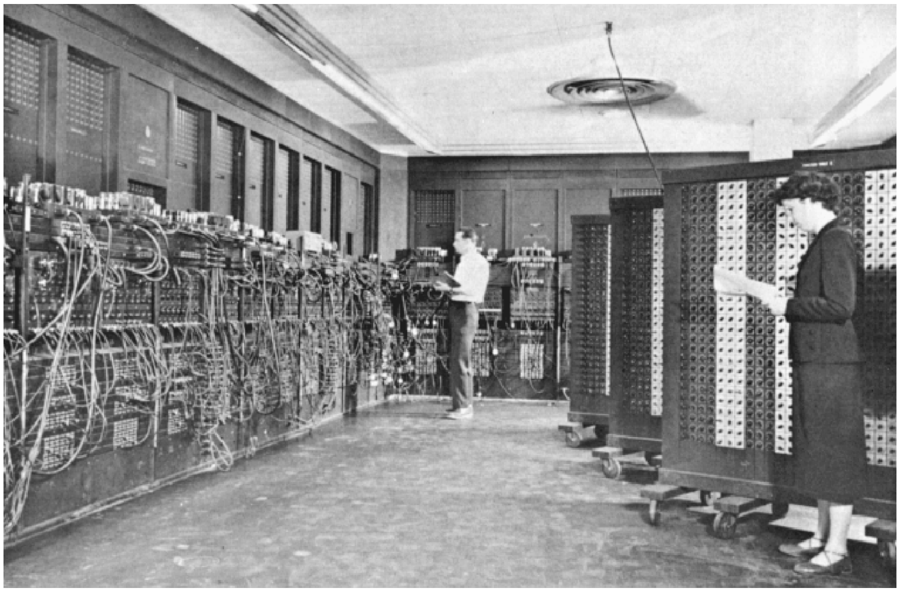
THE EVOLUTION OF NC

The principal of NC manufacturing has been evolving since the Industrial Revolution, although the actual procedures involved have developed with technology. Early attempts to automate production made use of belts, pulleys, and cams. However, manual labor was by far more cost effective than were the development and operation of big, new machines.

Not until World War II did industrialists realize that they couldn't meet both quantity and quality requirements at the same time. Machinists of the day could produce superior quality parts but not at high volumes. As the quantity of a certain product increased, the quality decreased due to the human factors involved.

During World War II the United States Army Ballistic Research Lab and the University of Pennsylvania collaborated on development of ENIAC, the world's first digital computer. This was an extremely large vacuum tube computer, which was used to calculate ballistic trajectory tables for artillery. Programming involved setting hundreds of switches and cables manually prior to having the machine sequence through the settings. In

The effects of World War II were significant in the development of NC machinery. (Courtesy U.S. Air Force.)



The world's first digital computer, ENIAC, contained more than 30,000 vacuum tubes and miles of cable. (Courtesy U.S. Army.)

the early 1950s the Massachusetts Institute of Technology developed a more advanced vacuum tube computer called the Whirlwind. This improved computational device was capable of executing thousands of times more instructions per second than ENIAC.

To ensure that all U.S. military airplanes were manufactured identically, the United States Air Force invited several companies to develop and manufacture numerical control systems that could handle the volume and repeatability.

The specific goals of developing NC were to:

IMPORTANT

1. Increase production
2. Improve the quality and accuracy of manufactured parts
3. Stabilize manufacturing costs
4. Manufacture and assemble complex parts quickly

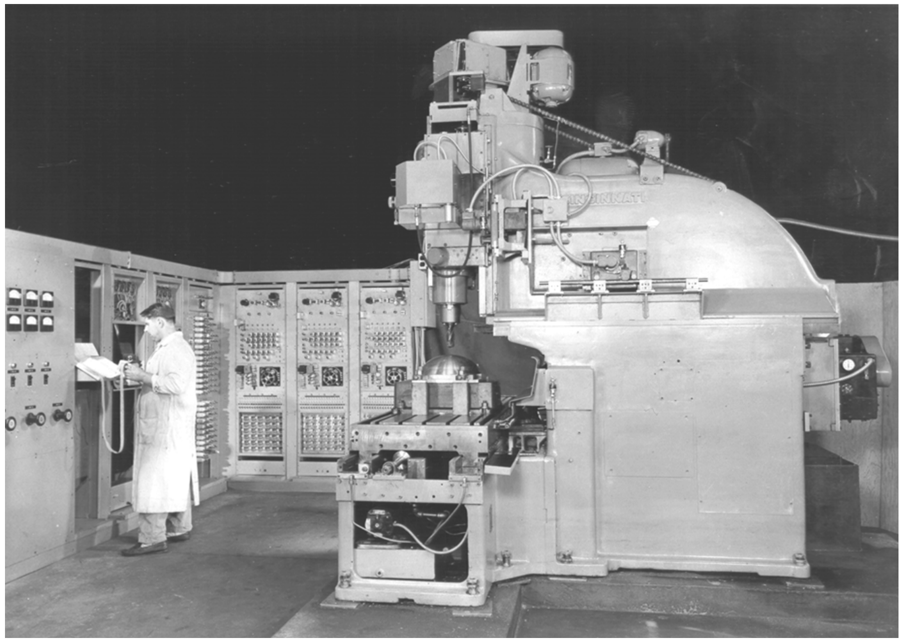
Along with programmable automation, NC was designed to readily accommodate changes in product design and to help produce parts that:

- Were similar in terms of the raw materials used
- Varied in size and geometry
- Were made in small- to medium-sized batches
- Required a sequence of similar steps to complete each workpiece

The first contract was awarded to the Parsons Corporation of Michigan, which had developed a control system that directed a spindle to many points in succession. Although the contract date was June 15, 1949, the demand for these systems was a direct result of the war effort.

In 1951, the Servomechanism Laboratory of the Massachusetts Institute of Technology (MIT) was given a subcontract by Parsons to develop a servo system for the machine tool. As MIT was also working on the Whirlwind at the time, the total NC development project thus was conducted at MIT.

In 1952, the first three-axis, numerically controlled, tape-fed machine tool was created. A Cincinnati Milacron Hydro-Tel Vertical Spindle

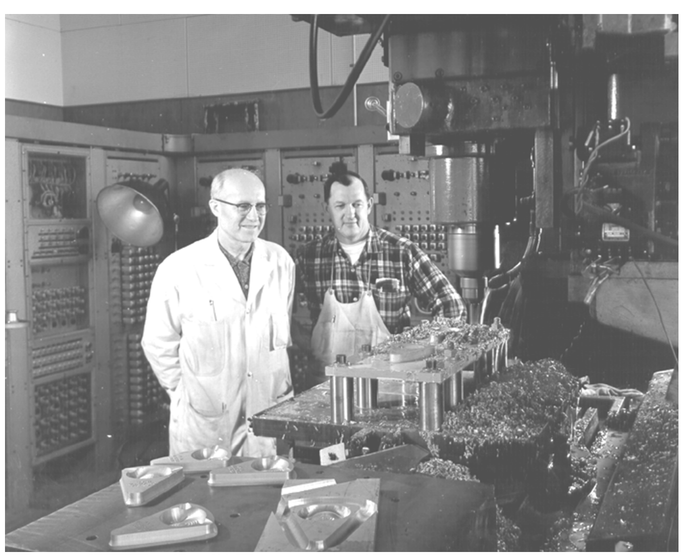


The Servo Mechanism Laboratory at MIT. (Courtesy MIT Musem Library.)

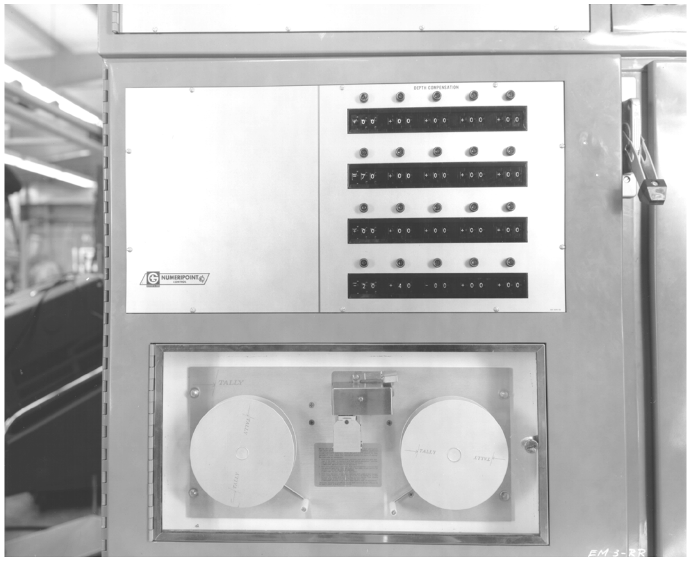
milling machine was retrofitted and controlled by the Whirlwind computer. The controller was equipped with optical sensors and used a straight binary perforated tape to hold the instructions; the tape was read via a mechanical feeding mechanism. In 1954, numerical control was announced to the public, and three years later the first production NC machines were delivered and installed.

By 1960, NC was widely accepted and readily available. Although the controllers used alphanumeric characters in their controlling code, it was still called numerical control.

The majority of these first generation NC machine tools required coded paper tape to run. The engineers would generate NC code on their computers, then encode long strips of paper tape by punching hole patterns in them. Because these hole patterns were encoded, it was difficult to identify part programs easily. Later, the use of "man-readables" solved



The first NC machine producing identical parts. (Courtesy MIT Musem Library.)



An early NC paper tape reader. (Courtesy Giddings and Lewis.)

this problem. Man-readables were nothing more than a special hole punching technique that yielded alphanumeric hole patterns that could be easily read by the operator. These were usually punched on a leader before the actual program started. Sometimes these punched tapes were very long and had to be stored on large reels. These reels of tape would then be taken to the shop floor, where the operator would insert them into the controller and run them. The tapes contained all the data required for machine operation. The machine tool would then perform exactly the same operations as many times as required.

Further research and development brought about new generations of NC machines. The subsequent introduction of computer numerical control, whereby a computer is used to control the machine tool, eliminated the dependence on bulky and fragile paper tape.

Direct numerical control and distributed numerical control (DNC) describe communications to a machine tool from a remote computer, as shown in Fig. 1.1. In direct numerical control, part program instruction blocks are communicated to a machine tool as required and as fast as the machine can accept them. This method of communication was very popular because it eliminated the paper tape system and increased the maximum length of a program. In distributed numerical control, whole programs or multiple programs are communicated to a CNC machine tool or several CNC machine tools, usually via an RS232 serial communications link. This process was made possible by the increased memory

A paper tape leader showing man-readables.

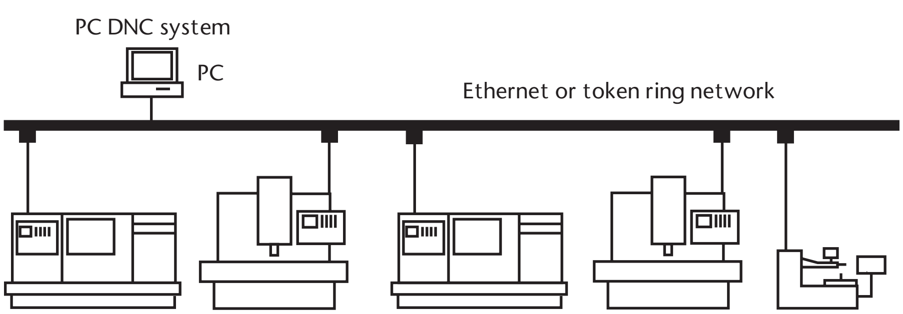


Figure 1.1
A diagram of a modern DNC layout.

capacity of CNC controllers. In the early days, controllers could not store programs, so programs were stored on paper tape. Later controllers were able to store only limited-sized programs. Modern controllers can store hundreds of programs on their built-in hard drive memory systems. With today's increased widespread use of networks, part programs can be catalogued on a central server computer and any CNC machine on the factory network, either locally or even remotely, utilizing popular Ethernet or TCP/IP Internet protocols, can request a specific CNC program file instantaneously even thousands of miles away. This modern setup centralizes the design and engineering center away from the shop floor. It also eliminates the need to have the part programs stored in the same location as the machine tools. This is also beneficial in improved production scheduling.

From 1955 to 1960, MIT also developed a computer-assisted programming system called automatically programmed tools (APT). This programming language was developed to ease the task of complicated three-axis programming, mainly in the aerospace industry. APT uses English-like words to describe the geometry and the tool motions on a part program. Figure 1.2 shows the point, line, and circle specification commands along with the movement commands that follow.

The great advantage of early modern CNC was the ability of the code-generating computer to move from the engineering department back onto the shop floor, where it was directed by the machinist. The computer and machine control unit (MCU) were now one unit, capable of creating the program and then storing it in memory and running it on demand. This also eliminated much of the need for paper tape. With the exception of

Figure 1.2
Example of an APT program.

```
PARTNO 3764
MACHIN/2167
CUTTER/.375
FEDRAT/5
SP = POINT/.25,.25,.5
P1 = POINT/0,0,.5
P2 = POINT/.25,.25,-.125
P3 = POINT/.5,.25,-.125
L1 = LINE/P2, ATANGL,0
C1 = CIRCLE/(1.25 +1.75),.375,.375
C2 = CIRCLE/1.750,1.950, .5
L2 = LINE/RIGHT, TANTO, C1, RIGHT, TANTO, C2
L3 = LINE/P1, LEFT, TANTO, C2
FROM/SP
GO/TO, P1
GO/TO, P2
GORGHT/L2,TANTO C1
GORGHT/L3, TANTO C2
GO/TO, SP
FINI
```

extremely large programs, most NC programs are stored on the machine tool's memory built into a computerized controller.

Machining centers, which take the place of half a dozen machines, are now capable of many operations—including milling, boring, drilling, facing, spotting, counterboring, threading, and tapping—all in one setup. These machines are mainly used in mid- to large-sized production runs and sometimes are dedicated to a family of parts manufacturing.

Now a well-established technology, CNC machines have become commonplace. Over 85 percent of machine tools manufactured today are CNC. The number of manufacturing systems has blossomed, and most engineering companies utilize high levels of computerization.

Computer integration can be implemented at almost any level—from a simple machine shop with a simple computer-aided manufacturing (CAM) system, to companies with several dispersed engineering, design, and production sites and many hundreds of machines and systems.

IMPORTANT

CNC technology has the following advantages over NC technology:

1. Programs can be entered at the machine and stored in memory.
2. Programs are easier to edit, so part programming and process design time are reduced.
3. There is greater flexibility in the complexity of parts that can be produced.
4. Three-dimensional geometric models of parts, stored in the computer, can be used to generate CNC part programs almost automatically, thus saving manual programming time.
5. Computers can be connected to other computers worldwide, either by direct modem connection or through a network, thereby allowing part programs to be transmitted directly to remote CNC machines.

CNC technology has the following disadvantages:

1. CNC is slightly more expensive, although today it would be rare to find an NC machine tool sold that is not CNC.
2. Possibly more training is required for the machine operator. This, however, depends on the complexity of the machine tool, as a CNC machine may actually require less training. Modern CNC controllers are now very user-friendly. This shortens the learning curve for machine operators, making the cost recovery period much shorter.
3. Maintenance costs may be greater.

MICROCOMPUTER TECHNOLOGY

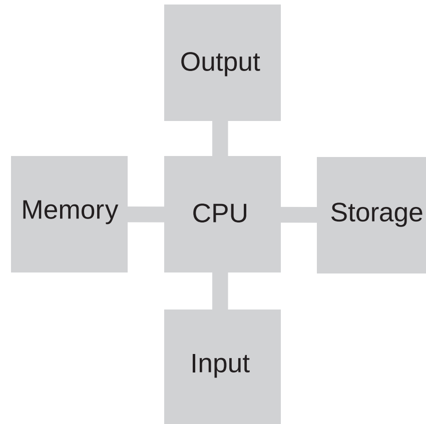
The modern computer is an electronic machine that performs mathematical or logical calculations in accordance with a predetermined set of instructions. The computer itself is called the hardware; the programs that run on the computer are called software.

The three basic components of a computer, as shown in Fig. 1.3, are:

REMEMBER

1. Central processing unit (CPU)

FIGURE 1.3
A diagram of the basic components that make up a computer.



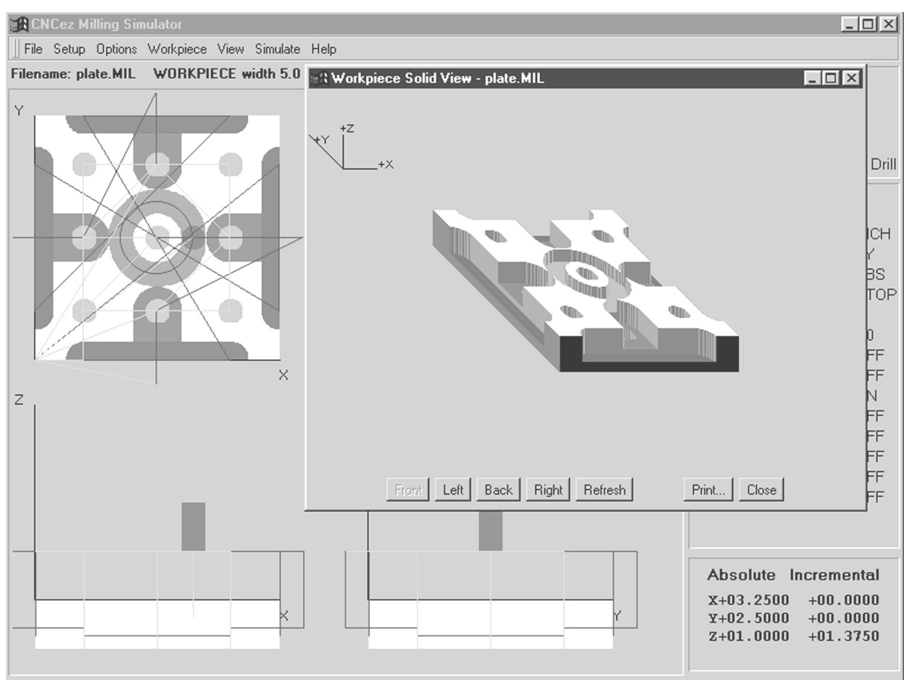
2. Memory
3. Input/output section

The CPU controls and sequences the activities of the computer components and performs the various arithmetic and logical operations. The memory is used by the CPU to store, retrieve, and manipulate data. The input/output section interprets incoming and outgoing signals that direct the CPU's operations.

Various peripheral devices associated with computers include monitors, scanners, printers, and plotters.

The use of computers in industry is now commonplace. Cheaper and faster personal computers have allowed companies to introduce computers at all levels. Various forms of computer-assisted programming are available for both shop floor control and NC programming.

The CNCez Solid View displays the results of the CNC program being executed. This is extremely useful for tool proving prior to running the program on the machine tool.



COMPUTER BASICS

Although computers have enhanced NC to a great extent, certain rules still remain in effect. One rule that still holds but is easier to live with today is:

Garbage in = Garbage out.

This rule, common in industry, was truer in the past than it is today. When writing NC programs using the old systems, programmers could check for errors only by running the program on the machine tool it was targeted for. Incorrect data entered resulted in the machine not running as required or not running at all—therefore the saying. With today's more powerful computers and software, such as CNCez, syntax checking and simulation enable the programmer to verify programs without running them on a production CNC machine tool, hence lowering production time and overall costs, and freeing up machine tools for manufacturing.

REMEMBER

NC APPLICATIONS

From the days of the first NC milling machine, there have been many applications for NC technology, ranging from milling, turning, and electric discharge machining (EDM) to laser, flame and plasma cutting, punching and nibbling, forming, bending, grinding, inspection, and robotics.

Although aerospace is still one of the principal industries that require and use NC technology extensively, other industries have also embraced it. Because of the continuing advances in computers and their affordability, the cost of NC technology has been dropping rapidly. Now, even small machine shops and small specialty industries have come to acquire this technology.

Today you can find NC products in many areas ranging from metalworking and automotive to electronics, appliances, engraving, sign making, jewelery design, and furniture manufacturing.

MILLING

The process of milling involves the use of a rotating cutter to remove material from a workpiece. Single- or multiple-axis control moves can generate either simple two-dimensional patterns or profiles, or complex three-dimensional shapes.

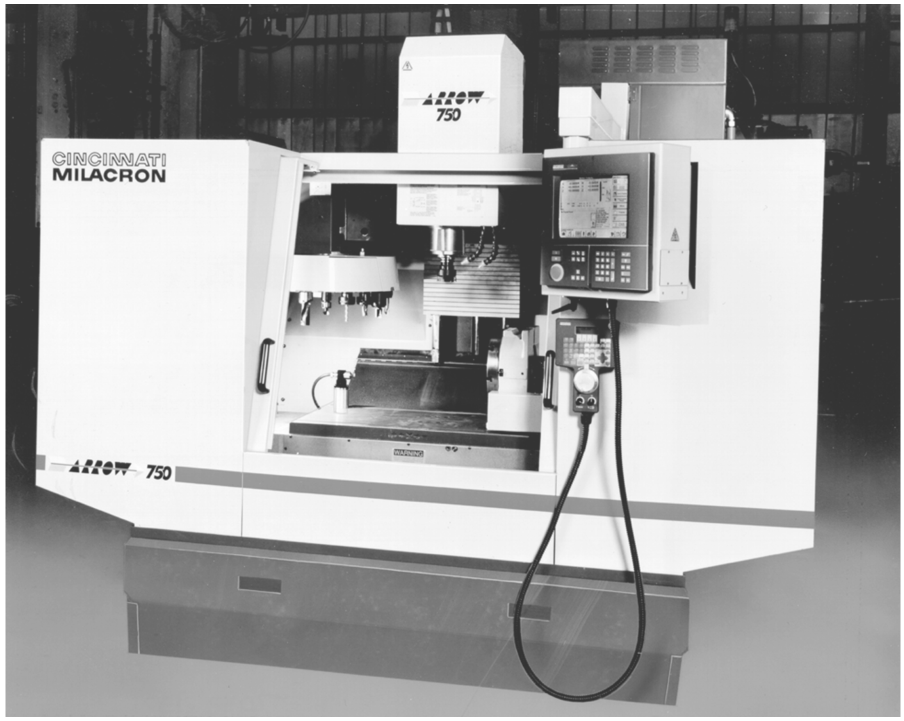
TURNING

Turning utilizes a cutter that moves perpendicularly through the center plane of a rotating workpiece. The part shape depends on the shape of the tool and the operations performed to obtain the finished part.

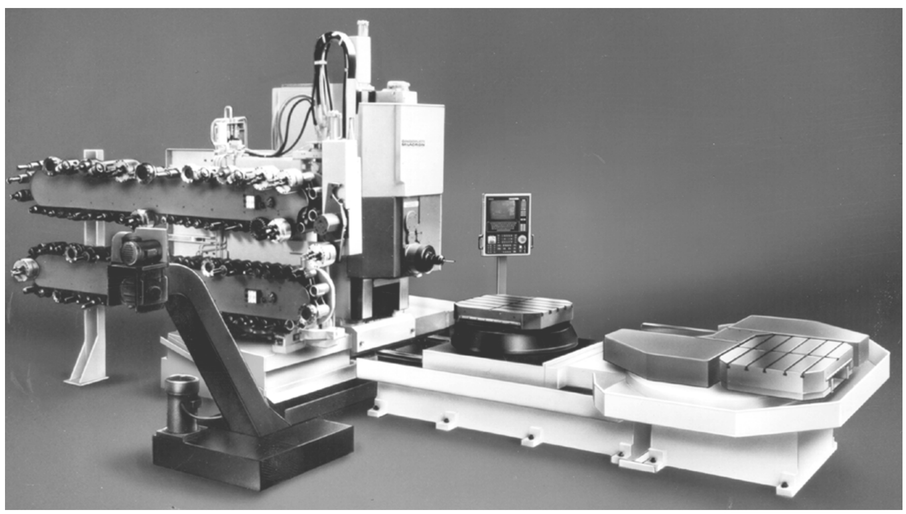
WIRE EDM

Electrical discharge machining, or wire EDM, uses an electrical discharge from a thin wire to achieve fine cuts through hard metal parts. Most EDM machines use two parallel planes in which each cutting point can move independently of the other. This is useful in producing tapered pieces used in the production of punch dies for stamping.

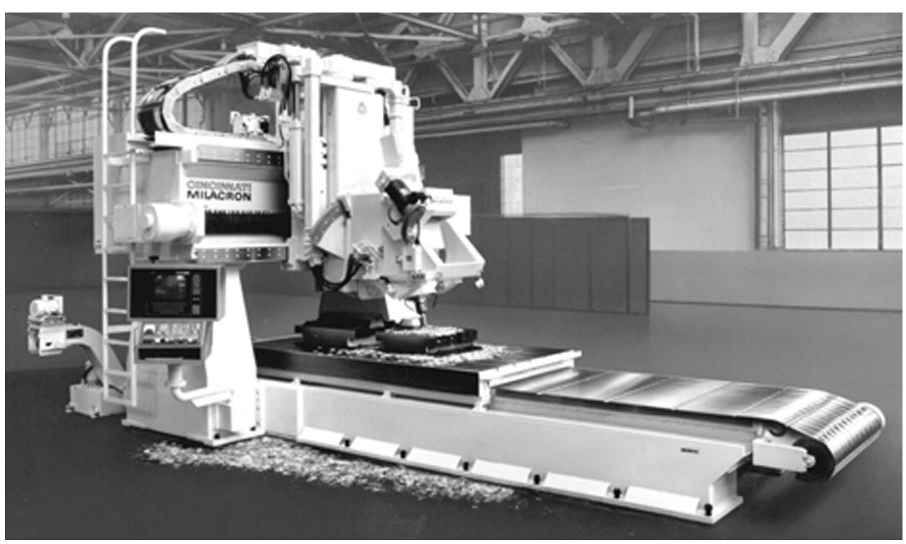
A Cincinnati Milacron Arrow 750 Machining Center with an A-Axis rotary option.
(Courtesy of Cincinnati Milacron.)



A Cincinnati Milacron Universal 5-Axis Machining Center with automatic pallet changer and chip conveyor option.
(Courtesy of Cincinnati Milacron.)



A large Cincinnati Milacron 5-Axis Gantry Profiling Mill.
(Courtesy of Cincinnati Milacron.)



A Cincinnati Milacron Falcon Turning Center.
(Courtesy Cincinnati Milacron.)

LASER, FLAME, AND PLASMA

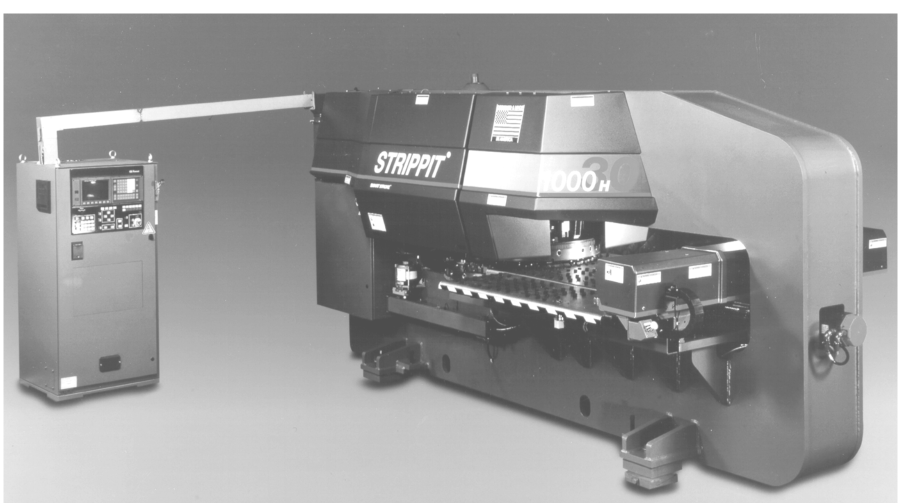
Laser, flame, and plasma cutting use a powerful beam of light, a concentrated flame, or a plasma arc, respectively, to remove material. Depending on the target and thickness of the material, each application has certain advantages.

PUNCHING AND NIBBLING

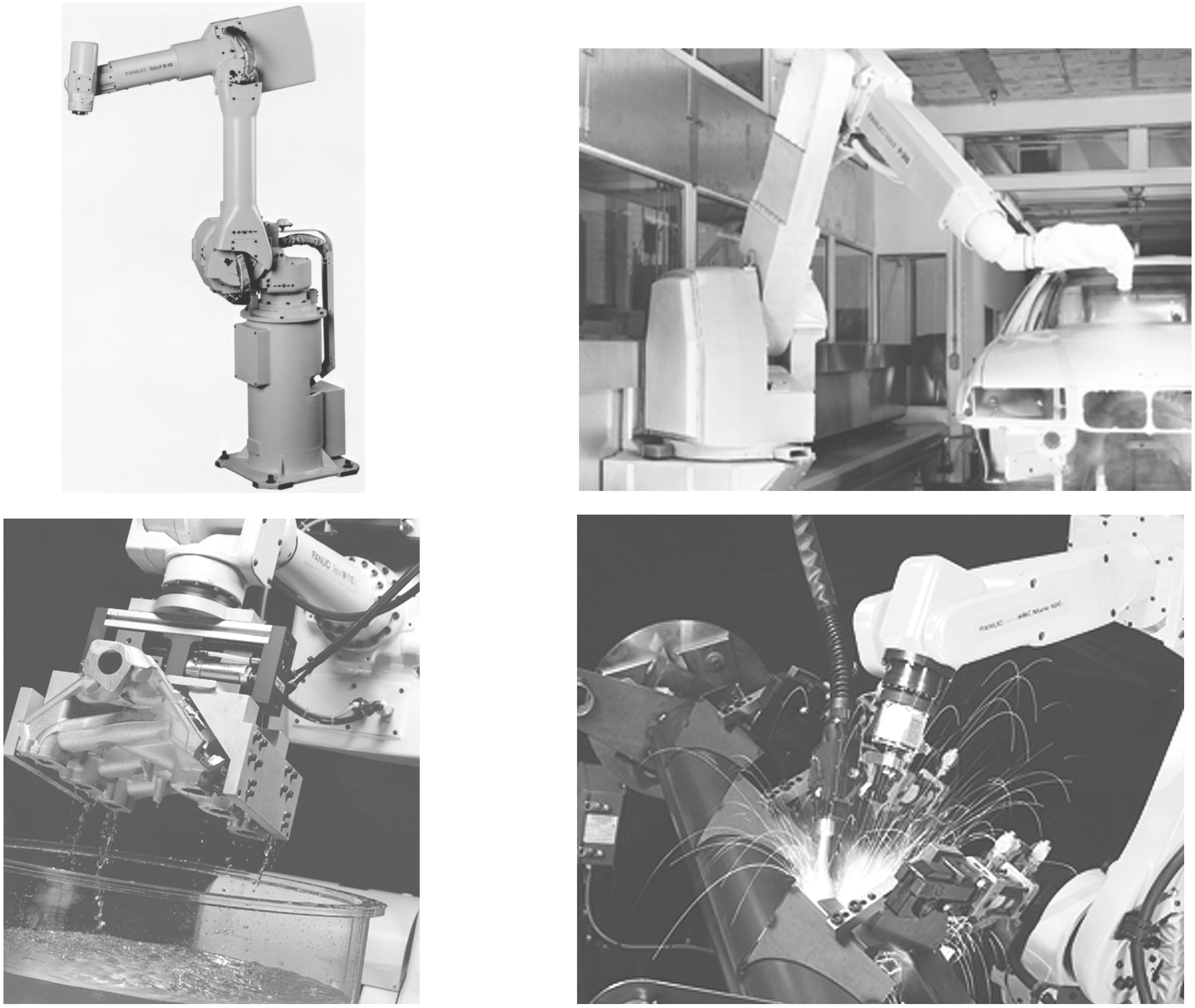
Punching and nibbling are used to cut patterns in sheets of metal by the use of punch dies. Repeated punches along a path achieves a nibbling effect that allows cutting of complex patterns, which would otherwise be very difficult with conventional means. Forming and louvering are also typical applications of CNC punch machines.

ROBOTS AND CNC

The widespread use of CNC in manufacturing is ideal for the use of industrial robots to perform repetitive tasks. Such tasks may involve handling heavy and sometimes hazardous materials. Sophisticated CNC machining centers can contain pallet changers and special interfaces



Strippit Fabri-Center punching and nibbling machine.
(Courtesy of Strippit, Inc.)



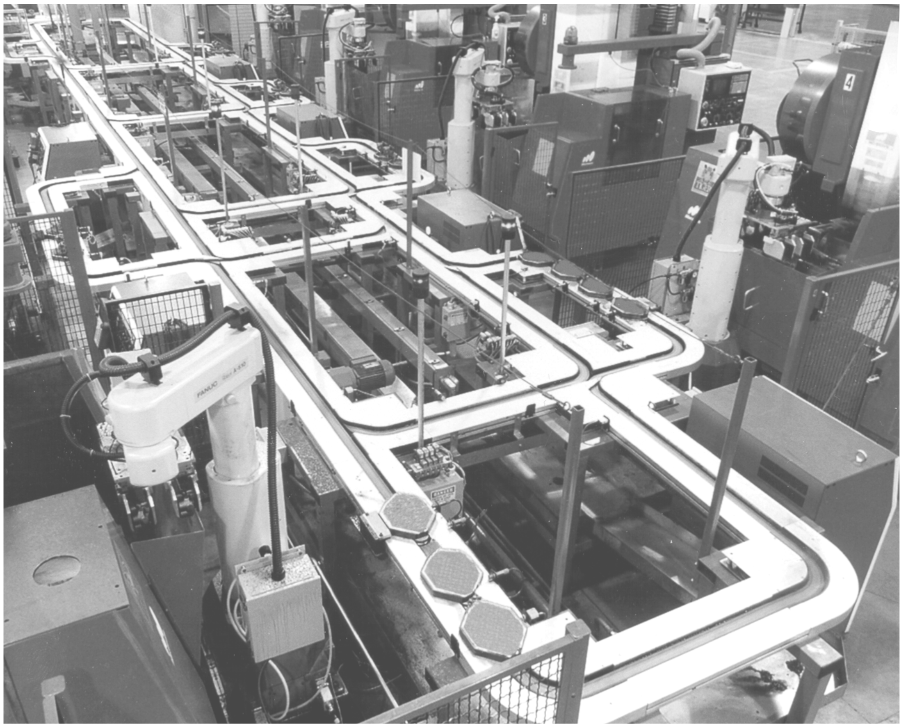
Fanuc industrial robots used in various applications. (Courtesy of Fanuc Robotics.)

that can easily accommodate industrial robots. Such specialty operations are commonplace in today's high-volume machining environments.

Although standards exist and there are similarities among controllers, many differences exist among the various controllers on the market. One manufacturer of controllers may have more than a dozen different models and a dozen different variations of one model alone. Although the basic principal of controllers is easy to understand, the thousands of variations of machine tools and applications require many different types of controllers. It is common to find two different machine tools using the same model of controller with slightly different options.

CONTROLLER STANDARDS

To understand CNC, you must first understand both the differences and similarities of controllers on the market. In addition to the differences in controllers based on the variety of machine tools and applications, other differences relate to the manufacturers and the standards, if any, they follow and how closely they follow those standards.



Fanuc Mfg. cell with several robots and CNC machines. (Courtesy of Fanuc Robotics.)

GE Fanuc 18-T CNC control used on a Hardinge® CONQUEST® T42 CNC Turning Center. Hardinge and CONQUEST are registered trademarks of Hardinge Brothers, Inc.

The TORCOMP Desktop CNC Gantry Training Machine, showing the components of a typical CNC machine tool.

CNC CONTROLLERS

IMPORTANT

There are three major components of a CNC machine tool:

1. The machine tool itself, which can be any one of many different types.
2. The motors and feedback mechanisms, which are very important because they are the link between the machine tool and the controller. Therefore the type, size, and resolution are very important considerations for different applications.
3. The heart of the CNC machine tool—the controller or machine control unit (MCU).

EIA AND ISO STANDARDS

The International Standardization Organization (ISO) and the Electronic Industries Association (EIA) developed two very similar standards that are generally followed worldwide: the ISO 6983 and the EIA RS274. Some countries may have their own standards, but most follow ISO and EIA. The main standards for NC provide simple programming instructions to enable a machine tool to carry out a particular operation. For example, the following lines of code will instruct a CNC milling machine that, on executing line or block number 100, the tool is to cut relative to the origin point at a feedrate of 20 in./min along the X axis 1.25 in. and the Y axis 1.75 in.

```
N95 G90 G20
N100 G01 X1.25 Y1.75 F20.0
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Axis designation on a machine tool and the coordinate system, both of which are covered in more detail in Chapter 2, are also standardized by EIA 267-C. This standard applies to all NC machine tools regardless of whether the controller follows a particular standard. This standard is equally important, if not more so, than the EIA RS274 standard, as it forms the link to computer-aided design and computer-aided manufacturing (CAD/CAM), which follow similar standards.

CONVERSATIONAL (NONSTANDARD)

Though rarer than conventional CNC controllers, an alternative is the conversational CNC controller. These controllers generally do not follow any standard, are mostly proprietary, and are supposed to be easy to use. The operator does not need to know how to program but only how to read and respond to the prompts on the controller screen. Generally, whereas simple machines that produce simple parts may use this system, more complex machines producing more complex parts may not. Therefore some CNC machines may offer both ISO/EIA standard programming and conversational programming. Besides the nonstandardization of conversational CNC controllers, their other drawback is that communication from CAD/CAM systems becomes more difficult. In general, a stand-alone machine, one that does not require programs created through a CAD/CAM system and will produce simple parts, is a good candidate for a conversational controller.

As you learn more about the CNC industry, you will soon discover that there are several main controller manufacturers. They include Fanuc, General Electric, Mitsubishi, Yasnak, and Bendix. However, some CNC machine tool companies, such as Cincinnati Milacron, Giddings, and Lewis and Bridgeport, may use their own proprietary controllers for their machine tools. In general, most of these companies follow the EIA/ISO program standards, so their programs are quite portable.

As you proceed through the rest of this workbook, the CD-ROM, and the CNCez simulation software, keep in mind that the standards used follow as closely as possible the EIA RS274 standard for basic three-axis NC Milling and two-axis NC Turning. Therefore programs developed with CNCez may require some modification for your particular machine tool. If you require more assistance, please consult the Technical Support section at the end of this workbook.

THE CNC PROCESS

In principal, the process of CNC manufacturing is the same as conventional manufacturing methods. Conventionally, shop drawings are generated by design engineers, who pass them to machinists. The machinists then read the drawings and methodically calculate toolpaths, cutter speeds, feeds, machining time, and the like.

In CNC programming, the machinist still has sole responsibility for the machine's operation. However, control is no longer exercised by manually turning the axis handwheels but through programming the use of the controller.

This is not to say that most proficient machinists will be computer programmers. Early CNC machines required manual input of G- and M-codes, but today a computer specialist is no longer needed for this task.

IMPORTANT

Note the following steps in CNC processing for both conventional and computer-aided methods.

IMPORTANT

FLOW OF CNC PROCESSING

1. Develop or obtain the part drawing.
2. Decide which machine(s) will perform the operations needed to produce the part.
3. Decide on the machining sequence and decide on cutter-path directions.
4. Choose the tooling required.
5. Do the required math calculations for the program coordinates.
6. Calculate the spindle speeds and feedrates required for the tooling and part material.
7. Write the CNC program.
8. Prepare setup sheets and tool lists (these will also be used for manufacturing operators).
9. Verify and edit the program, using either a virtual machine simulator such as CNCez or on the actual machine tool, creating a prototype.
10. Verify and edit the program on the actual machine and make changes to it if necessary.
11. Run the program and produce the final part.

IMPORTANT

FLOW OF COMPUTER-AIDED CNC PROCESSING

1. Develop or obtain the three-dimensional geometric model of the part, using CAD.
2. Decide which machining operations and cutter-path directions are required to produce the part (sometimes computer assisted or from engineering drawings and specifications).
3. Choose the tooling to be used (sometimes computer assisted).
4. Run a CAM software program to generate the CNC part program, including the setup sheets and list of tools.
5. Verify and edit the program, using a virtual machine simulator such as CNCez.
6. Download the part program(s) to the appropriate machine(s) over the network and machine the prototype. (Sometimes multiple machines will be used to fabricate a part.)
7. Verify the program(s) on the actual machine(s) and edit them if necessary.
8. Run the program and produce the part. If in a production environment, the production process can begin.

QUALITY CONTROL

As the operator uses the CNC machine tool and its controller, it will become evident which tools and machining procedures work best. This information should be documented, periodically reviewed, and used in all subsequent part programs for that particular machine. This becomes an iterative process, requiring constant improvement. Doing this will also enhance the efficiency of part programs and reduce runtime problems.

LAB EXERCISES

1. What is NC?

2. How did CNC come to be developed?

3. Draw a block diagram of a computer.

4. Draw a block diagram of a CNC mill.

5. Why are standards needed for CNC programming?

6. What is DNC?

7. List the steps in the CNC process.

8. Name some of the advantages of CNC.

9. What are some of the characteristics that CNC-produced parts should have?

10. Describe in your own words the CNC process.