M01_VALE6033_05_SE_C01.QXD 7/20/12 7:19 PM Page 1

CHAPTER
ONE

INTRODUCTION TO COMPUTER NUMERICAL CONTROL MANUFACTURING

1.1 CHAPTER OBJECTIVES

At the conclusion of this chapter you will be able to

1. Explain what computer numerical control (CNC) is and what basic components comprise CNC systems.
2. State the objectives, advantages, and special requirements concerning CNC use.
3. Identify the different media used to input and store CNC programs.
4. Describe the two different punched-tape formats used with CNC machines.

1.2 INTRODUCTION

The basic concepts of numerical control (NC) and computer numerical control (CNC) technology are discussed. Traditional NC and contemporary CNC hardware configurations are described. The important benefits to be derived from CNC operations are listed and explained. The different types of media used for storage and input of CNC programs are then explored. The reader is introduced to different formats for punched tape, and machining centers with automatic tool changers, the latest development in CNC, are considered.

1.3 NUMERICAL CONTROL DEFINITION, ITS CONCEPTS AND ADVANTAGES

NC has been used in industry for more than 40 years. Simply put, NC is a method of automatically operating a manufacturing machine based on a code of letters, numbers, and special characters. A complete set of coded instructions for executing an operation is called a program. The program is translated into corresponding electrical signals for input to motors that run the machine. NC machines can be programmed manually. If a computer is used to create a program, the process is known as computer-aided programming. The approach taken in this text will be in the form of manual programming.

Traditionally, NC systems have been composed of the following components:

Tape punch: converts written instructions into a corresponding hole pattern. The hole pattern is punched into tape which is passed through the tape punch. Much older units used a typewriter device called a Flexowriter, and later devices included a microcomputer coupled with a tape punch unit.

Tape reader: reads the hole pattern on the tape and converts the pattern to a corresponding electrical signal code.

Controller: receives the electrical signal code from the tape reader and subsequently causes the NC machine to respond.

NC machine: responds to programmed signals from the controller. Accordingly, the machine executes the required motions to manufacture a part (spindle rotation on/off, table and or spindle movement along programmed axis directions, etc.). See Figure 1.1.

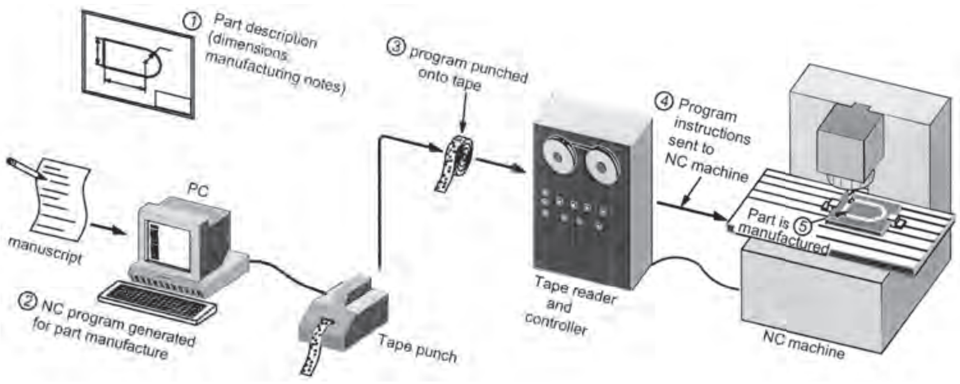

FIGURE 1.1 Components of traditional NC systems.

NC systems offer some advantages over manual production methods:

1. Better control of tool motions under optimum cutting conditions.
2. Improved part quality and repeatability.
3. Reduced tooling costs, tool wear, and job setup time.
4. Reduced time to manufacture parts.
5. Reduced scrap.
6. Better production planning and placement of machining operations in the hands of engineering.

1.4 DEFINITION OF COMPUTER NUMERICAL CONTROL AND ITS COMPONENTS

A CNC machine is an NC machine with the added feature of an onboard computer. The onboard computer is often referred to as the machine control unit or MCU. Control units for NC machines are usually hardwired, which means that all machine functions are controlled by the physical electronic elements that are built into the controller. The onboard computer, on the other hand, is "soft" wired, which means the machine functions are encoded into the computer at the time of manufacture, and they will not be erased when the CNC machine is turned off. Computer memory that holds such information is known as ROM or read-only memory. The MCU usually has an alphanumeric keyboard for direct or manual data input (MDI) of part programs. Such programs are stored in RAM or the random-access memory portion of the computer. They can be played back, edited, and processed by the control. All programs residing in RAM, however, are lost when the CNC machine is turned off. These programs can be saved on auxiliary storage devices such as punched tape, magnetic tape, or magnetic disk. Newer MCU units have graphics screens that can display not only the CNC program but the cutter paths generated and any errors in the program.

The components found in many CNC systems are shown in Figure 1.2.

Machine control unit: generates, stores, and processes CNC programs. The MCU also contains the machine motion controller in the form of an executive software program. See Figure 1.3.

NC machine: responds to programmed signals from the MCU and manufactures the part.

1.5 ADVANTAGES OF CNC COMPARED WITH NC

CNC opens up new possibilities and advantages not offered by older NC machines.

1. Reduction in the hardware necessary to add a machine function. New functions can be programmed into the MCU as software.

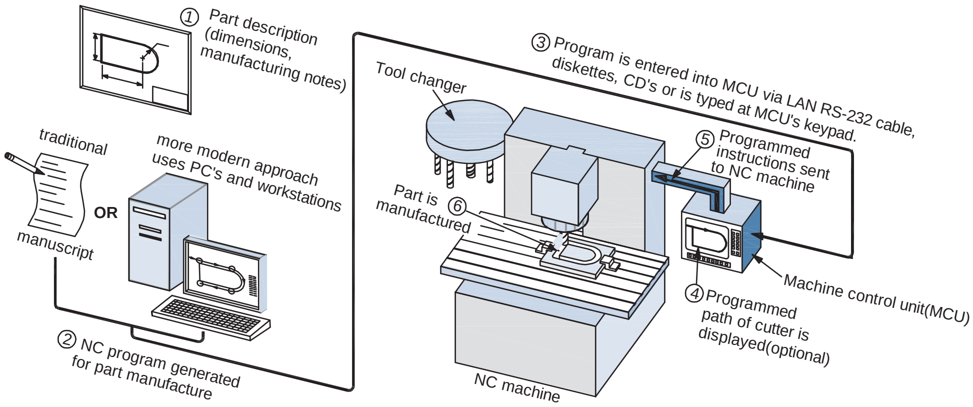

FIGURE 1.2 Components of modern CNC systems.

FIGURE 1.3 A modern machine control unit.
(Photo courtesy of Dejan Lazarevic/Shutterstock.com)

2. The CNC program can be written, stored, and executed directly at the CNC machine.
3. Any portion of an entered CNC program can be played back and edited at will. Tool motions can be electronically displayed upon playback.
4. Many different CNC programs can be stored in the MCU.
5. Several CNC machines can be linked together to a main computer. Programs written via the main computer can be downloaded to any CNC machine in the network. This is known as direct numerical control or DNC. See Figure 1.4.

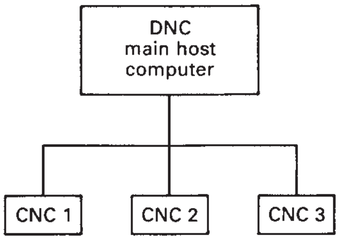

FIGURE 1.4 Direct numerical control.

6. Several DNC systems can also be networked to form a large distributive numerical control system. Refer to Figure 1.5.
7. The CNC program can be input from flash or floppy disks or downloaded from local area networks.

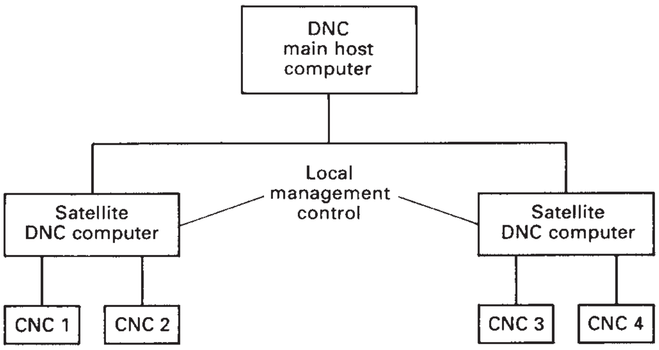

FIGURE 1.5 Distributive numerical control.

1.6 SPECIAL REQUIREMENTS FOR UTILIZING CNC

CNC machines can dramatically boost productivity. The CNC manager, however, can only ensure such gains by first addressing several critical issues, such as the following:

1. Sufficient capital must be allocated for purchasing quality CNC equipment.
2. CNC equipment must be maintained on a regular basis by obtaining a full-service contract or by hiring an in-house technician.
3. Personnel must be thoroughly trained in the operation of CNC machines. In particular, many jobs require setups for machining parts to comply with tolerances of form and function (GD&T).
4. Careful production planning must be studied because the hourly cost of operation of a CNC machine is usually higher than that for conventional machines.

1.7 FINANCIAL REWARDS OF CNC INVESTMENT

Investors are encouraged to look to the CNC machine tool as a production solution with the following savings benefits:

1. Savings in direct labor. One CNC machine's output is commonly equivalent to that of several conventional machines.
2. Savings in operator training expenses.
3. Savings in shop supervisory costs.
4. Savings due to tighter, more predictable production scheduling.
5. Savings in real estate, since fewer CNC machines are needed.
6. Savings in power consumption, since CNC machines produce parts with a minimum of motor idle time.
7. Savings from improved cost estimation and pricing.
8. Savings due to the elimination of construction of precision jigs, the reduced need for special fixtures, and reduced maintenance and storage costs of these items.
9. Savings in tool engineering/design and documentation. The CNC's machining capability eliminates the need for special form tools, special boring bars, special thread cutters, etc.
10. Reduced inspection time due to the CNC machine's ability to produce parts with superior accuracy and repeatability. In many cases, only spot-checking of critical areas is necessary without loss of machine time.

Using Payback Period to Estimate Investment Efficiency

The payback period calculation estimates the number of years required to recover the net cost of the CNC machine tool.

$$\text{Payback Period} = \frac{\text{Net Cost of CNC} - \text{Net Cost of CNC} \times \text{Tax Credit}}{\text{Savings} - \text{Savings} \times \text{Tax Rate} + \text{Yearly Depreciation of CNC} \times \text{Tax Rate}}$$

Using Return on Investment (ROI) to Estimate Investment Efficiency

The ROI calculation predicts what percent of the net cost of the CNC will be recovered each year. The ROI calculation accounts for the useful life of the CNC machine tool.

$$\text{ROI} = \frac{\text{Average Yearly Savings} - \text{Net Cost of CNC/Years of Life}}{\text{Net Cost of CNC}}$$

Example 1.1

Given the investment figures in Table 1.1 for implementing a new CNC machine tool, determine the payback period and the annual return on investment. The CNC is conservatively estimated to have a useful life of 12 years.

$$\text{Payback Period} = \frac{95{,}250 - 95{,}250 \times .1}{63{,}100 - 63{,}100 \times .46 + 10{,}900 \times .46}$$

$$\text{Payback Period} = 2.19\,\text{years}$$

This calculation estimates that the net cost of the CNC will be recovered in 2.19 years.

$$\text{ROI} = \frac{63{,}100 - 95{,}250/12}{95{,}250}$$

$$\text{ROI} = .57$$

This calculation estimates that the investor can expect 57% of the net cost of the CNC (or .57 × $95,250 = $54,293) to be recovered each year if the CNC machine's useful life is 12 years.

TABLE 1-1

Initial investment ($)	One-time savings in tooling ($)	Net cost of CNC ($)	Average yearly savings ($)	Tax credit (10%)	Tax rate (46%)	Yearly depreciation of CNC ($)
130,250	35,000	95,250	63,100	.1	.46	10,900

1.8 CNC MACHINING CENTERS AND TURNING CENTERS

Machining centers are the latest development in CNC technology. These systems come equipped with automatic tool changers capable of changing 90 or more tools. Many are also fitted with movable rectangular worktables called pallets. The pallets are used to automatically load and unload workpieces. At a single setup, machining centers can perform such operations as milling, drilling, tapping, boring, counterboring, and so on. Additionally, by utilizing indexing heads, some centers are capable of executing these tasks on many different faces of a part and at specified angles. Machining centers save production time and cost by

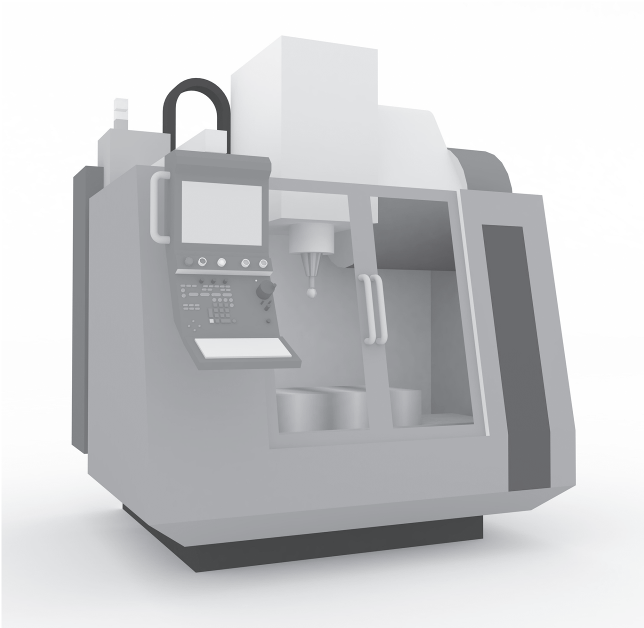

FIGURE 1.6 A vertical spindle machining center.
(Photo courtesy of Hardinge Inc.)

reducing the need for moving a part from one machine to another. Two types of machining centers are shown in Figures 1.6 and 1.7.

A more complete discussion of the important features found on machining centers is deferred until Chapter 4.

Turning centers with increased capacity tool changers are also making a strong appearance in modern production shops. These CNC machines are capable of executing many different types of lathe cutting operations simultaneously on a rotating part. A modern turning center is shown in Figure 1.8.

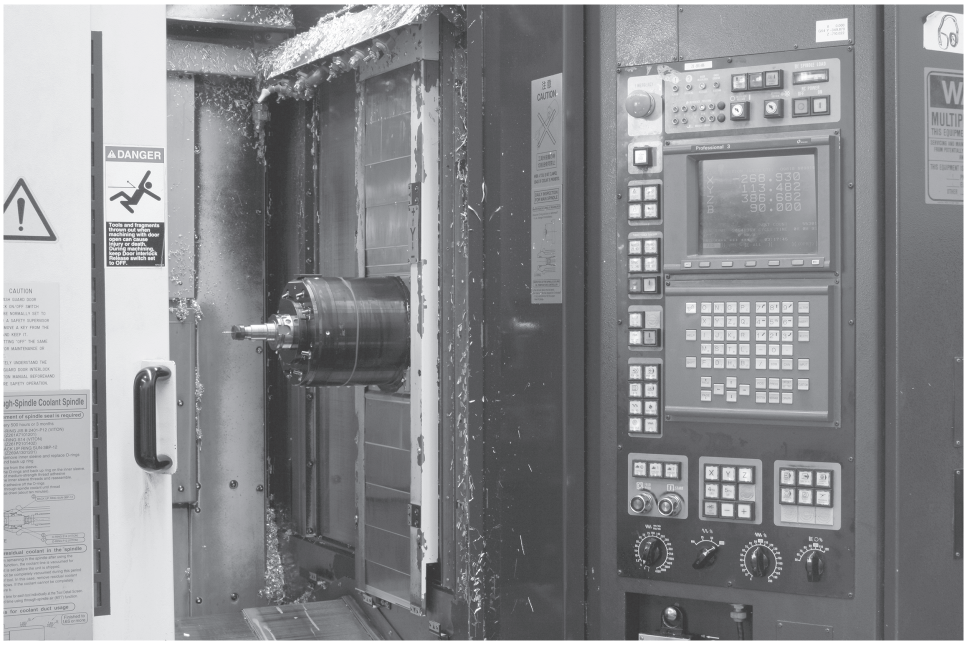

FIGURE 1.7 A horizontal spindle machining center with an automatic tool changer and two pallet work changers.
(Photo courtesy of metalpix/Alamy)

FIGURE 1.8 A modern CNC turning center.
(Photo courtesy of Giovanni Burlini/Fotolia.com)

1.9 OTHER TYPES OF CNC EQUIPMENT

In addition to machining centers and turning centers, CNC technology has also been applied to many other types of manufacturing equipment. Among these are wire electrical discharge machines (wire EDM) and laser cutting machines.

Wire EDM machines utilize a very thin wire (.0008 to .012 in.) as an electrode. The wire is stretched between diamond guides, and carbide that conducts current to the wire, which cuts the part like a bandsaw. Material is removed due to the erosion caused by a spark that moves horizontally with the wire. CNC is used to control horizontal table movements. Wire EDM machines are very useful for producing mold inserts, extrusion and trim dies, as well as form tools. See Figure 1.9.

Laser cutting CNC machines utilize an intense beam of focused laser light to cut the part. Material under the laser beam undergoes a rapid rise in temperature and is vaporized. If the beam power is high enough, it will penetrate through the material. Because no mechanical cutting forces are involved, lasers cut parts with minimal distortion. They have been very effective in machining slots and drilling holes. See Figure 1.10.

1.10 CNC INPUT AND STORAGE MEDIA

It will be useful for the reader to become acquainted with the basic concept of binary number code prior to discussing input and storage methods. Internally, computers and the MCU operate by a system of electrical switches. A **1** (one) is processed as an *open* switch and a **0** (zero) is processed as a *closed* switch. All numbers, letters, and special characters are represented in terms of a unique set of zeros and ones. The *only* code the computer and MCU can work on is *binary.* All externally generated code must first be translated into binary before these devices can act on it. The binary code from the computer and MCU must also be translated back into a code operators can understand. The translation process is automatically executed by devices inside the computer.

The information necessary to perform CNC operations could be entered manually into the control unit, but this is a long and inefficient process. The machine is also prevented from making parts while this is being done. Past input media included 1 in. wide

FIGURE 1.9 A CNC-controlled wire cutting EDM machine.
(Photo courtesy of James V. Valentino.)

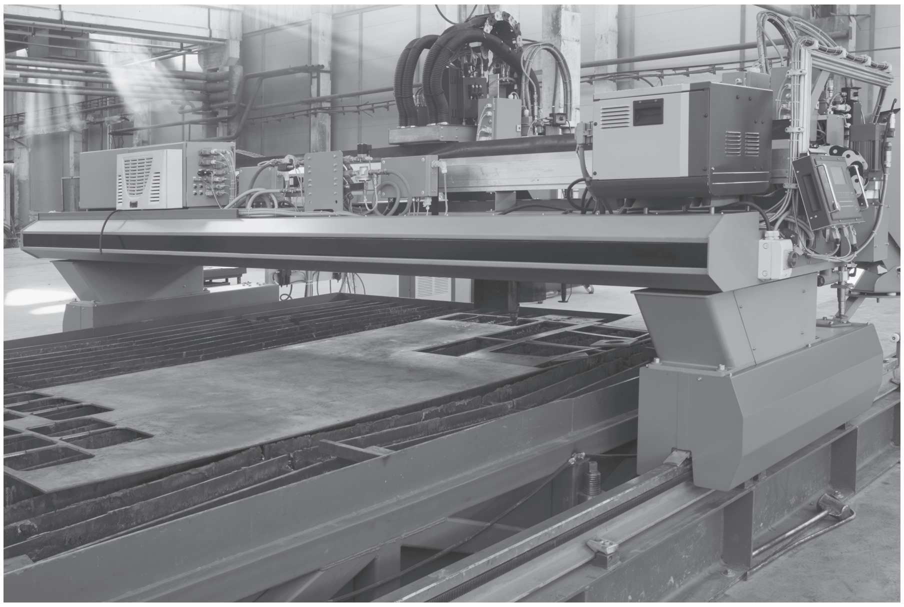

FIGURE 1.10 A laser cutting CNC machine.
(Photo courtesy of terex/fotolia.com)

punched tape made of paper, paper-Mylar, or aluminum-Mylar laminates. The program was punched into the tape in a hole pattern.

Modern CNC technology uses an array of new devices for storing and loading programs written with the aid of a microcomputer or larger mainframe computer. These are shown in Figure 1.11.

Disks

These devices store a program in the form of a magnetic pattern on a plastic disk. During operation, the disk spins and the pattern is read by recording heads in the disk drive unit. Disks, also known as “floppy” disks, can store up to 1.44 megabytes (MB) of information.

CD-ROM

The compact disc (CD) is a popular device for storing information in the form of a pattern of etched pits. An optical laser is used to read the pit pattern on the spinning disc. CDs offer many advantages over other types of storage devices: they are a very stable and durable medium, ensuring almost indefinite storage life. Additionally, they are capable of storing large amounts of information. A typical CD has a storage capacity of 680 MB. Recordable (CD-R) discs can have data written on them only *once*. Re-writeable disks (CD-RW) can be erased and rewritten with new data. The CD drive used for this purpose must also be a CD “burner” capable of re-writing data to the CD.

Disks and CD-ROMs are used with personal computers (PCs) and workstations. They are referred to as random access media. This means that any information on them can be found and retrieved almost instantaneously.

Portable Hard Drives

These palm 1-1 size devices store data in the form of a magnetic pattern on a spinning disk, and are connected directly to any USB port on a PC or workstation. The USB bus power is utilized so no additional power cords or adapters are needed. They dramatically increase the amount of digital data that can be stored. The smaller pocket hard drive units have a storage capacity of between 2.5 GB and 5 GB. The slightly larger portable units can store data starting in the 40 GB range all the way up to 120 GB. In essence, they act as additional hard drives.

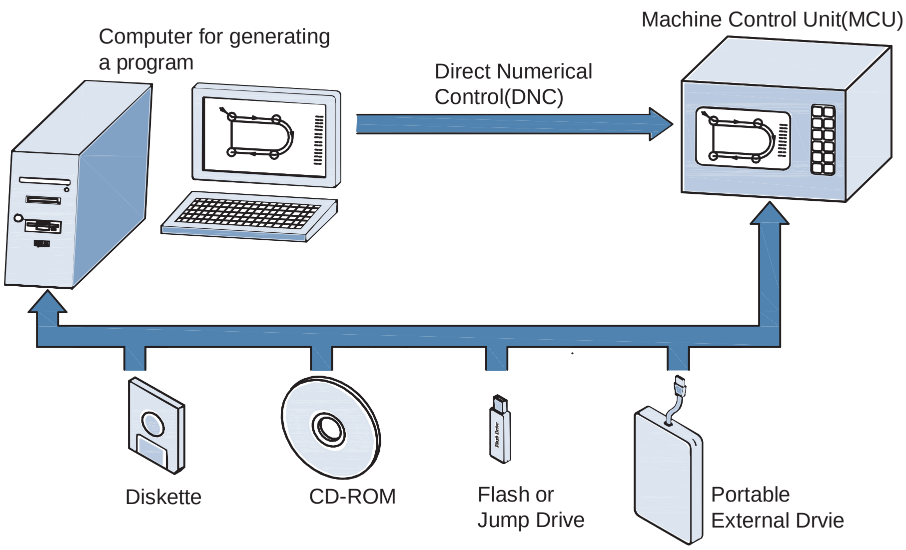

FIGURE 1.11 Modern CNC input and storage methods.

Flash or Jump Drives

A flash or jump drive is a small, portable unit about the size of a stick of gum that plugs directly into a computer's USB port. Flash memory stores data with the use of a special type of *electrically erasable programmable read-only memory* (EEPROM) chip. Data is written by applying an electric field to the entire chip, or to predetermined sections of the chip called blocks. Flash drives are available in various storage sizes: 512 MB, 2 GB, 4 GB, and 8 GB. The advantages of using flash devices instead of CDs or external hard drives are listed as follows:

- No fragile moving parts that can break if dropped.
- Far smaller in size.
- Do not require time-consuming configuration to connect to the computer.
- USB ports are more common than CD or DVD burners.
- Flash devices are automatically re-writable and do not require a special drive.

1.11 CHAPTER SUMMARY

The following key concepts were discussed in this chapter:

1. Numerical control (NC) is a method of automatically operating a manufacturing machine based on a programmed set of instructions.
2. A CNC machine is similar to an NC machine except that in a CNC machine an onboard computer is used to store, edit, and execute programmed instructions.
3. CNC use involves substantial investments in equipment, production planning, and training.
4. CNC machine tools greatly boost productivity.
5. Different methods of input include manual data input (MDI); input through punched tape, floppy disks, zip disks, CD-ROMs, portable hard drives, and flash drives; and direct transmission from a remote computer (DNC).
6. The MCU operates in binary code only. All programs must be translated into binary.
7. Storage devices include floppy disks, CD-ROMs, portable hard drives, and flash drives.

REVIEW EXERCISES

1.1. What is numerical control (NC) and what components traditionally comprised NC systems?

1.2. What are four objectives of numerical control?

1.3. What advantages does numerical control offer over manual methods?

1.4. What is a computer numerical control (CNC) machine?

1.5. What improvements do today's modern CNC machines offer over traditional NC machines?

1.6. What is meant by the terms *direct numerical control* and *distributive numerical control*?

1.7. Name four requirements that must be satisfied prior to using CNC in a shop.

1.8. Describe four devices for storing and inputting CNC programs.

1.9. What advantages do flash drives offer over other types of storage media?

1.10. What is binary code?

1.11. Name three advantages offered by machining centers.

1.12. Describe the financial rewards of CNC investment.

1.13. **a.** What is estimated by payback period?
b. What is estimated by return on investment (ROI)?