**بسمه تعالی**

**دانشگاه فنی و حرفه ای**

**دانشکده انقلاب اسلامی**

**انستیتو مکانیک**

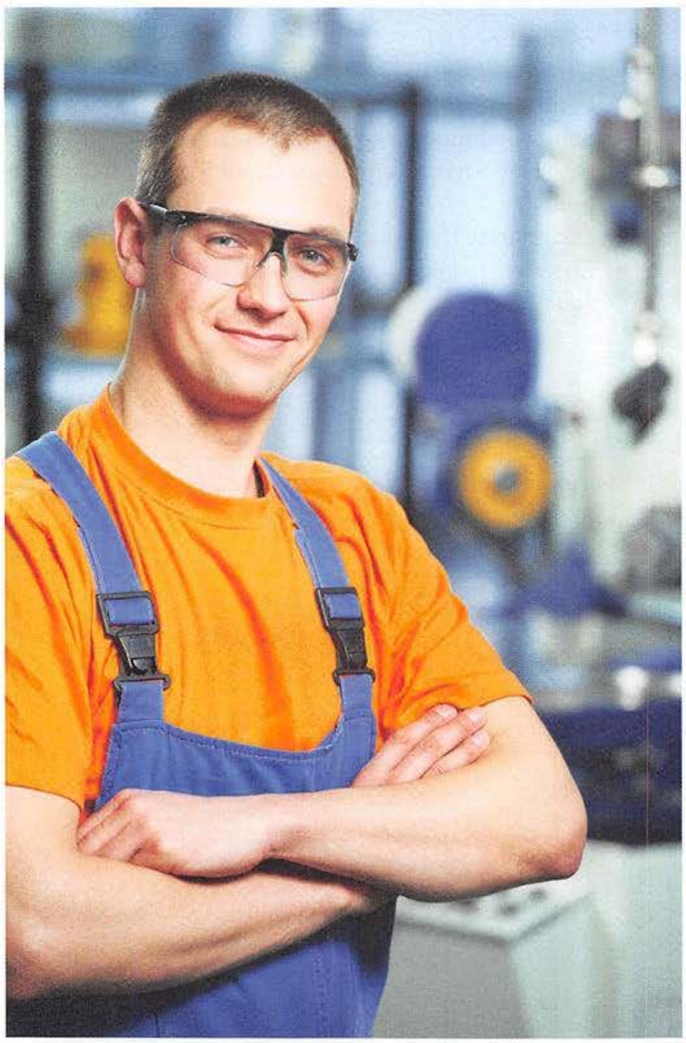
# زبان فنی کاردانی ساخت و تولید

**استاد هاشمی**

A ***career*** is a job that requires specialized training and commitment to the profession. Many people want a career that is both challenging and interesting. Their philosophy is that if you enjoy your job, you will never "work" a day in your life. Others are satisfied with whatever job comes along. With which viewpoint do you agree?

If you are looking for a career that is challenging, interesting, and rewarding, the field of machining offers many opportunities. See **Figure 2-1**. Whether you choose one of the machine shop areas or select a career in a related field, you will find that the study of *Machining Fundamentals* is basic to all of them.

No matter which occupational choice you make, you should realize that you will have to keep up with technical progress. To be successful and advance in your career, a continuing program of education is usually necessary.



Dmitry Kalinovsky/Shutterstock.com

**Figure 2-1.** The field of metal machining offers many opportunities for semiskilled and skilled workers, technicians, and professional personnel.

## 2.1 Machining Job Categories

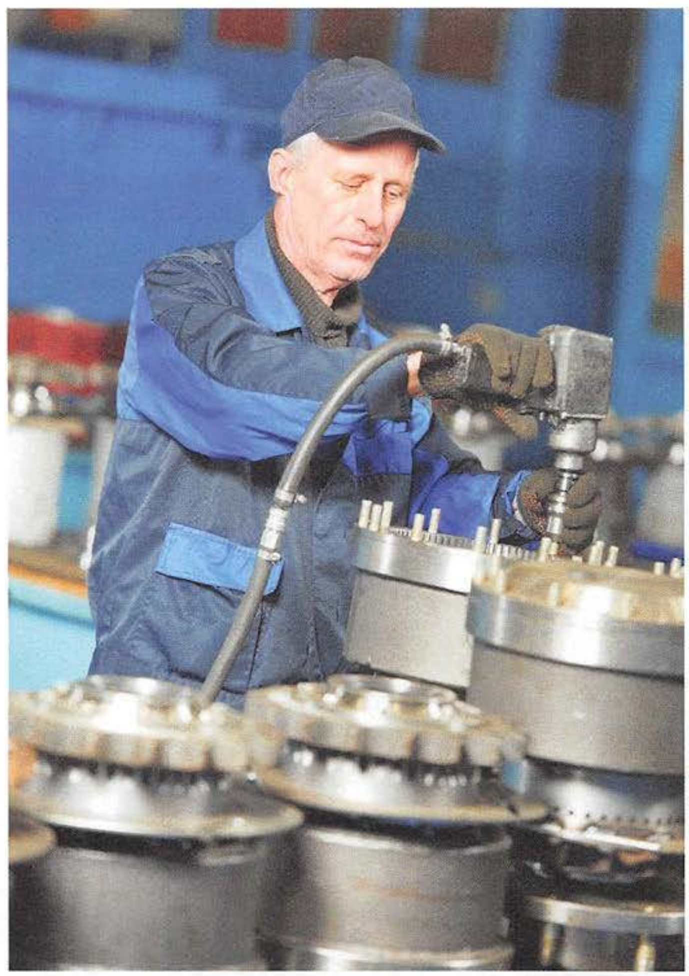
Jobs in material machining fall into four general categories:

- Semiskilled workers.
- Skilled workers.
- Technicians.
- Professionals.

### 2.1.1 Semiskilled Workers

A ***semiskilled worker*** performs basic, routine operations that do not require a high degree of skill or training. Semiskilled workers may be classified into the following general groups:

- Those who are helpers for skilled workers.
- Those who operate machines and equipment used in making things. The machines are set up by skilled workers.
- Those who assemble the various manufactured parts into final products, **Figure 2-2**.



Dmitry Kalinovsky/Shutterstock.com

**Figure 2-2.** Many semiskilled workers are employed in assembly industries, where they assemble manufactured parts into complete units. Training periods to learn these job skills are relatively short.

Most semiskilled work is found in production shops that have many repetitive operations. In general, semiskilled workers are told what to do and how the work is to be done. There is little chance for advancement from semiskilled jobs without additional education and training. Semiskilled workers are often the first to lose their jobs when there is a downturn in the economy and may have difficulty finding another job due to their lack of education. It is therefore a good idea for semiskilled workers to consider furthering their education and training.

## 2.1.2 Skilled Workers

A ***skilled worker*** has been trained to do more complex tasks. Skilled workers are found in all areas of material machining. Many skilled workers obtain their training as an ***apprentice*** in an apprenticeship program (on-the-job training while working with skilled machinists), **Figure 2-3**. Four or more years of instruction under an experienced machinist is generally required. In addition to working in the shop, an apprentice usually studies related subjects, such as math, science, English, print reading, metallurgy, safety, and production techniques. On completion of an apprenticeship program, the worker is capable of performing the precise work essential to the trade.

In recent years, the demand for skilled workers has grown tremendously. Workers entering the field can receive their training through the armed forces, **Figure 2-4**, or in career and technical education programs offered in high schools and community colleges. Many community college programs are offered in conjunction with local industry.

US Army

**Figure 2-4.** The Army and other branches of the armed forces offer excellent opportunities for learning a trade. These servicewomen are learning to machine parts on a manual lathe. The coursework they complete can be used toward obtaining National Institute of Metalworking Skills (NIMS) credentials.
*(Use of military imagery does not imply or constitute endorsement of Goodheart-Willcox Publisher, its products, or services by the US Department of Defense.)*

There are several areas in which a machinist may concentrate. Some of these areas of specialization are discussed in the following sections.

Monkey Business Images/Shutterstock.com

**Figure 2-3.** The apprentice studies under an experienced machinist for a period of four or more years. The training program also includes the study of related subjects, such as math, English, and science.

## All-Around Machinist

An all-around machinist is skilled in the setup and operation of most types of machine tools. He or she must be familiar with both manual and computer-controlled machine tools and how they are programmed, **Figure 2-5**. An all-around machinist is expected to plan and carry out all of the operations needed to machine a job.

Many all-around machinists work in ***job shops***. Some job shops specialize in creating custom or experimental machining projects for various clients. Other job shops specialize in manufacturing products with very small production runs.

## Tool and Die Maker

A ***toolmaker*** is a highly skilled machinist who specializes in producing the tools and tooling needed for machining operations. These include the following:

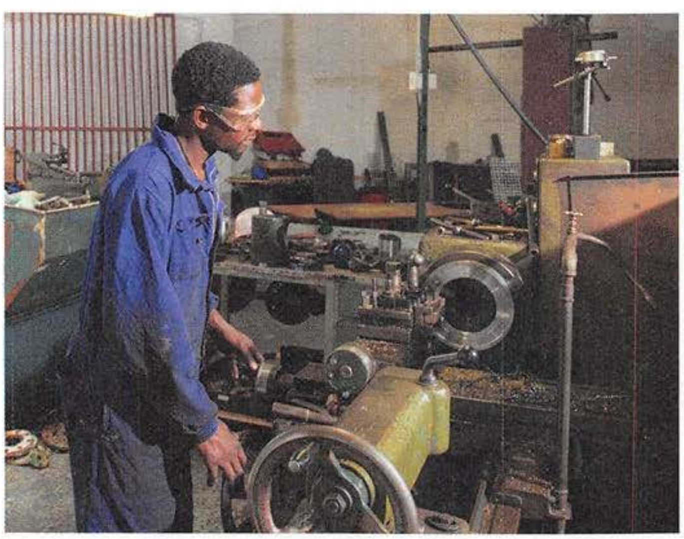
- **Dies.** Special tools for shaping, forming, stamping, or cutting metal or other materials.
- **Jigs.** Devices that position work and guide cutting tools.
- **Fixtures.** Devices that hold work while it is machined.
- **Gauges.** Devices that hold work while it is being measured.

These tools are necessary for modern mass production techniques. Toolmakers must have a broader background in machining operations and mathematics than most other skilled workers in the trade. See **Figure 2-6**.

A die maker specializes in making the punches and dies needed to stamp out parts, such as auto body panels, electrical components, and similar products. He or she also produces the dies for making extrusions (metal shaped by being pushed through an opening in a metal disc of proper configuration).

Precision Castparts Corp.

**Figure 2-6.** A tool and die maker checking the dies used for molding a plastic pattern used to cast a jet engine component. Master tooling ensures that other sections of the engine, made elsewhere in the United States, Israel, and Europe, will fit together perfectly.



John-james Gerber/Shutterstock.com

**Figure 2-5.** The all-around machinist can set up and operate most types of machine tools, both manual or CNC.

Tools used in die castings (parts made by forcing molten metal into a mold) are often called *dies*, which is incorrect. Tools that have molten material forced into them are called *molds*, and the correct term for the professional that builds molds is *mold maker*. Like the toolmaker, die makers and mold makers are highly skilled machinists.

## Layout and Setup Specialists

The layout specialist is a machinist who interprets the drawings and uses precision measuring tools to mark off where metal must be removed by machining from castings, forgings, and metal stock. This person must be very familiar with the operation and capabilities of machine tools. He or she is well-trained in mathematics and print reading.

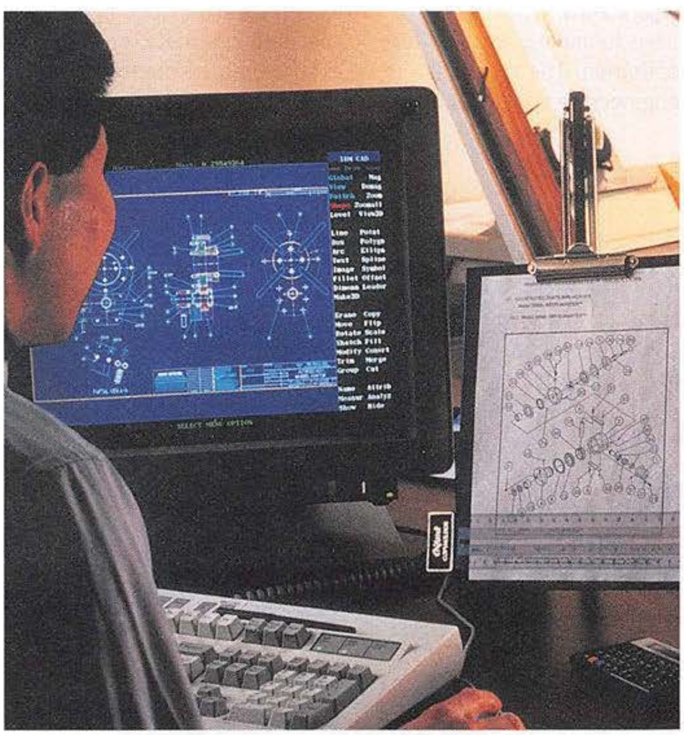
A setup specialist is a person who locates and positions ("sets up") tooling and work-holding devices on a machine tool for use by a machine tool operator. With CNC equipment, the setup specialist may also be required to load part programs into the machine controller and adjust various machine offsets. This worker may also show the machine tool operator how to do the job, and often checks the accuracy of the machined part. See **Figure 2-7**.

## Part Programmer

A ***part programmer*** inputs data into a computer-controlled (CNC) machine tool for machining a product. CNC machine tools have revolutionized the fields of machining and manufacturing. However, computers must be programmed by a highly skilled part programmer who studies the drawings and determines the sequences, tools, and motions the machine tool must carry out to machine the part, **Figure 2-8**.

*Hydromat, Inc.*

**Figure 2-7.** A setup specialist is a master machinist who prepares machine tools for operation by less highly trained personnel. After thoroughly checking the machined part to be sure it meets specifications, the setup specialist turns the machine tool over to a machine operator.



*Tri-Tool, Inc.*

**Figure 2-8.** The programmer prepares the machining information, such as tools, tool paths, and machining sequence, for a CNC program that will direct the entire machining process of a specific part. The programmer must thoroughly understand machining technology.

To perform this task, a part programmer must have the following qualifications:

- Formal training in computer hardware as it relates to machine tool operation.
- Formal training in computer-aided design (CAD) and computer-aided manufacturing (CAM) software.
- Experience in reading and interpreting drawings.
- A thorough grounding in machining technology and procedures.
- A working knowledge of cutting speeds and feeds for various tools and materials.
- Extensive training in mathematics.

In high-volume production settings, the part programmer is also responsible for program adjustments and modifications that require knowledge above that of an operator or setup specialist. Many community colleges and career and technical education centers offer programs in CNC programming, CAD, and CAM.

### Supervisor or Manager

A supervisor or manager is usually a skilled machinist who has been promoted to a position of greater responsibility. This person directs other workers in the shop and is responsible for meeting production deadlines and keeping work quality high, **Figure 2-9**. In many shops, the manager may also be responsible for training and other tasks.

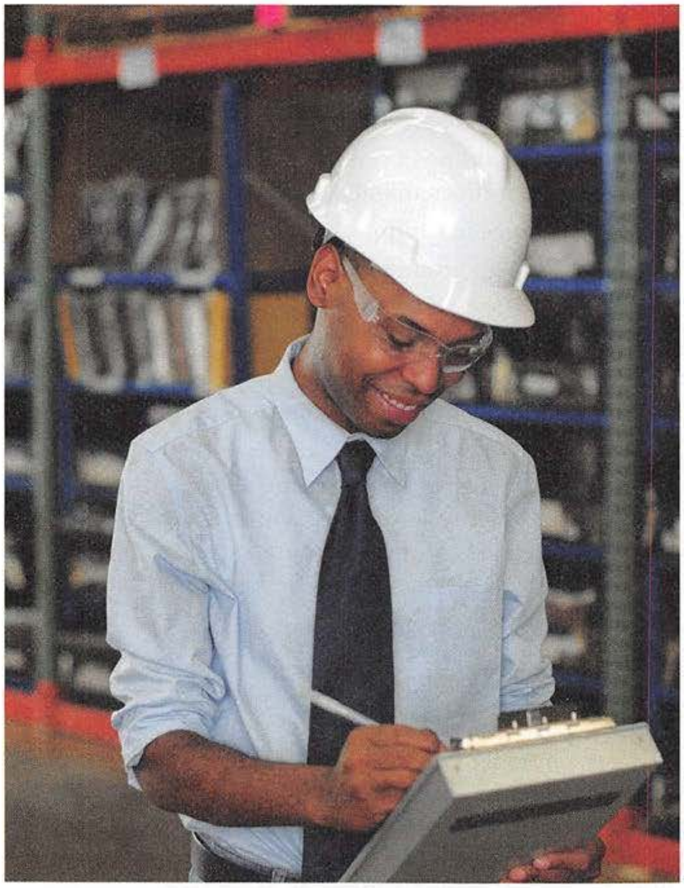
**GREEN MACHINING**

**Green Manufacturing**

Green manufacturing describes a two-fold trend in manufacturing: manufacturing green products and making the process of manufacturing green. Green products are environmentally friendly in their use. Green products are durable, free of toxic compounds, and often biodegradable. As part of green manufacturing, green products are produced with less waste and less pollution than traditional manufacturing practices and are often made from renewable or recycled materials. International attention on environmentally friendly manufacturing using renewable resources has driven a drastic increase in green manufacturing worldwide. "Greening" the manufacturing process by reducing waste and pollution improves efficiency and can also lead to innovation and job growth.

## 2.1.3 Technicians

A ***technician*** is a member of the production team who operates in the realm between the shop and engineering departments. The position is an outgrowth of today's highly technological and scientific world. The job usually requires at least two years of college, with a program of study centered



Steve Good/Shutterstock.com

**Figure 2-9.** The supervisor or manager of the production department works very closely with machinists, engineers, metallurgists, and other staff. Supervisors may also be responsible for planning projects, ordering stock, meeting production deadlines, and ensuring high-quality work.

Chuck Rausin/Shutterstock.com

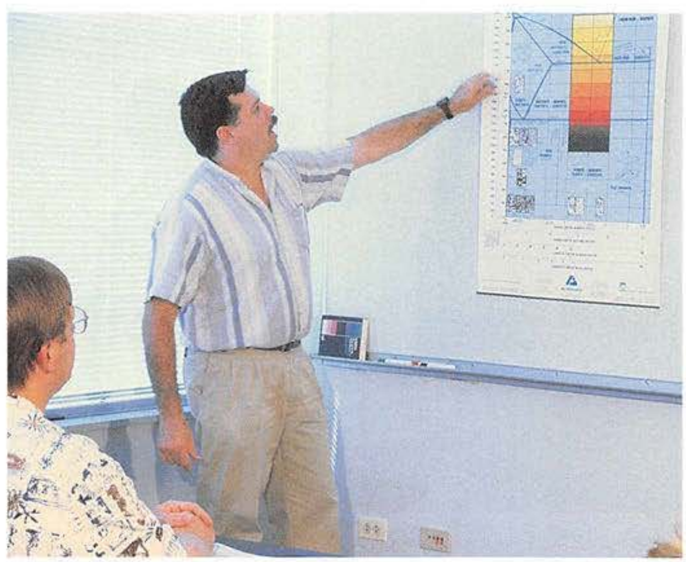
**Figure 2-10.** This quality control technician is inspecting a die used to make plastic patterns to be used in a metal casting operation. The technician must ensure that the die meets engineering specifications before being shipped to customers.

on math, science, English, computer science, quality control, manufacturing, and production processes. Many state and community colleges offer two-year ***associate's degree*** programs devoted to preparing students for such technical positions.

The technician assists the engineer by testing various experimental devices and machines, compiling statistics, making cost estimates, and preparing technical reports. Many inspection and quality control programs are managed by technicians, **Figure 2-10**. Technicians also repair and maintain computer controlled machine tools and robots.

## 2.1.4 Professionals

Several professions offer many excellent opportunities in the fields of machining, metalworking, and manufacturing. Teaching is a challenging profession that offers a freedom not found in most other professions. Teaching can be a very satisfying profession on a personal level, although it is a field that students often overlook, **Figure 2-11**. Teachers of industrial arts, industrial technology, vocational education, and career and technical education are in a fortunate



Goodheart-Willcox Publisher

**Figure 2-11.** The teaching profession is a challenging one. Many skilled educators will be needed in machining technology if the United States is to maintain its position as a world leader.

position. It is not an overcrowded profession, and there will be a demand for teachers for many years to come. To teach machining, four years of college training are usually needed, **Figure 2-12**. While industrial experience is ordinarily not required, it will prove very helpful.

Engineering is another fast-growing and challenging profession. An ***engineer*** uses mathematics, science, and knowledge of manufacturing principles to develop new products and processes for industry, **Figure 2-13**. A four-year ***bachelor's degree*** is usually the minimum requirement for entering the engineering profession. Some men and women have been able to enter the profession without a degree after a number of years of experience as machinists, drafters, or engineering technicians. However, they are usually required to take additional college-level training.

Industrial engineers are primarily concerned with the safest and most efficient use of machines, materials, and personnel, **Figure 2-14**. In some instances, an industrial engineer may be responsible for the design of special machinery and equipment to be utilized in manufacturing operations.

Mechanical engineers are normally responsible for the design and development of new machines, devices, and ideas. This engineering specialty is also involved with the redesign of or improvements to existing equipment, **Figure 2-15**. Some mechanical engineers specialize in different types of mechanical systems, such as heating and cooling systems, automotive vehicles, and robotics.

Tool and manufacturing engineers often work with the other engineers. A principal concern of the mechanical engineer is the design and development of the original

*William Schotta, Millersville University*

**Figure 2-12.** This college student may someday teach machine technology. During four or more years of training, she will learn all phases of machine tool operation and programming.

## WORKPLACE SKILLS

### Investigating Education and Training

You will need to consider what educational level is necessary for entering each career you investigate. How much training or experience is needed? Can people enter the field with less training and acquire expertise while working on the job? Are special certificates, licenses, or credentials needed? You can become a machinist through an apprenticeship program, earn a degree from a community college, or earn credentials through the National Institute of Metalworking Skills (NIMS).

Before deciding on a specific career, you may wish to shadow someone who holds the type of job you desire. Job shadowing is the process of observing a person in the workplace to learn more about his or her job and its requirements. In addition, you may seek to have a mentor's assistance. A mentor is someone with greater experience and knowledge who guides you in your career.

You might also consider assisting someone who knows how to do the job tasks well, such as working in an internship or apprenticeship. An internship is an arrangement with an educational institution whereby a student is supervised while working with a more experienced jobholder. An apprenticeship involves learning a trade under the direction and guidance of an expert worker. You also gain valuable experience through working at a part-time job or volunteering at community or charitable organizations.

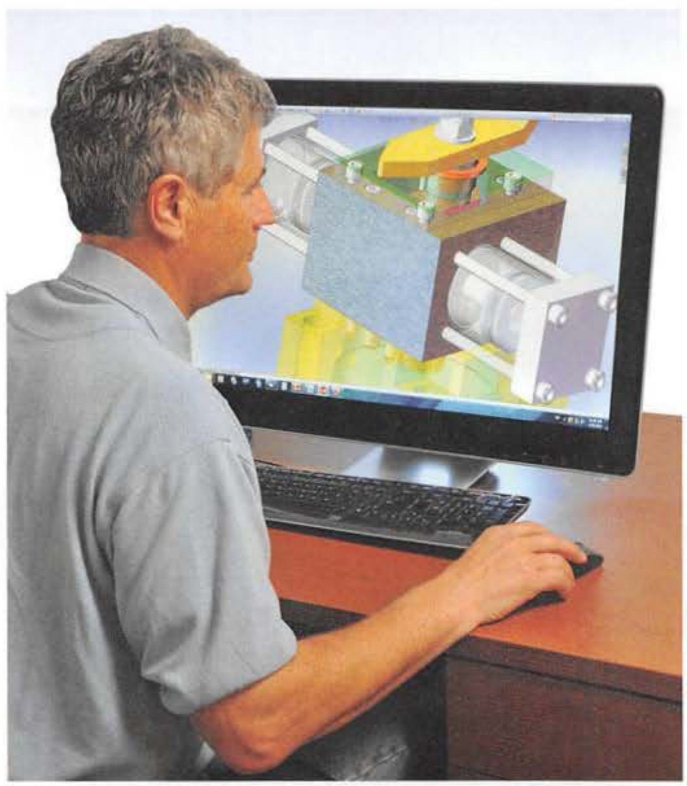
Perhaps your plan of study leads you to acquire a license or become certified. Other programs may require a college degree. An associate's degree is a two-year college degree. A bachelor's degree is a college degree usually requiring four years of study. A master's degree requires another year or two of study beyond a bachelor's degree. A master's degree is also called a graduate degree.

Corepics VOF/Shutterstock.com

**Figure 2-13.** An engineer inspects the rotors of a huge industrial wind turbine that will be used to test the aerodynamic qualities of everything from aircraft to automobiles.

Minerva Studio/Shutterstock.com

**Figure 2-14.** Industrial engineers have many duties. Industrial engineers may be responsible for maintaining a safe work environment, managing workflow, and/or making the most efficient use of the machines and materials.



Chuck Rausin/Shutterstock.com

**Figure 2-15.** Mechanical engineers are responsible for the design and development of new machines, devices, and ideas.

or prototype model. When this model has been thoroughly tested and has met design requirements, the product is turned over to the tool and manufacturing engineer to devise methods and means required to manufacture and assemble the item, **Figure 2-16**.

Metallurgical engineers are involved in the development and testing of metals that are used in products and manufacturing processes. These engineers work closely with manufacturing and mechanical engineers to ensure that the proper materials are specified for new designs.

# 2.2 Preparing to Find a Job in Machining Technology

Machining technology is a technical area with constantly developing new ideas, materials, processes, and manufacturing techniques. This continual development creates new occupational opportunities. A recent study reported that the average graduate will be employed in at least ten different jobs in his or her lifetime, and many of these jobs do not even exist yet!

OSG Tap & Die, Inc.

**Figure 2-16.** Tool and manufacturing engineers devise new methods to manufacture complex products. This engineer is setting up a CNC machine for a new cycle.

## 2.2.1 Obtaining Information on Machining Occupations

There are many sources of occupational information. The most accessible sources include the school's career center, technical education instructors, and the Internet. State employment services are also excellent sources for local and state employment opportunities, as are the various trade unions concerned with the metalworking trades. Information on technical occupations is also available from community colleges. Many of them offer associate's degrees in technical areas.

You may also wish to contact the field and regional offices of the Office of Apprenticeship of the US Department of Labor for information on apprenticeship programs in your area. The *Occupational Outlook Handbook*, available on the US Department of Labor's website and in published formats, describes many specific job categories and estimates the future demand for workers in each occupation. See **Figure 2-17**.

## 2.2.2 Traits Employers Look for in an Employee

Industry is always on the lookout for people who are not afraid to work and assume responsibility. Employers also look for the following traits in an employee, often referring to scholastic records, references, and previous employers to obtain the necessary information:

- **Skills and knowledge.** Has the technical skills and knowledge necessary for an entry position. Does work neatly and accurately. Pays attention to details.
- **Integrity and honesty.** Adheres to company policies, including those related to drugs and alcohol in the workplace. These traits are just as important as technical skills and knowledge.
- **Comprehension.** Is able to understand oral and written instructions and to read and interpret prints.
- **Dependability.** Has a good attendance and punctuality record in class and at former jobs.
- **Teamwork.** Shows the ability to work well with peers and supervisors.
- **Communication.** Has the reading, writing, and speaking skills to effectively communicate ideas.
- **Self-confidence.** Takes pride in work and does not knowingly turn out inferior or substandard material.
- **Accountability.** Is able to assume responsibility and be accountable for his or her actions.
- **Initiative.** Volunteers ideas and demonstrates leadership.
- **Grooming and dress.** Presents a positive personal appearance.

CHAPTER 17

# The Milling Machine

## Chapter Outline



## Learning Objectives

After studying this chapter, you will be able to:
- Identify the various types of milling machines.
- Describe milling operations and methods.
- Select the proper cutter for the job to be done.
- Explain how milling cutters are held and driven on milling machines.
- Calculate cutting speeds and feeds.
- List the purposes of cutting fluids.
- Describe milling work-holding attachments.
- Understand and follow milling safety practices.

## Technical Terms

arbor
climb milling
column-and-knee milling machine
conventional milling
cutting speed
face milling
feed
fixed-bed milling machine
horizontal milling machine
peripheral milling
side milling cutter
vertical milling machine

A milling machine rotates a multitoothed cutter into the workpiece to remove material, **Figure 17-1**. Each tooth of the cutter removes a small, individual chip of material. A variety of cutting operations can be performed on a milling machine. The milling machine is capable of machining flat or contoured surfaces, slots, grooves, recesses, threads, gears, spirals, and other configurations.

Milling machines are available in more variations than any other family of machine tools, **Figure 17-2**. These machines are well suited to computer-controlled operation. Work may be clamped directly to the machine table, held in a fixture, or mounted in or on one of the numerous workholding devices available for milling machines.

## 17.1 Types of Milling Machines

It is difficult to classify the various categories of milling machines because their designs tend to merge with one another. For practical purposes, however, milling machines may be grouped into two large families:

- Fixed-bed milling machines.
- Column-and-knee milling machines.

BIG Kaiser Precision Tooling Inc.

**Figure 17-1.** A milling machine rotates a multitoothed cutter into the workpiece.

Photo courtesy of Grizzly Industrial, Inc. www.grizzly.com

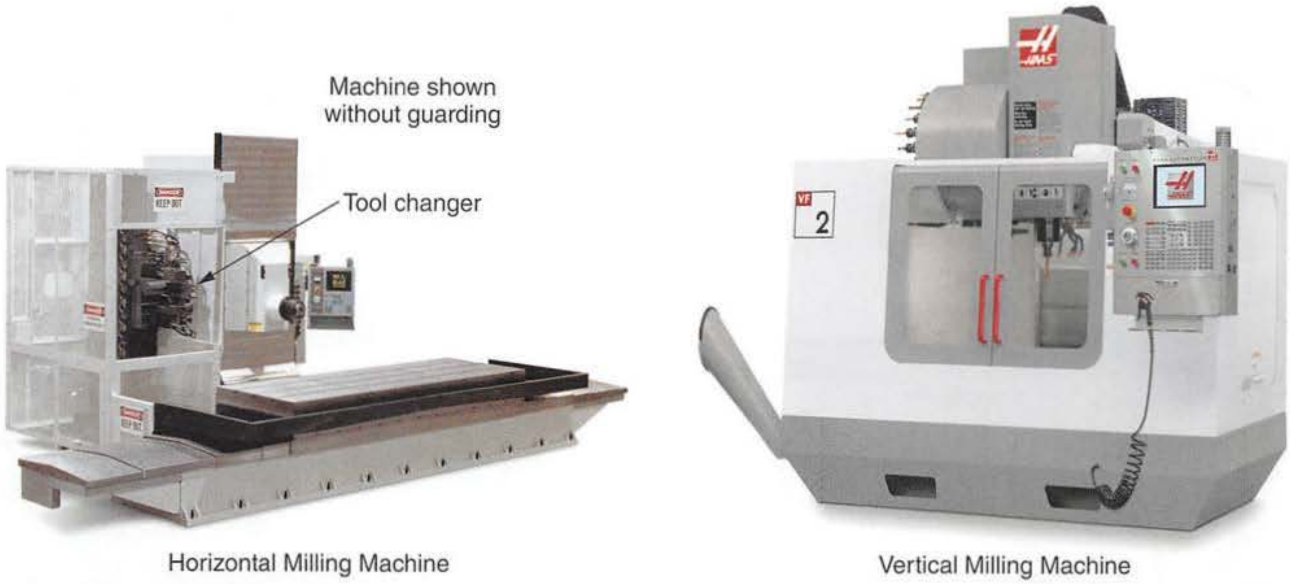
**Figure 17-2.** A knee-type vertical milling machine that incorporates longitudinal and traverse power feeds, digital readout, and a built-in coolant system.

Both groups are made with horizontal or vertical spindles, **Figure 17-3**. On a ***horizontal milling machine***, the cutter is fitted onto an arbor mounted in the machine on an axis parallel with the worktable. Multiple cutters may be mounted on the spindle for some operations.

The cutter on a ***vertical milling machine*** is normally perpendicular (at a right angle) to the worktable. However, on many vertical milling machines, the spindle can be tilted to perform angular cutting operations.

### 17.1.1 Fixed-Bed Milling Machines

***Fixed-bed milling machines*** have a very rigid worktable construction and support, **Figure 17-4**. The worktable moves only in a longitudinal (back and forth/X-axis) direction, and can vary in length from 3′ to 30′ (0.9 to 9.0 m). Vertical (up and down/Z-axis) and cross (in and out/Y-axis) movements are obtained by moving the cutter head.

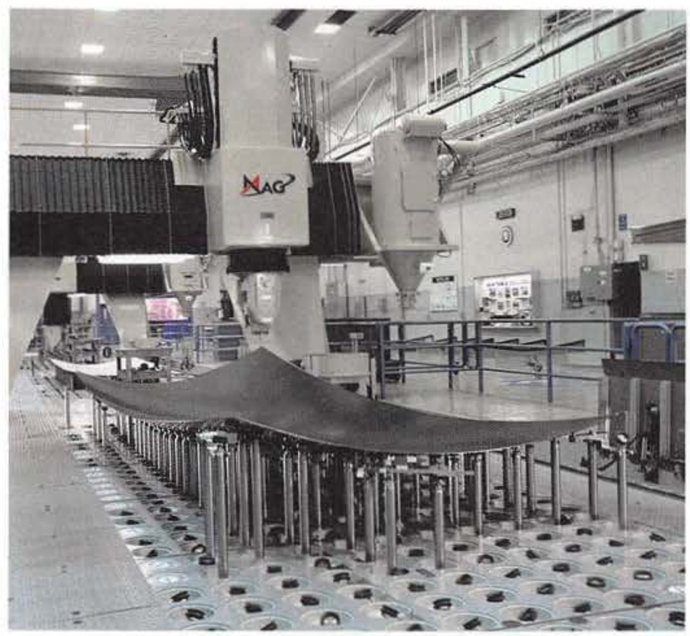



Haas Automation, Inc.

**Figure 17-3.** Horizontal and vertical CNC milling machines.

Autocon Technologies, Inc.

**Figure 17-4.** Fixed-bed or bed mills have a very rigid worktable that moves only in a longitudinal direction. The machine shown can be operated manually or by CNC.



MAG IAS, LLC

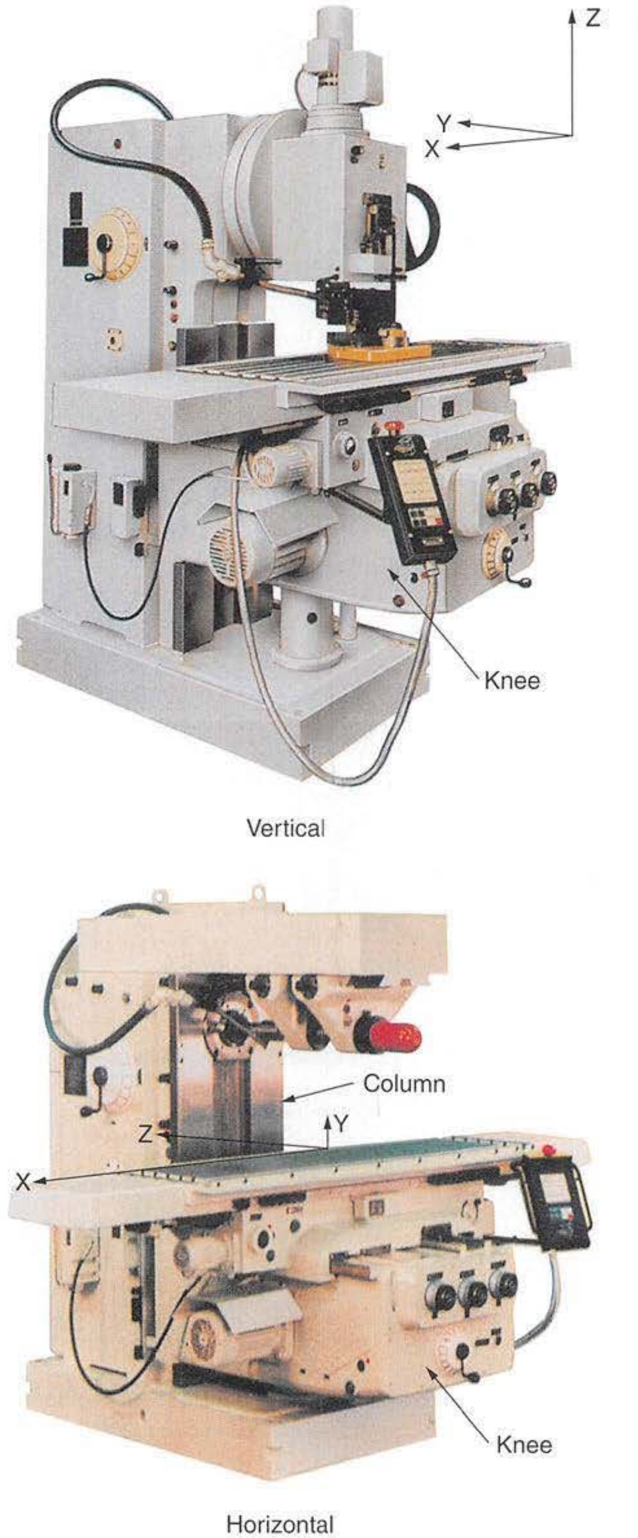
**Figure 17-5.** This large, 5-axis, fixed-bed, vertical profiler milling machine is cutting a contoured section of an aircraft wing skin.

Fixed-bed milling machines can be further classified as horizontal, vertical, or planer machines. The bed permits heavy cutting on large workpieces, **Figure 17-5**.

## 17.1.2 Column-and-Knee Milling Machines

The ***column-and-knee milling machine*** is so named because of the parts that provide movement to the workpiece. They consist of a column that supports and guides the knee in vertical (up and down/Z-axis) movement and a knee that supports the mechanism for obtaining table movements. These movements are traverse (in and out/Y-axis) and longitudinal (back and forth/X-axis). See **Figure 17-6**.

These machines are commonly referred to as *knee-type milling machines*. The three basic categories of knee-type milling machines are plain (horizontal) milling machines, universal milling machines, and vertical milling machines.

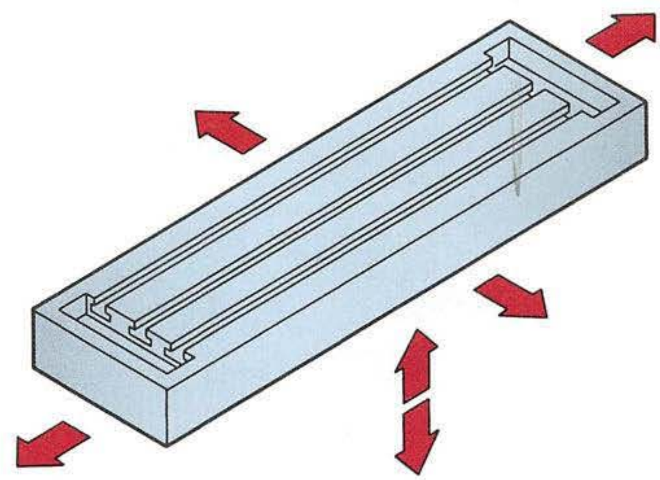



WMW Machinery Company, Inc.

**Figure 17-6.** Column-and-knee milling machines.


Sharp Industries, Inc.

**Figure 17-7.** Plain milling horizontal machine.



Goodheart-Willcox Publisher

**Figure 17-8.** Table movements of a plain horizontal milling machine.

## Plain Milling Machine

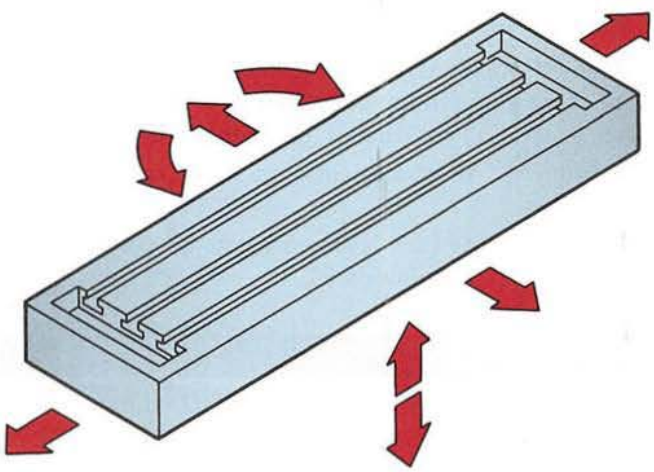
On the plain milling machine, the cutter spindle projects horizontally from the column, **Figure 17-7**. The worktable has three movements: vertical, cross, and longitudinal (X, Y, and Z axes), **Figure 17-8**.

## Universal Milling Machine

A universal milling machine, **Figure 17-9**, is similar to the plain milling machine, but the table has a fourth axis of movement. On this type of machine, the table can be swiveled on the saddle through an angle of 45° or more, **Figure 17-10**. This makes it possible to produce spiral gears, spiral splines, and similar workpieces.

WMW Machinery Company, Inc.

**Figure 17-9.** On a universal horizontal milling machine, the table can be swiveled 45° or more.



Goodheart-Willcox Publisher

**Figure 17-10.** Table movements possible on a universal milling machine.

## Vertical Milling Machine

A vertical milling machine differs from the plain and universal machines in that its cutter spindle is vertical, at a right angle to the top of the worktable. See **Figure 17-11**. The cutter head can be raised and lowered by hand or by power feed. This type of milling machine is best suited for use with an end mill or face mill cutter.

Types of vertical mills include swivel-head, sliding-head, and rotary-head mills. A swivel-head milling machine, **Figure 17-12**, is the type often found in training programs. The spindle can be swiveled for angular cuts.


Rem Sales, Inc.

**Figure 17-11.** The vertical milling machine.

### GREEN MACHINING

#### Cleaning Machined Parts

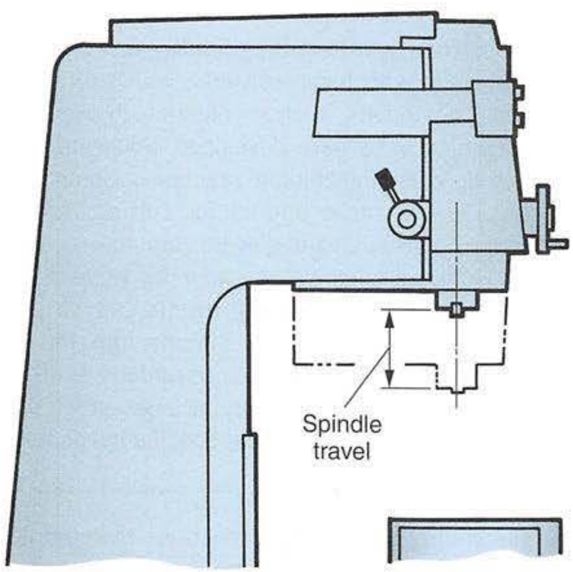
After machining with cutting fluids, parts are traditionally cleaned with harsh solvents, which often contain harmful chemicals, such as chlorine. Newer methods for cleaning parts have developed alongside the push for other green machining practices. Green cleaning options mirror those offered for cutting fluids—eco-friendly, nontoxic cleaning agents are now readily available. Nontoxic cleaners are safer for workers and the environment. These cleaning agents can be disposed of more easily (sometimes directly into the sewage system) because they are less hazardous. With continued support from the industry at large, green cleaning options are expanding to meet specific needs in various machining fields.

On the sliding-head milling machine, the spindle head is fixed in a vertical position. The head can be moved up and down (vertically) by hand or under power, **Figure 17-13**.

The spindle on the rotary-head milling machine can be moved vertically and in circular arcs of adjustable radii about a vertical centerline, **Figure 17-14**. It can be adjusted manually or under power feed.

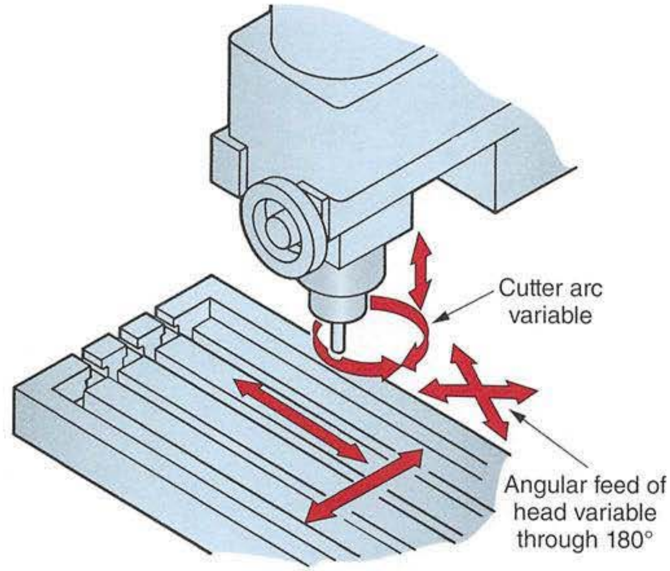

Republic-Lagun Machine Tool Co.

**Figure 17-12.** A typical swivel-head milling machine.




Goodheart-Willcox Publisher

**Figure 17-13.** The spindle head is fixed in a vertical position on a sliding-head milling machine. The entire head is moved to make cutting adjustments.




Goodheart-Willcox Publisher

**Figure 17-14.** Spindle movements possible on a rotary-head vertical milling machine. Milling machines with CNC capabilities are replacing this type of machine.

## 17.1.3 Methods of Milling Machine Control

The method employed to control table movement is another way of classifying milling machines, as well as all machine tools in general. There are four methods of control:

- **Manual.** All movements are made by hand lever control.
- **Semiautomatic.** Movements can be controlled by either hand or power feed.

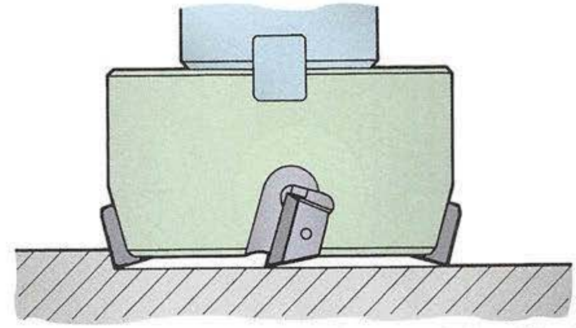
**SAFETY NOTE**

The operator should always verify that all hand cranks and handwheels are disengaged before activating power feed features.

- **Fully automatic.** A complex hydraulic feed arrangement that follows two- or three-dimensional templates to automatically guide one or more cutters. Specifications can also be programmed to guide the cutters and table through the required machining operations.
- **Computerized (CNC).** Machining coordinates are entered into a computer using a programming language. Instructions from the computer operate actuators (electric, hydraulic, or pneumatic devices) that move the table and cutter or cutters through the required machining sequence. Manually operated milling machines can be retrofitted with computerized control systems, **Figure 17-15.**

Autocon Technologies, Inc.

**Figure 17-15.** This manual vertical milling machine was retrofitted with a CNC control unit. The retrofit provides two-axis (X and Y) machine control capabilities and displays depth (Z axis) information on the monitor.



A

Goodheart-Willcox Publisher

B

Sandvik Coromant Co.

**Figure 17-16.** Face milling. A—The surface being machined is parallel with the cutter face. B—An example of face milling.

Small milling machines may have power feed available only for longitudinal table movement. On larger machines, automatic feed or power feed is used for all table movements.

Table movement (feed) can be engaged at cutting speed. However, there is a rapid traverse feed that allows fast power movement in any direction of feed engagement. This permits work to be positioned at several times the fastest rate indicated on the feed chart. The operator positions the automatic power feed control lever to give the desired directional movement and activates the rapid traverse lever.

**SAFETY NOTE**

Never activate rapid traverse while the cutter is positioned in a cut.

## 17.2 Milling Operations

There are two main categories of milling operations. ***Face milling*** is machining performed on a surface that is parallel to the cutter face, **Figure 17-16**. Large, flat surfaces are machined using this technique. ***Peripheral milling,*** also known as *edge milling,* is machining performed on a surface that is parallel with the periphery of the cutter, **Figure 17-17**.

There are also two distinct methods of milling: conventional milling and climb milling. In ***conventional milling,*** also known as *up-milling,* the work is fed into the rotation of the cutter, **Figure 17-18A**. The chip is at minimum thickness at the start of the cut. The cut is so light that the cutter has a tendency to slide over the work until sufficient pressure builds up to cause the teeth to bite into the material. This initial sliding motion, followed by the sudden breakthrough as the tooth completes the cut, leaves the "milling marks" so familiar on many milled surfaces. The marks and ridges can be kept to a minimum by keeping the table gibs properly adjusted.

In ***climb milling*** or *down-milling,* the work moves in the same direction as cutter rotation, **Figure 17-18B**. Full engagement of the cutter tooth is instantaneous. The sliding action of conventional milling is eliminated, resulting in a better finish and longer tool life. The main advantage of climb milling is the tendency of the cutter to press the work down on the worktable or holding device.

Climb milling is not recommended on light machines, nor on large older machines that are not in top condition or

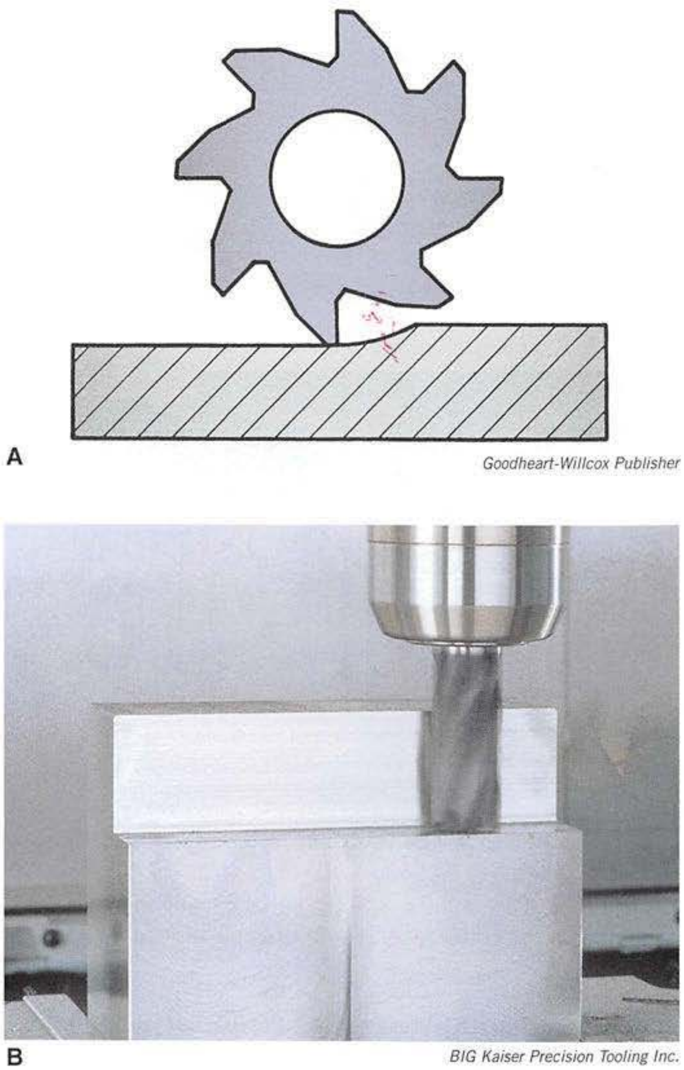



**Figure 17-17.** Peripheral milling. A—In this milling method, the surface being machined is parallel with the periphery of the cutter. B—An example of peripheral milling.

are not fitted with an antibacklash device to take up play. There is danger of a serious accident if there is play in the table, or if the work or work-holding device is not mounted securely.

# 17.3 Milling Cutter Basics

The typical milling cutter is circular in shape with a number of cutting edges (teeth) located around its circumference. Milling cutters are manufactured in a large number of stock shapes, sizes, and kinds. See **Figure 17-19**.

## 17.3.1 Milling Cutter Classification

Milling cutters are often classified by the method used to mount them on the machine. Milling cutters can be mounted directly by their shanks, directly to the spindle nose, or with an arbor. Shank cutters are fitted with either a straight or taper shank that is an integral part of the cutter. They are held in the machine by collets or sleeves. Arbor cutters have a suitable hole for mounting to an arbor.

There are two general types of milling cutters. Solid cutters are made with the shank, body, and cutting edges all in one piece, **Figure 17-20**. Indexable insert cutters have teeth made of a cutting material. The teeth are brazed or clamped in place, **Figure 17-21**. Worn and broken teeth can be replaced easily instead of discarding the entire cutter.

## 17.3.2 Milling Cutter Materials

Considering the wide range of materials that must be machined, the ideal milling cutter should have the following attributes:

- **High abrasion resistance.** The cutting edges should not wear away rapidly due to the abrasive nature of some materials.

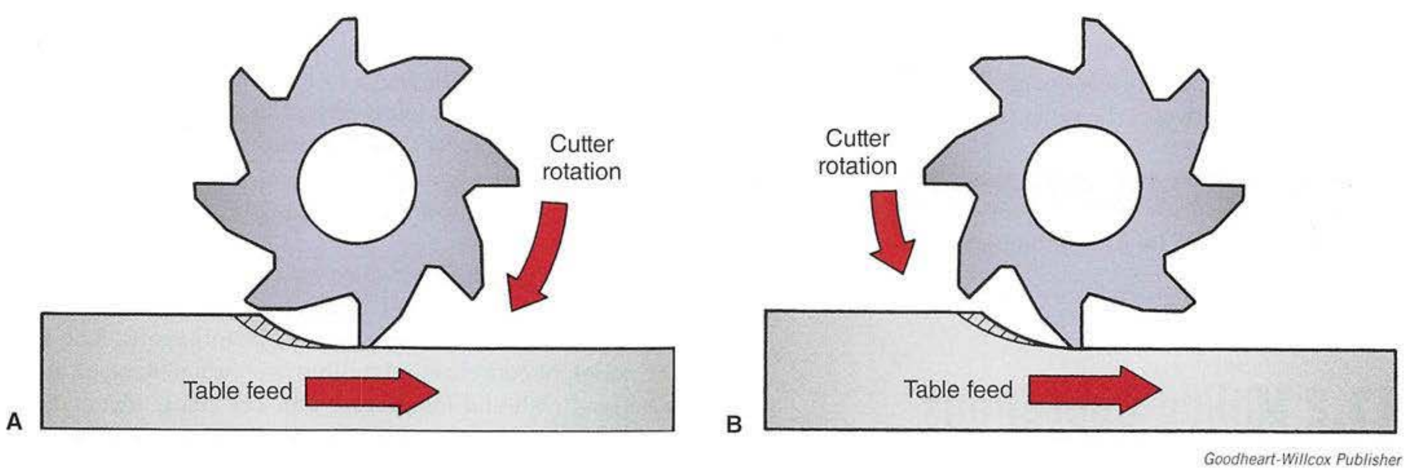
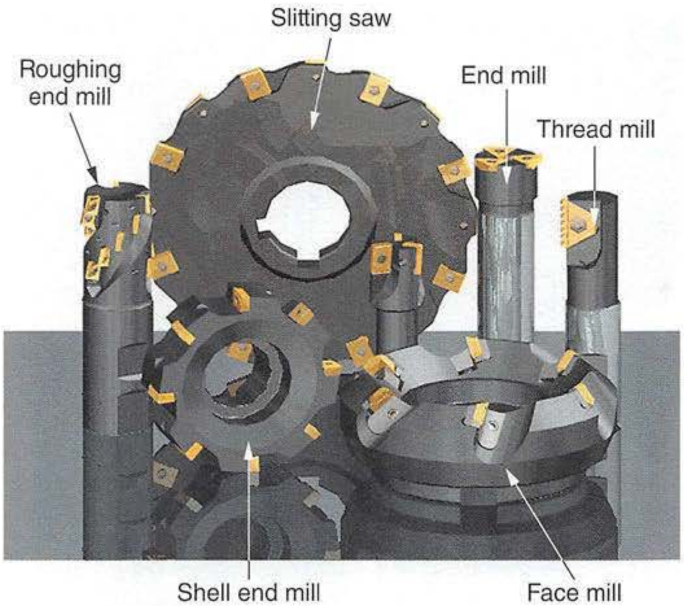



**Figure 17-18.** Milling methods. A—Cutter and work movement in conventional or up-milling. B—Cutter and work movement in climb or down-milling.




Kennametal

**Figure 17-19.** A selection of indexable insert milling cutters.

Photo courtesy of Grizzly Industrial, Inc. www.grizzly.com

**Figure 17-20.** A selection of two- and four-flute HSS solid milling cutters. The gold on the cutters is a titanium nitride (TiN) coating that increases wear resistance and the lifetime of the cutter significantly.

- **Red hardness.** The cutting edges should not be affected by the terrific heat generated by many machining operations.
- **Edge toughness.** The cutting edges should not readily break down due to the loads imposed on them by the cutting operation.

Since no single material can meet these requirements in all situations, cutters are made from materials that are, by necessity, a compromise.

High-speed steels (HSS) are the most versatile cutter materials. Cutters made from HSS are excellent for general-purpose work and where vibration and chatter are problems. They are preferred for use on low-power machines.

HSS milling cutters can be improved by the application of surface lubricating treatments, surface hardening treatments, or coatings (such as chromium, tungsten, or tungsten carbide) to the cutting surfaces. The treated tools cost two to six times as much as conventional HSS tools, but they may last 5% to 10% longer or provide 50% to 100% higher metal removal rates with the same tool life.

Dapra Corporation

**Figure 17-21.** A variety of cutters with indexable carbide inserts. When the cutting edges dull, new cutting edges are rotated into position. The inserts are available in different grades. The grade chosen for a job depends on the material being machined.

Cemented tungsten carbides include a broad family of hard metals. They are produced by powder metallurgy techniques and have qualities that make them suitable for metal cutting tools. Cemented carbides can, in general, be operated at speeds 3 to 10 times faster than conventional HSS cutting tools. Cemented carbide cutters are excellent for long production runs and for milling materials with a scale-like surface, such as cast iron, cast steel, or bronze.

In most cases, only the cutting tips (not the entire cutter) are made of cemented carbides. They are brazed or clamped to the cutter body. See **Figure 17-22**. Most inserted-tooth cutters use indexable inserts. Each insert has several cutting edges. When an edge becomes dull, the insert is indexed (turned) so that a new cutting edge contacts the metal.

## 17.4 Types and Uses of Milling Cutters

Milling cutters are commonly grouped into categories based on their shape and function. Selection of the proper cutting tool is very important to efficient milling operations. The following are the most commonly used milling cutters, with a summary of the work for which they are best suited.

Mitsubishi Materials USA Corporation

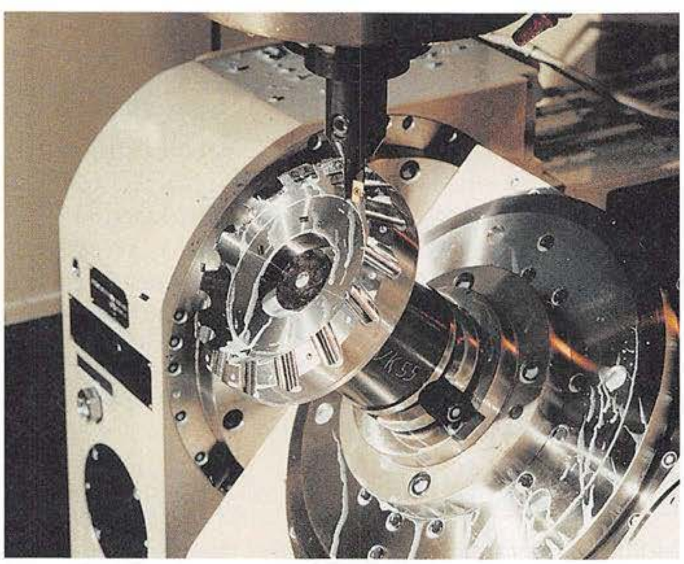
**Figure 17-22.** These inserted-tooth cutters have teeth that are clamped to the cutter body. The cutter teeth (gold in this photo) can be indexed four times to present a fresh cutting edge as they wear.

## 17.4.1 End Mills

End milling cutters are designed for machining slots, keyways, pockets, and similar work, **Figure 17-23**. The cutting edges are on the circumference and end. End mills may have straight or helical flutes, **Figure 17-24**, and have straight or taper shanks, **Figure 17-25**. Straight shank end mills are available in single- and double-end styles, **Figure 17-26**.

The terms *right-hand* and *left-hand* are used to describe the direction of cutter rotation and the helix of the flutes, **Figure 17-27**. When viewed from the cutting end, a right-hand cutter rotates counterclockwise, and a left-hand cutter rotates clockwise.

Ball-nose end mills, **Figure 17-28**, are used for tracer milling, computer-controlled contour milling, die-sinking, fillet milling, and other radius work. A cut with a depth equal to one-half the end mill diameter can generally be taken in solid stock. See **Figure 17-29**.

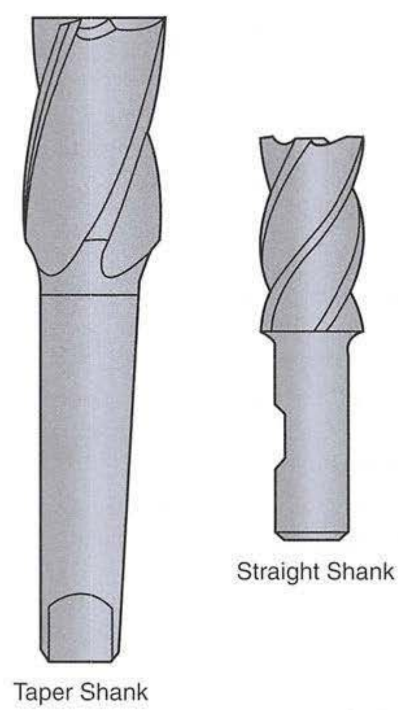


Kennametal

**Figure 17-23.** An indexable-insert end mill cutting clearance slots on a face milling cutter.

Mitsubishi Materials USA Corporation

**Figure 17-24.** End mills with multiple indexable inserts are available with either helical or straight flutes. Two face cutters are also shown.

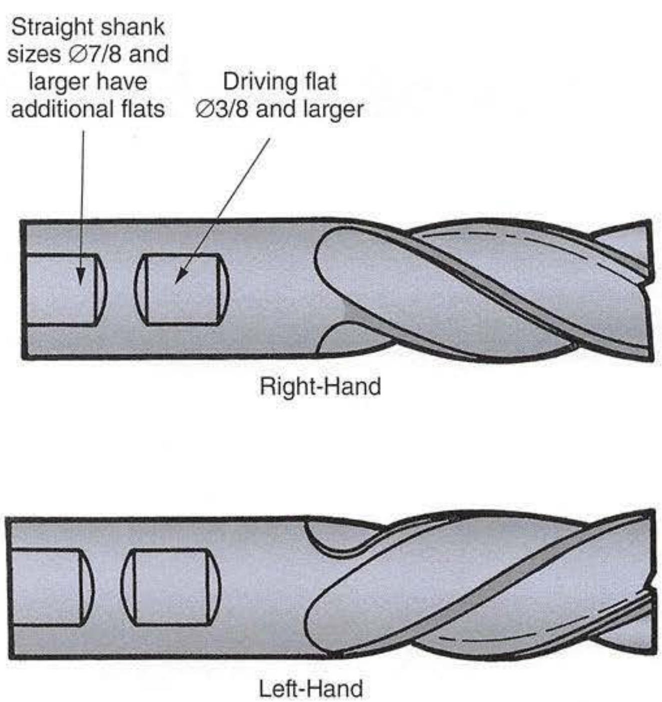



Goodheart-Willcox Publisher

**Figure 17-25.** Straight shank and taper shank end mills.

Goodheart-Willcox Publisher

Figure 17-26. Three large single-end end mills and a smaller double-end end mill.




Goodheart-Willcox Publisher

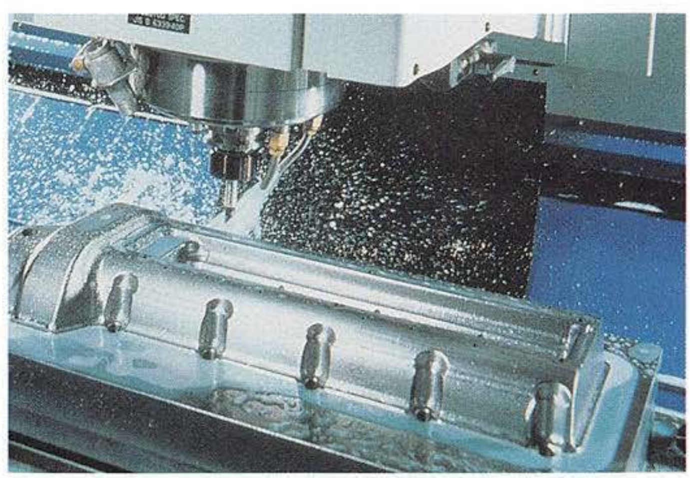
Figure 17-27. A right-hand cutter rotates counterclockwise when viewed from the cutting end. A left-hand cutter rotates clockwise.

Several end mill styles are available, including:

- **Two-flute end mill.** Can be fed into the work like a drill. It has two cutting edges on the circumference, with the end teeth cut to the center, **Figure 17-30**.
- **Multiflute end mill.** Can be run at the same speed and feed as a comparable two-flute end mill, but has a longer cutting life and produces a better finish. It is recommended for conventional milling when plunge cutting (feeding into the work like a twist drill) is not necessary. See **Figure 17-31**.
- **Shell end mill.** Has teeth similar to those on a multiflute end mill but is mounted on a stub arbor, **Figure 17-32**. The cutter is designed for both face and end milling. Shell end mills are made with right-hand cut/right-hand helix or with left-hand cut/left-hand helix.

Mitsubishi Materials USA Corporation

Figure 17-28. A ball-nose end mill has a rounded tip. These mills have two replaceable cutting inserts.



Delcam International

Figure 17-29. A ball-nose end mill being used for three-dimensional milling.

Goodheart-Willcox Publisher

**Figure 17-30.** The two-flute end mill can be fed into work like a drill.

Goodheart-Willcox Publisher

**Figure 17-31.** Multiflute end mills. The peripheral grooves in the cutter at right reduce chip size, lowering cutting forces. Most modern cutters have a nitride coating that improves resistance to abrasive wear and corrosion.

Goodheart-Willcox Publisher

**Figure 17-32.** Three indexable insert shell end mills.

# CAREER CONNECTION

## Industrial Machinery Mechanic

### What does an industrial machinery mechanic do?

The machinery in any manufacturing area requires routine and expert service from professionals trained in the maintenance and repair of these machines. These professionals may be called *industrial machinery mechanics, maintenance workers*, or *millwrights*. Manufacturing machinery layouts change regularly to meet the needs of production.

### What education and skills are needed to be an industrial machinery mechanic?

Candidates for industrial mechanic positions need at least a high school diploma and some additional technical training. Relevant courses include computer programming, electronics, mechanical drawing, mathematics, physics, welding, and print reading. Some community colleges also offer associate's degree programs in industrial maintenance.

### What is it like to be an industrial machinery mechanic?

Industrial machinery mechanics often work in manufacturing environments that depend heavily on machinery, such as factories, power plants, and refineries. Each facility will have its own schedule of shifts, so work hours may vary. Due to exposure to manufacturing and machining hazards, this work can be dangerous. Follow all safety procedures and wear recommended personal protective equipment to avoid injury or illness.

According to the *Occupational Outlook Handbook*, over half of the industrial mechanics in the United States are employed by manufacturing industries. Their median annual wage is $49,600.

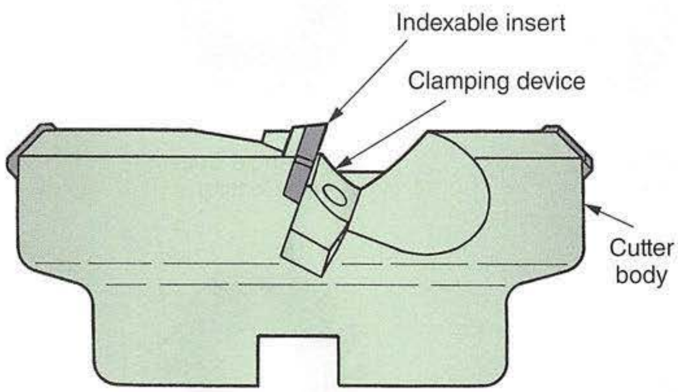
## 17.4.2 Face Milling Cutters

Face milling cutters are used to machine large, flat surfaces parallel to the face of the cutter, **Figure 17-33**. The teeth are designed to make roughing and finishing cuts in one operation. Because of their size and cost, most face milling cutters have inserted cutting edges. See **Figure 17-34**. Facing cutters can be mounted directly to a machine's spindle nose or on a stub arbor.

A fly cutter is a single-point cutting tool used as a face mill. An example is shown in **Figure 17-35**. Fly cutters are capable of machining very fine surface finishes. Fly cutters should not be used to make heavy roughing cuts.

## 17.4.3 Arbor Milling Cutters

Common arbor milling cutters include plain milling cutters, side milling cutters, angle cutters, metal-slitting saws, and formed milling cutters. Each of these types is described in the following sections. Refer to **Figure 17-36**.




Goodheart-Willcox Publisher

A

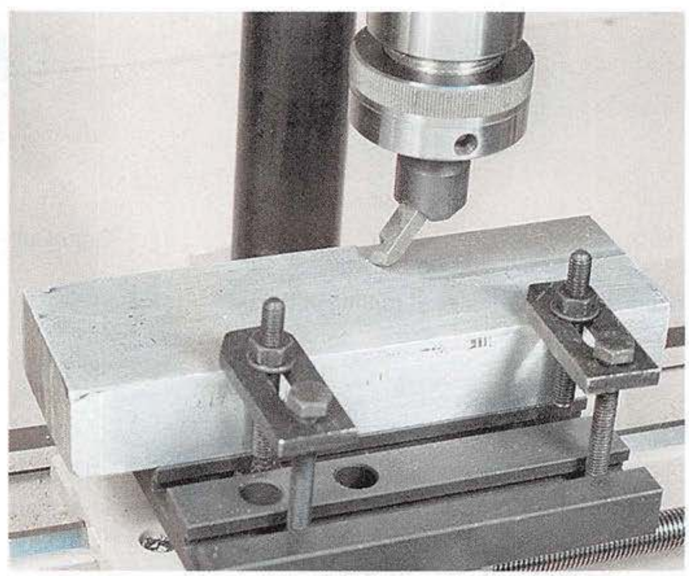
B

Mitsubishi Materials USA Corporation

**Figure 17-33.** Face mill with indexable inserts. A—The replaceable inserts are mechanically clamped in place on the cutter body. As cutting edges wear, the inserts can be turned (indexed) to present a fresh cutting edge. B—An example of a face mill with indexable inserts. Insert selection is based on the material to be machined.

Valenite, Inc.

**Figure 17-34.** This face milling cutter has an unusual design, making use of bearing-mounted inserts that rotate as they cut. The manufacturer claims that the better heat dissipation provided by the rotating inserts increases cutter life and permits higher cutting speeds.



Goodheart-Willcox Publisher

**Figure 17-35.** The fly cutter is a single-point cutting tool used for face milling.


**Figure 17-36.** Examples of milling cutters.

## Plain Milling Cutter

Plain milling cutters are cylindrical, with teeth located around their circumference. Plain milling cutters less than 3/4″ (20 mm) are made with straight teeth. Wider plain cutters, called *slab cutters*, are made with helical teeth designed to cut with a shearing action. This reduces the tendency for the cutter to chatter.

The different designs of plain milling cutters serve different purposes, as follows:

- **Light-duty plain milling cutter.** Used chiefly for light slabbing cuts and shallow slots.
- **Heavy-duty plain milling cutter.** Recommended for heavy cuts when considerable material must be removed.

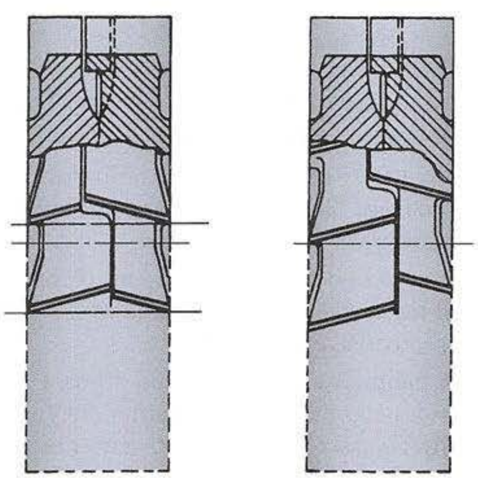
It has fewer teeth than a comparable light-duty cutter. The cutting edges are better supported, and chip spaces are ample to handle the larger volume of chips.

- **Helical plain milling cutter.** Has fewer teeth than either of the two previously mentioned cutters. The helical cutter can be run at high speeds and produces exceptionally smooth finishes.

## Side Milling Cutter

Cutting edges are located on the circumference and on one or both sides of ***side milling cutters***. They are made in solid form or with inserted teeth. Types of side milling cutters include the following:

- **Plain side milling cutter.** The teeth are on the circumference and on both sides of the cutter. It is recommended for side cutting, straddle milling, and slotting. Plain side milling cutters are available in diameters ranging from 2″ (50 mm) to 8″ (200 mm) and in widths from 3/16″ (5 mm) to 1″ (25 mm).
- **Staggered-tooth side milling cutter.** Has alternating right-hand and left-hand helical teeth that help reduce chatter. They also provide adequate chip clearance for higher operating speeds and feeds than are possible with the plain side milling cutter. This type of cutter is especially good for machining deep slots.
- **Half side milling cutter.** Has helical teeth on the circumference but side teeth on one side only. It is made as a right-hand or left-hand cutter, and it is recommended for heavy straddle milling and milling to a shoulder.
- **Interlocking side milling cutter.** This cutter is ideally suited for milling slots or bosses and for making other types of cuts that must be held to extremely close tolerances. The unit is made as two cutters with interlocking teeth that can be adjusted to the required width using spacers or collars, **Figure 17-37**. The alternating right and left shearing action eliminates side pressures, producing a good surface finish.



Morse Tool Co.

**Figure 17-37.** Tooth pattern on interlocking side milling cutters.

## Angle Cutters

Angle cutters differ from other cutters in that the cutting edges are neither parallel nor at right angles to the cutter axis.

- **Single-angle milling cutter.** Teeth are on the angular face and on the side adjacent to the large diameter. Single-angle cutters are made in both right-hand and left-hand cut, with included angles of 45° and 60°.
- **Double-angle milling cutter.** Used to mill threads, notches, serrations, and similar work. Double-angle cutters are manufactured with included angles of 45°, 60°, and 90°. Other angles can be special-ordered.

## Metal-Slitting Saws

Metal-slitting saws are thin milling cutters that resemble circular saw blades. They are employed for narrow slotting and cutoff operations. Slitting saws are available in diameters as small as 2 1/2″ (60 mm) and as large as 8″ (200 mm).

- **Plain metal-slitting saw.** Used for ordinary slotting and cutoff operations. It is essentially a thin plain milling cutter. Both sides are ground concave for clearance. The hub is the same thickness as the cutting edge. It is stocked in thicknesses ranging from 1/32″ (0.8 mm) to 3/16″ (5 mm).
- **Side chip clearance slitting saw.** Similar to the plain side milling cutter, this saw is especially suitable for deep slotting and sawing applications because of its ample chip clearance.

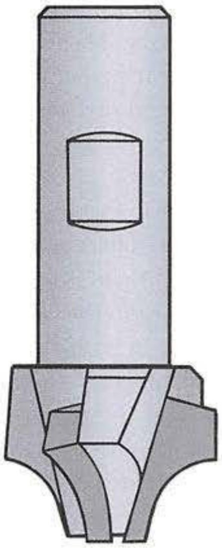
## Formed Milling Cutters

Formed milling cutters are used to accurately duplicate a required contour. A wide range of shapes can be machined with the standard cutters available. See **Figure 17-38**. Included in this cutter classification are the concave cutter, convex cutter, corner-rounding cutter, and gear cutter.

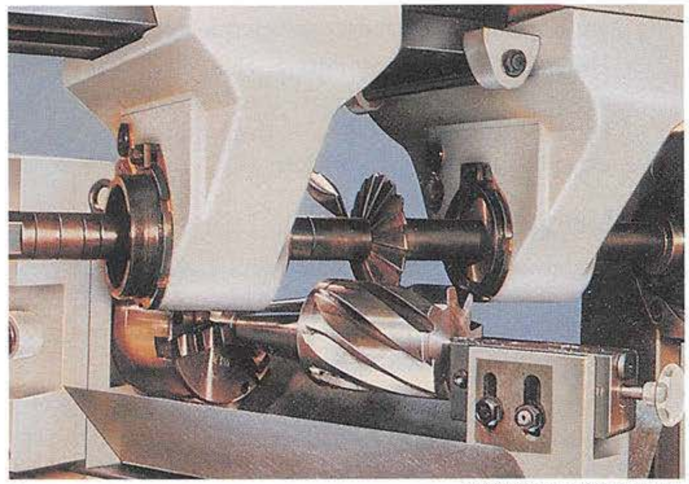
# 17.4.4 Miscellaneous Milling Cutters

Some milling cutters commonly used in industry do not fit into any of the previously mentioned groups. These cutters include:

- **T-slot milling cutter.** Has cutting edges for milling the bottoms of T-slots after they have been cut with an end mill or side cutter, **Figure 17-39**.
- **Woodruff keyseat cutter.** Used to mill the semicircular keyseat for a Woodruff key.
- **Dovetail cutter.** Used to mill dovetail ways and is used in much the same manner as the T-slot cutter. See **Figure 17-40**.

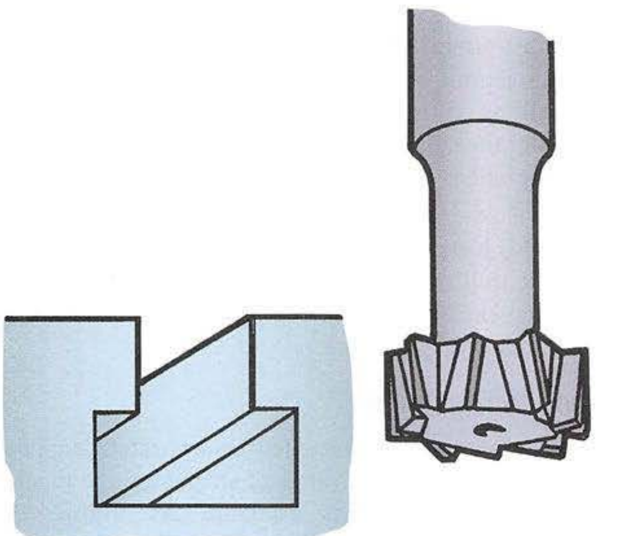


A Goodheart-Willcox Publisher



B WMW Machinery Company, Inc.

**Figure 17-38.** Formed milling cutters. A—Corner-rounding end mill with replaceable tungsten carbide cutting edges. B—Gear cutter. Note that the table is swiveled at an angle to the cutting tool. This feature makes it possible to machine helical-flute workpieces like the one being cut.



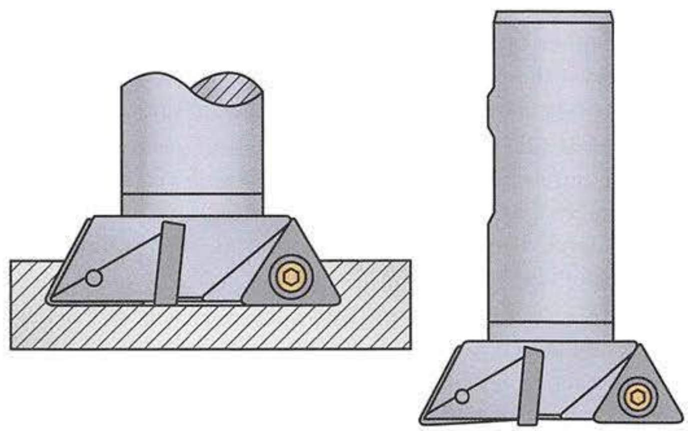
Goodheart-Willcox Publisher

**Figure 17-39.** A T-slot milling cutter and the cut it produces.

## 17.4.5 Care of Milling Cutters

Milling cutters are expensive and can be easily damaged if care is not taken in their use and storage. The following recommendations will help extend cutter life:

- Use sharp cutting tools. Machining with dull tools results in low-quality work and eventually damages the cutting edges to such an extent that they cannot be salvaged by grinding.
- Properly support tools and make sure the work is held rigidly.
- Use the correct cutting speed and feed for the material being machined.



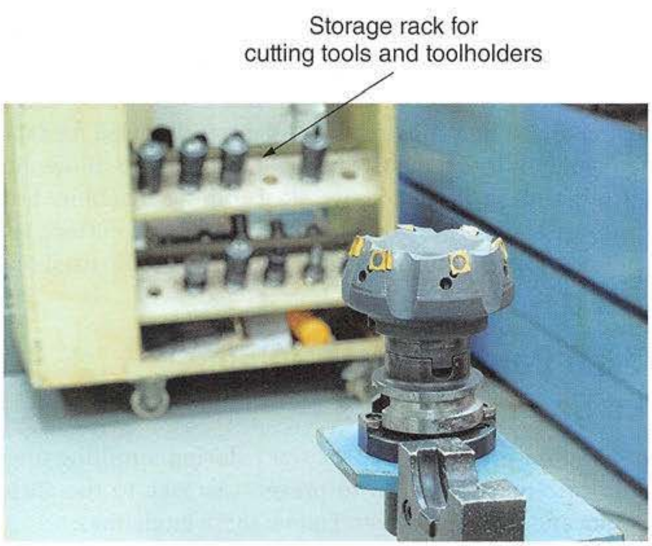
Goodheart-Willcox Publisher

**Figure 17-40.** A dovetail cutter with indexable insert cutting edges.

- Ensure an ample supply of cutting fluid, **Figure 17-41.**
- Use the correct cutter for the job.
- Store cutters in individual compartments or on wooden pegs. They should never come in contact with other cutters or tools. See **Figure 17-42.**
- Clean cutters before storing them. If they are to be stored for any length of time, it is best to give them a light protective coating of oil.
- Never hammer a cutter onto an arbor. Examine the arbor for nicks or burrs if the cutter does not slip onto it easily. Do not forget to key the cutter to the arbor.
- Place a wooden board under an end mill when removing it from a vertical milling machine. This will prevent cutter damage if it is dropped accidentally. Protect your hand with a heavy cloth or gloves.

Sharnoa Corp.

**Figure 17-41.** Rigidly supported cutters permit heavier cuts and prolong cutter life. An ample supply of cutting fluid is essential.




PathomP/Shutterstock.com

**Figure 17-42.** Store cutters in a rack or in individual compartments so that they are not in contact with other tools.

## 17.5 Holding and Driving Cutters

An ***arbor*** is a device used to hold and drive cutters on metalworking machines. Arbors are made in a number of sizes and styles.

### 17.5.1 Arbor Styles

Arbors with self-holding tapers were used on some small hand milling machines and on older models of larger millers, but these are seldom used now. There are three basic arbor styles in general use today, **Figure 17-43**:

- Style A is fitted with a small pilot end that runs in a bronze bearing in the arbor support. This style is best used when maximum arbor support clearance is required.
- Style B has a large bearing collar that can be positioned on any part of the arbor. This feature permits heavy cuts by allowing the bearing support to be mounted as close to the cutter as possible for maximum cutter support.
- Style C is used to hold smaller sizes of shell end and face milling cutters that cannot be mounted directly to the spindle nose.

In general, use the shortest arbor possible that will permit adequate clearance between the arbor support and the work.

Both style A and style B arbors have a keyway milled their entire length. This allows a key to be used to prevent the cutter from revolving on the arbor. See **Figure 17-44**.

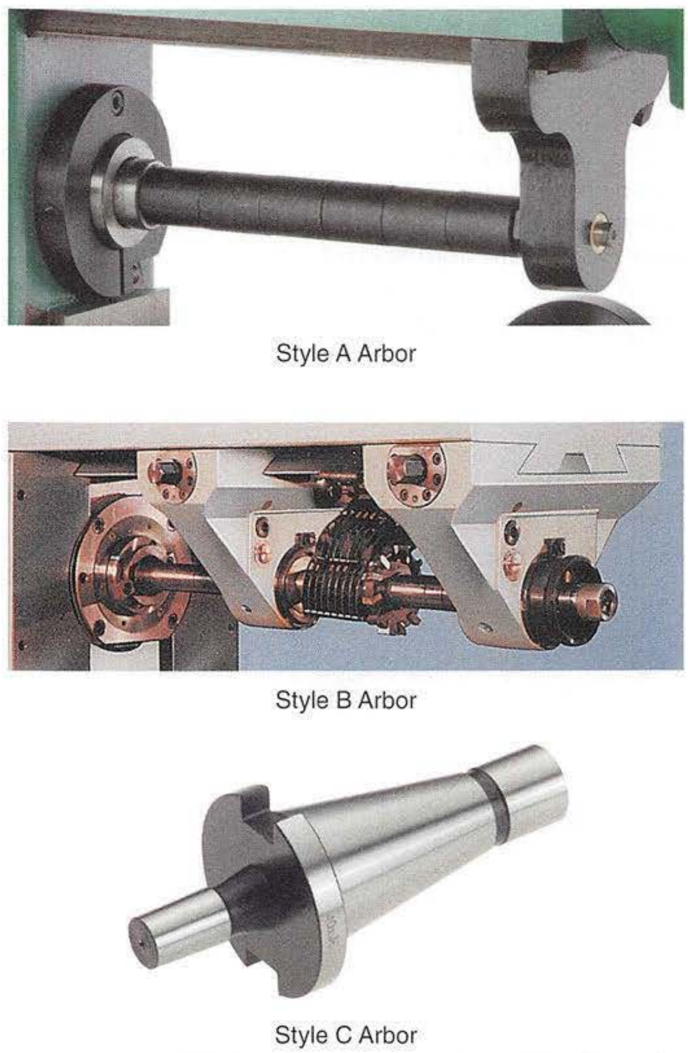
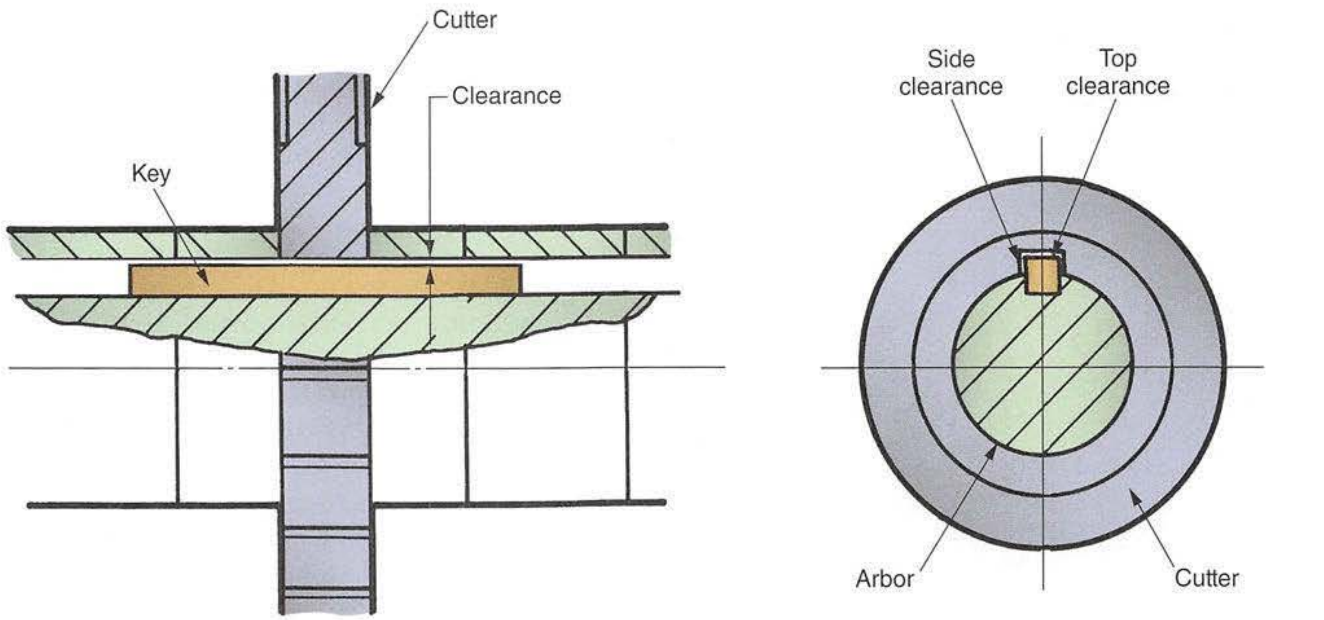



Photo courtesy of Grizzly Industrial, Inc. www.grizzly.com; WMW Machinery Company, Inc.

**Figure 17-43.** Basic arbor styles.




Goodheart-Willcox Publisher

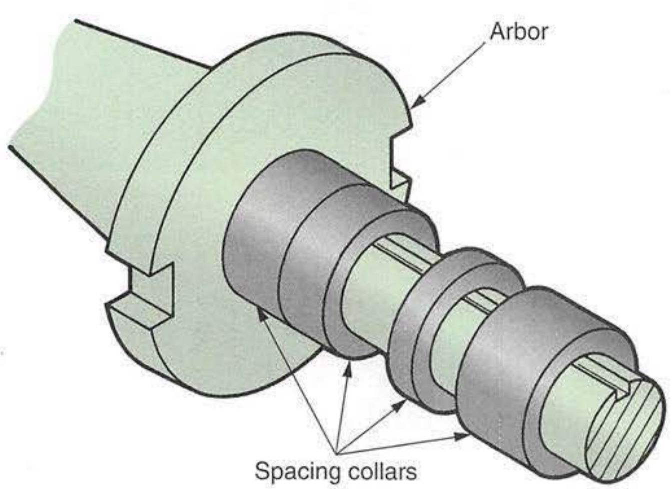
**Figure 17-44.** Keying the cutter to the arbor prevents it from slipping during the cutting operation.

## 17.5.2 Other Holding Devices

Accurately made in a number of widths, spacing collars allow two or more cutters to be precisely spaced for gang and saddle milling, **Figure 17-45.** A left-hand threaded nut tightens the cutter and collars on the arbor. The nut should not be tightened directly against the bearing collar on the style B arbor, because the bearing may be damaged.

A draw-in bar is used on most vertical and horizontal milling machines, **Figure 17-46.** It fits through the spindle and screws into the arbor or collet to hold it firmly on the spindle. Drive keys on the nose of the spindle fit into corresponding slots on the arbor, collet, or collet holder to provide positive (nonslip) drive.

End mills may be mounted in spring collets, adapters, shell end mill holders, or stub arbors, depending on the type of work to be done. See **Figure 17-47.** Spring collets accommodate straight shank end mills and drills. Some collets must be fitted in a collet chuck. Adapters are used for taper shank end mills and drills. Shell end mill holders allow shell end mills to be fitted to a vertical milling machine. Stub arbors are short arbors that permit various side cutters, slitting saws, formed cutters, and angle cutters to be used on a vertical mill.



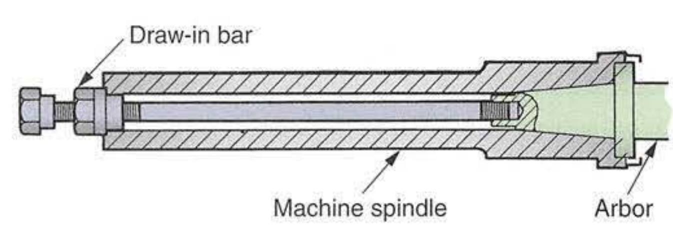

Goodheart-Willcox Publisher

**Figure 17-45.** Spacing collars are manufactured in many different widths. They are used to position one or more cutters on the arbor.

## 17.5.3 Care of Cutter Holding and Driving Devices

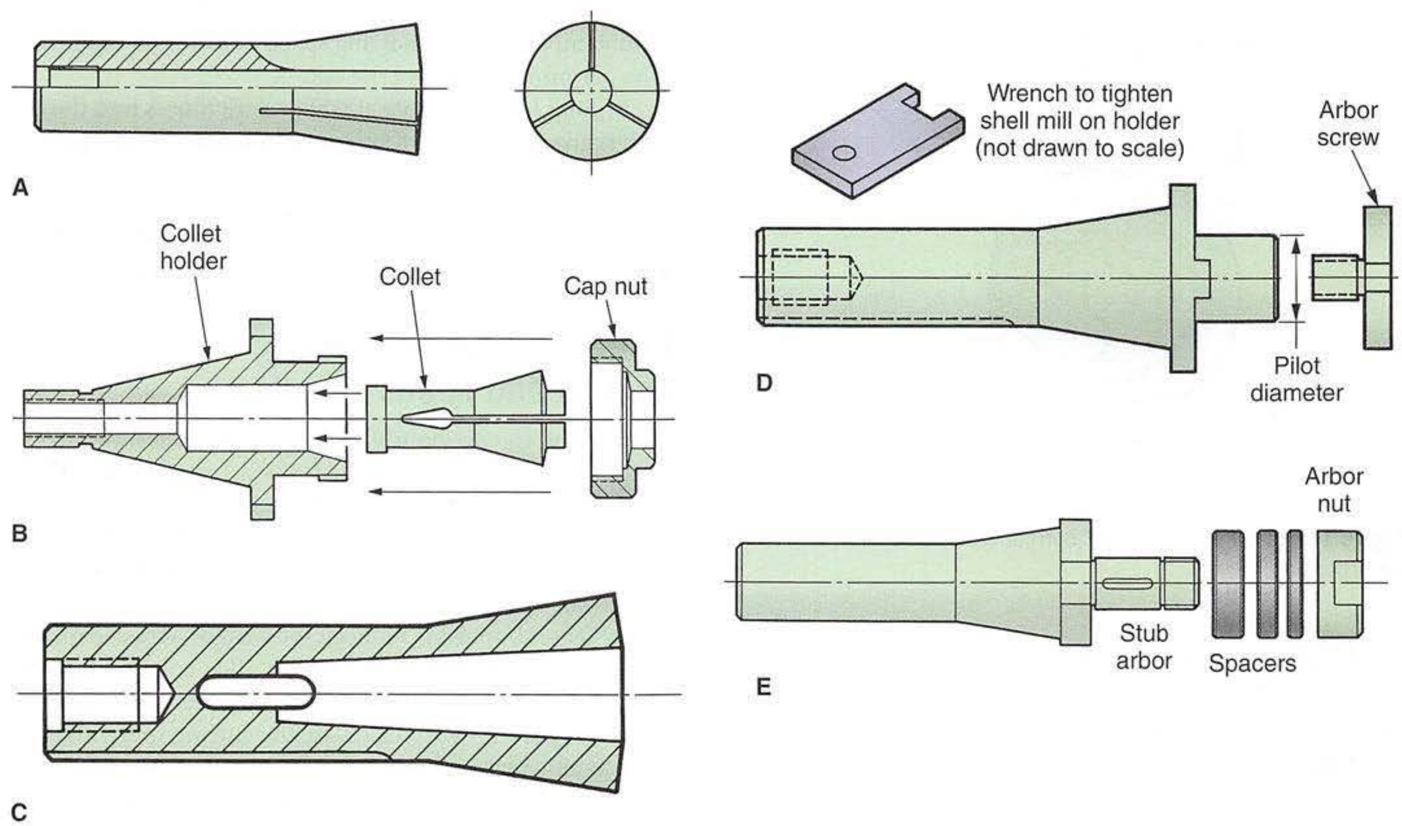
To maintain precision and accuracy during a milling operation, care must be taken to prevent damage to the cutter holding and driving devices. Follow these guidelines:

- Keep the taper end of the arbor and the spindle taper clean and free of nicks.




Goodheart-Willcox Publisher

**Figure 17-46.** The draw-in bar holds the arbor on the spindle. Avoid operating a milling machine if the arbor is not held in place with a draw-in bar.



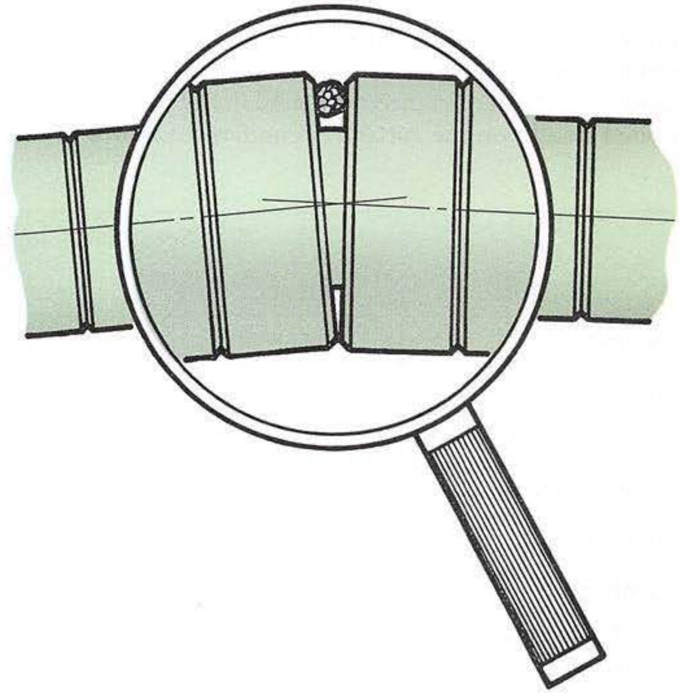

Goodheart-Willcox Publisher

**Figure 17-47.** Mounting devices. A—Spring collet (R-8 taper). B—Collet chuck and collet. C—Adapter used with taper shank cutting tools. D—Shell end mill holder (R-8 taper). E—Stub arbor (R-8 taper).

- Clean and lubricate the bearing sleeve before placing the arbor support on it, and make sure the bearing sleeve fits snugly.
- Clean the spacing collars before slipping them onto an arbor, **Figure 17-48**. Otherwise, cutter runout will occur, making it difficult to make an accurate cut.
- Store arbors separately and in a vertical position.
- Never loosen or tighten an arbor nut unless the arbor support is locked in place, because this could spring the arbor so that it will not run true.
- Use a wrench of the correct size on the arbor nut, **Figure 17-49**. Make sure at least four threads are engaged before tightening the arbor nut.
- Avoid tightening an arbor nut by striking the wrench with a hammer or mallet. This can crack the nut and distort the threads.
- Do not force a cutter onto an arbor. Check to see what is making it difficult to slide on. Correct any problem.
- Key all cutters to the arbor.

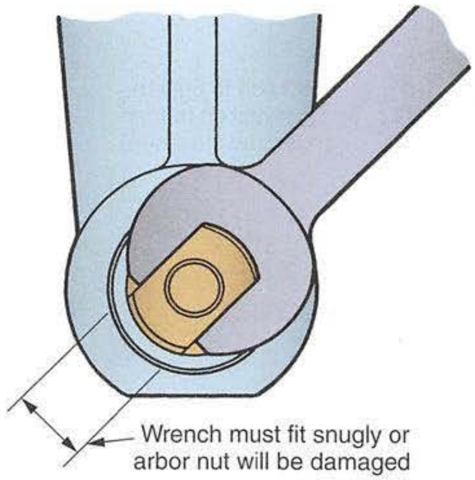
To remove an arbor or adapter from the machine:

1. Loosen the draw-in bar nut a few turns. Do not remove it from the arbor completely.
2. Tap the draw-in bar with a lead hammer to loosen the arbor in the spindle.



Goodheart-Willcox Publisher

**Figure 17-48.** A chip between spacing collars can cause an arbor to be sprung out of true. The end in the arbor is greatly exaggerated in this drawing.




Goodheart-Willcox Publisher

**Figure 17-49.** Use a wrench of correct type and size to loosen an arbor nut.

3. Hold the loosened arbor with one hand and unscrew the draw-in bar with the other.
4. Remove the arbor from the spindle. Clean and store it properly.

## 17.6 Milling Cutting Speeds and Feeds

The time required to complete a milling operation and the quality of the finish is almost completely governed by the cutting speed and feed rate of the cutter. Milling ***cutting speed*** refers to the distance, measured in feet or meters, that a point (tooth) on the cutter's circumference moves in one minute. It is expressed in feet per minute (fpm) or meters per minute (mpm). Milling cutting speed depends on the revolutions per minute (rpm) of the cutter.

Milling ***feed*** is the rate at which work moves into the cutter. It is given in feed per tooth per revolution (ftr). Proper feed rate is probably the most difficult setting for a machinist to determine. In view of the many variables (width of cut, depth of cut, machine condition, cutter sharpness), feed should be as coarse as possible, consistent with the desired finish.

### 17.6.1 Calculating Cutting Speeds and Feeds

Considering the previously mentioned variables, the speeds listed in **Figure 17-50**, and the feeds listed in **Figure 17-51**, are suggested. The usual procedure is to start with the mid-range figure and increase or decrease speeds until the most satisfactory combination is obtained, consistent with cutter life and surface quality.

In general, speed is reduced for hard or abrasive materials, deep cuts, and metals with high alloy content. Speed is increased for soft materials, better finishes, and light cuts. Refer to **Figure 17-52** to calculate the cutting speed and feed for a specific material.

**Example Problem:** Determine the approximate cutting speed and feed for a 6″ (152 mm) diameter side cutter (HSS) with 16 teeth, when milling free cutting steel.

**Information Available:**

Recommended cutting speed for free cutting steel (midpoint in range) = 200 fpm

Recommended feed per tooth (midpoint in range) = 0.008″

Cutter diameter = 6″

Number of teeth on cutter = 16

| Material | High-Speed Steel Cutter | | Carbide Cutter | |
|---|---|---|---|---|
| | Feet per Minute | Meters per Minute* | Feet per Minute | Meters per Minute* |
| Aluminum | 550–100 | 170–300 | 2200–4000 | 670–1200 |
| Brass | 250–650 | 75–200 | 1000–2600 | 300–800 |
| Low-Carbon Steel | 100–325 | 30–100 | 400–1300 | 120–400 |
| Free-Cutting Steel | 150–250 | 45–75 | 600–1000 | 180–300 |
| Alloy Steel | 70–175 | 20–50 | 280–700 | 85–210 |
| Cast Iron | 45–60 | 15–20 | 180–240 | 55–75 |

Reduce speeds for hard materials, abrasive materials, deep cuts, and high alloy materials. Increase speeds for soft materials, better finishes, light cuts, frail work, and setups. Start at midpoint on the range and increase or decrease speed until best results are obtained.

*Figures rounded off.

Goodheart-Willcox Publisher

**Figure 17-50.** Recommended cutting speeds for milling. Speed is given in surface feet per minute (fpm) and in surface meters per minute (mpm).

CHAPTER **19**

# Precision Grinding

## Chapter Outline



## Learning Objectives

After studying this chapter, you will be able to:
- Explain how precision grinders operate.
- Identify the various types of precision grinding machines.
- Describe the work-holding devices used with surface grinders.
- Select, dress, and true grinding wheels.
- Identify types of cutting fluids used in grinding operations.
- Safely operate a surface grinder using various work-holding devices.
- Solve common surface grinding problems.
- List safety rules related to precision grinding.
- Identify other types of precision grinding operations, including cutter sharpening, cylindrical grinding, internal grinding, centerless grinding, form grinding, and other grinding techniques.

## Technical Terms

centerless grinding
creep grinding
dwell
electrolytic grinding
form grinding
internal grinding
platens
plunge grinding
precision grinding
tooth rest
traverse grinding
universal tool and cutter grinder

Grinding, like milling, drilling, sawing, and turning, is a cutting operation. However, instead of using one, two, or several cutting edges, grinding makes use of an abrasive tool composed of thousands of cutting edges. See **Figure 19-1**. Since each of the abrasive particles is actually a separate cutting edge, the grinding wheel might be compared to a many-toothed milling cutter.

In ***precision grinding***, each abrasive grain removes a minute amount of material. It is one of the few machining operations that can produce a smooth, accurate surface on material regardless of its hardness. Grinding is frequently used as a finishing operation.

## 19.1 Types of Surface Grinders

Although all grinding operations might be called *surface grinding* because all grinding is done on the surface of the material, industry classifies surface grinding as the grinding of flat surfaces. There are two basic types of surface grinding machines:

- Planer surface grinders use a reciprocating motion to move the worktable back and forth under the grinding wheel. Three variations of planer surface grinding are illustrated in **Figure 19-2**.
- Rotary surface grinders have circular worktables that revolve under the rotating grinding wheel. Two variations of the technique are shown in **Figure 19-3**.

The planer surface grinder is frequently found in training situations. It slides the work back and forth under the edge of the grinding wheel. Table movement can be controlled manually or by means of a mechanical or hydraulic drive mechanism.

On a manually operated machine, all work and grinding wheel movements are made by hand. The large traverse handwheel moves the table to the left and right. The smaller cross-feed handwheel moves the table in and out. The down-feed handwheel moves the grinding wheel up and down. This handwheel is located on the top of the vertical column.

Variations of this type of surface grinder can be run manually or automatically. To prepare the machine for automatic operation, the operator simply fills in the blanks when requested by the menu prompts. No computer or CNC experience is needed. As the operator creates the part manually,

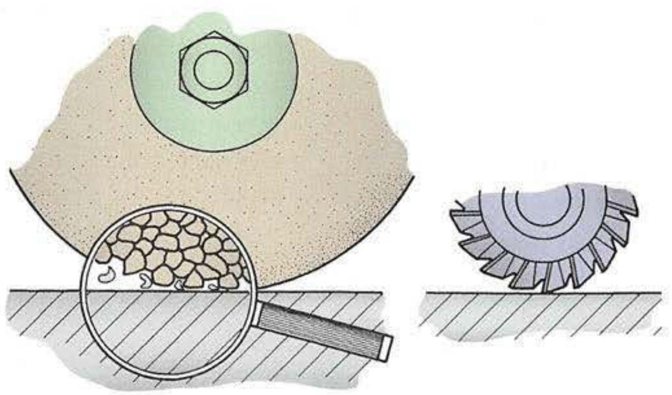
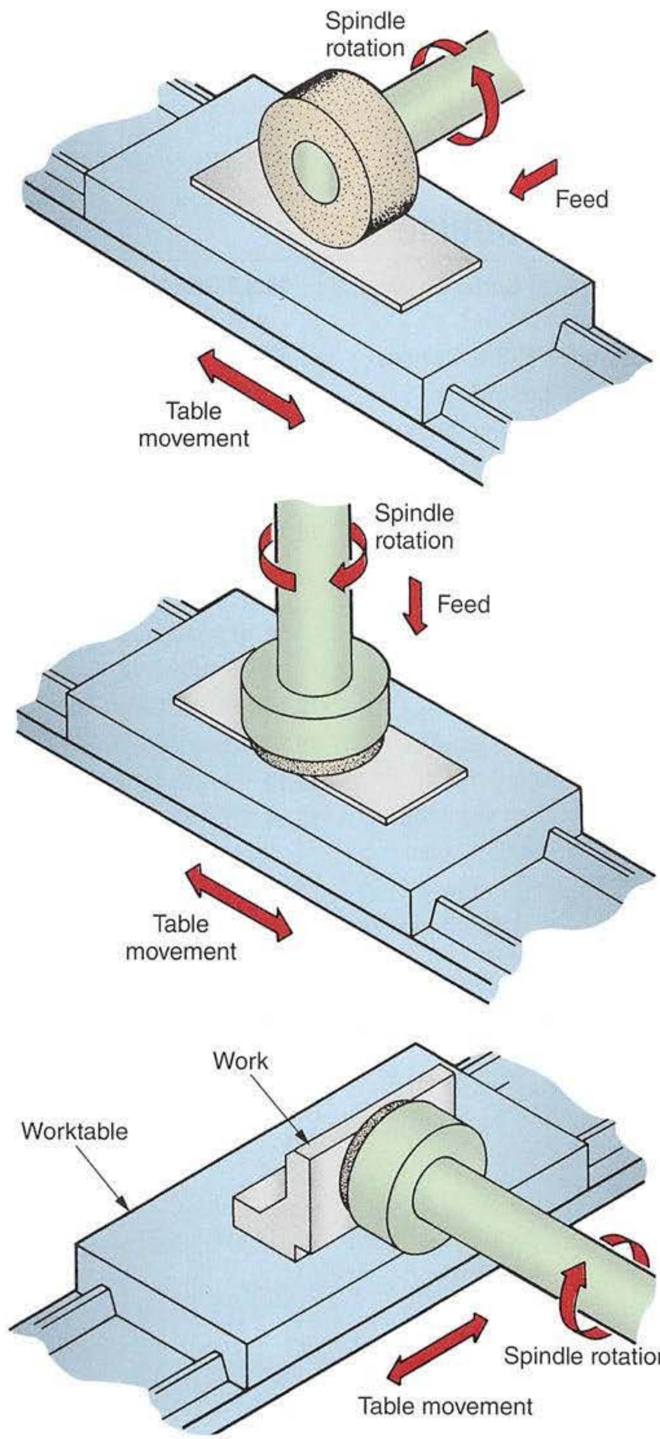
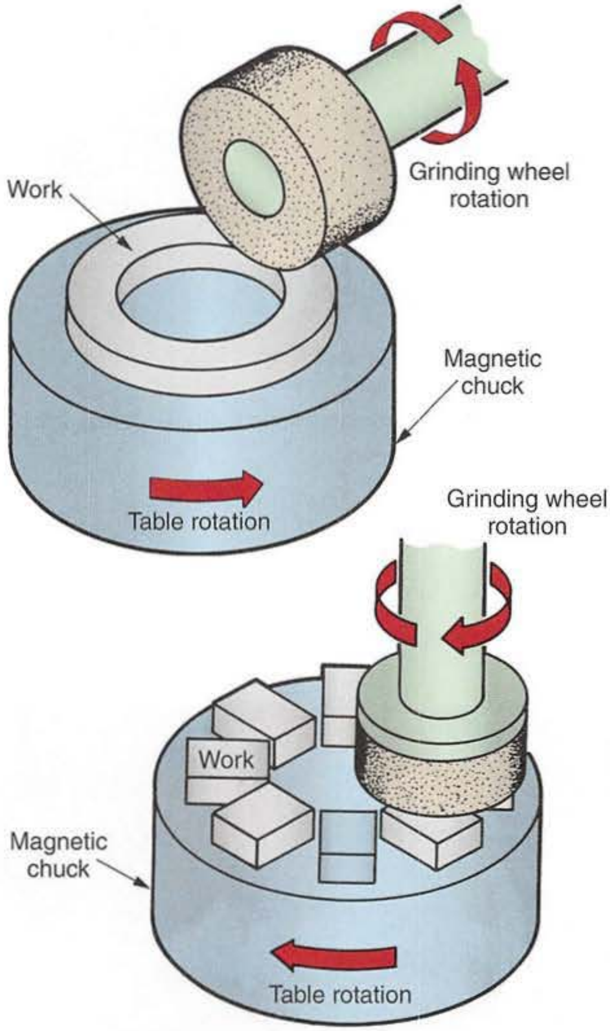

Goodheart-Willcox Publisher

**Figure 19-1.** A grinding wheel removes material in the same manner as a milling cutter, but the chips of metal removed are much smaller.



Goodheart-Willcox Publisher

**Figure 19-2.** Three variations of the planer surface grinder.




Goodheart-Willcox Publisher

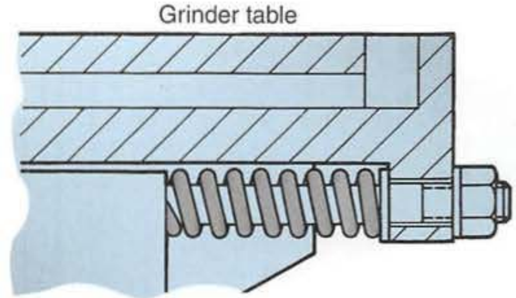
**Figure 19-3.** Two variations of the rotary-type surface grinder.

pressing a button after each move, the machine "memorizes" how the part is made. The machine can run subsequent parts automatically.

Manual and automatic machines operate in much the same manner. However, the person using a manually operated machine must develop a rhythm to get a smooth, even cutting stroke. Spring stops act as cushions at the end of maximum table travel, **Figure 19-4**.

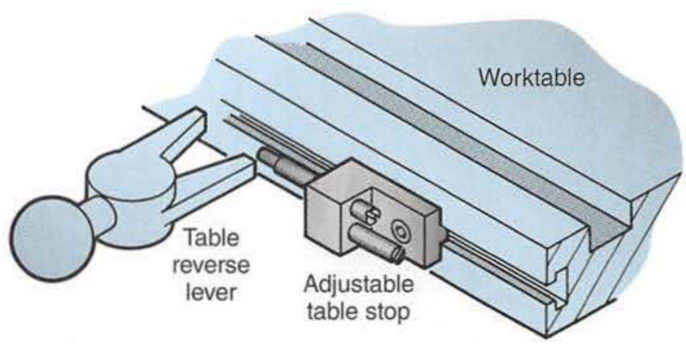
Adjustable table stops on the hydraulically activated traverse feed permit the operator to position the table precisely, **Figure 19-5**. At the end of the stroke, table direction reverses automatically. The automatic cross-feed moves the work in or out a predetermined distance at the completion of each cutting cycle.

A control console is located on the front of the machine. From this console, the operator can start and stop table travel and control table speed. Some grinding machines have a control for ***dwell***—a hydraulic cushion at the end of each stroke.




Goodheart-Willcox Publisher

**Figure 19-4.** Springs are often used on the worktable guide to cushion the end of the stroke on manually operated surface grinders.




Goodheart-Willcox Publisher

**Figure 19-5.** An adjustable table stop is used to regulate the length of the worktable stroke.

## 19.2 Work-Holding Devices

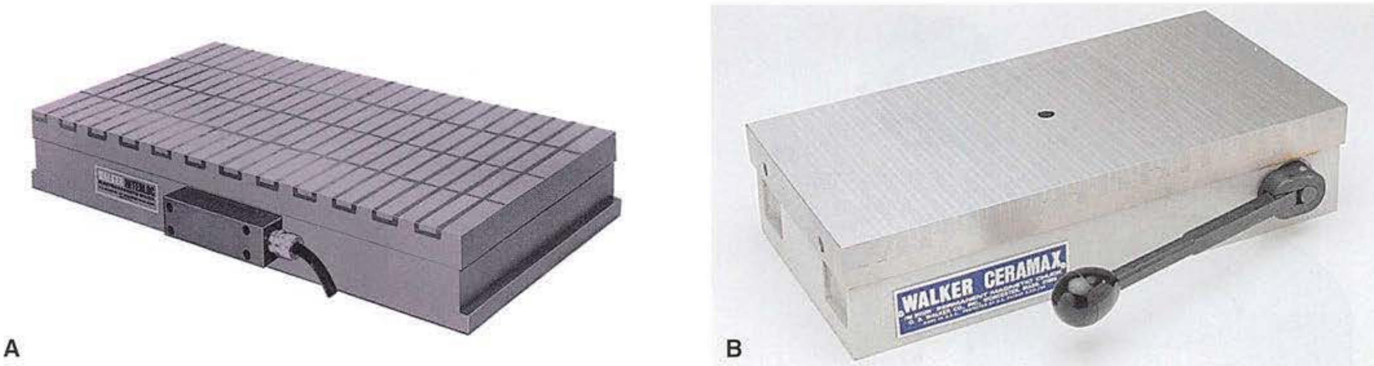
Much of the work machined on a surface grinder is held in position by a magnetic chuck. The chuck holds the work using magnetic force. Nonmagnetic materials (such as aluminum and brass) can be ground by bracing them with steel blocks or parallels to prevent movement.

An electromagnetic chuck uses an electric current to create a strong magnetic field. Another type of magnetic chuck uses a permanent magnet. This eliminates the cords needed for electromagnets and the danger of the work flying off the chuck if the electrical connection is accidentally broken. See **Figure 19-6**.

Frequently, work mounted on a magnetic chuck becomes magnetized and must be demagnetized before it can be used. A demagnetizer is used to neutralize the magnetic field.

Other ways to mount work on a surface grinder include:

- A universal vise, **Figure 19-7A**.
- An indexing head with centers, **Figure 19-7B**.
- Clamps to hold the work directly on worktable.
- A precision vise.
- Double-faced masking tape (used to hold thin sections of nonmagnetic materials). Refer to **Figure 19-8**.

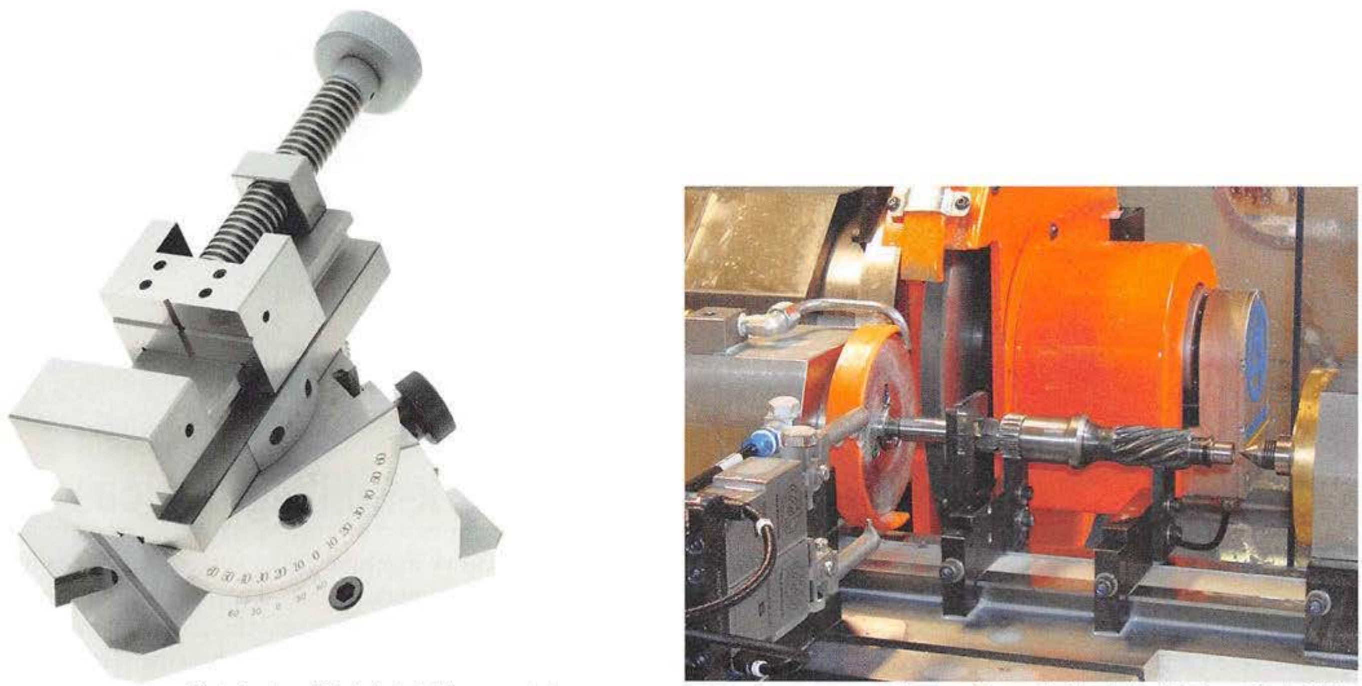



A

B

O.S. Walker Co.

**Figure 19-6.** Magnetic chucks. A—An electromagnetic chuck uses an electric current to create a magnetic field. B—A magnetic chuck with a permanent magnet.



A Photo Courtesy of Grizzly Industrial, Inc. www.grizzly.com

B Courtesy of Vermont Machine Tool and the Bryant Grinder Division

**Figure 19-7.** Work-holding devices. A—A universal vise can be used for grinding operations. B—Centers and an indexing head are used for grinding tasks when the shape of the work permits. An indexing head is used in much the same manner as the dividing head in milling.

# 19.3 Grinding Wheels

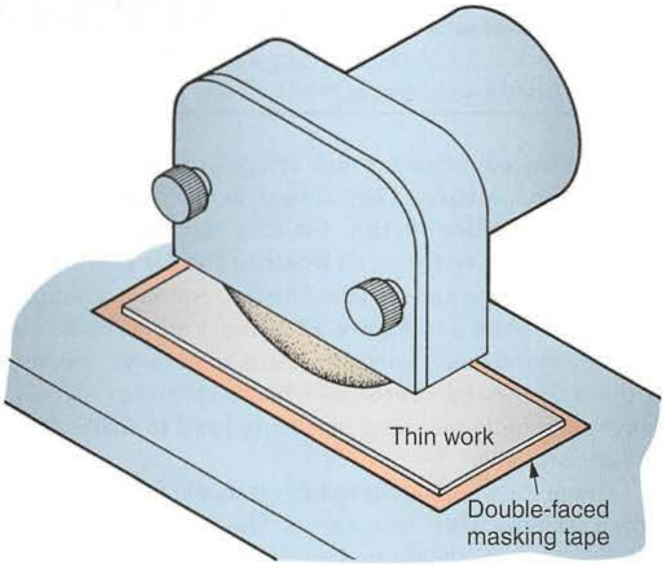
As mentioned at the beginning of this chapter, each abrasive particle in a grinding wheel is a cutting tooth. As the wheel cuts, metal chips dull the abrasive grains and wear away the bonding material (medium that holds the abrasive particles together). In the ideal grinding wheel, the bonding material would wear away slowly enough to get maximum use from the individual abrasive grains, but rapidly enough to permit dulled abrasive particles to drop off and expose new particles.

Because so many factors affect grinding wheel efficiency, the wheel eventually dulls and must be dressed with a diamond dressing tool. See **Figure 19-9**. Failure to dress the wheel of a precision grinding machine will, in time, result in the wheel face becoming loaded or glazed and unable to cut freely.

Only manufactured abrasives are suitable for high-speed grinding wheels. Their properties, including the spacing of abrasive particles and composition of the bonding medium, can be controlled to get the desired grinding performance, **Figure 19-10**.

## 19.3.1 Grinding Wheel Marking System

To help ensure grinding performance, a standard system of marking grinding wheels has been defined by the American



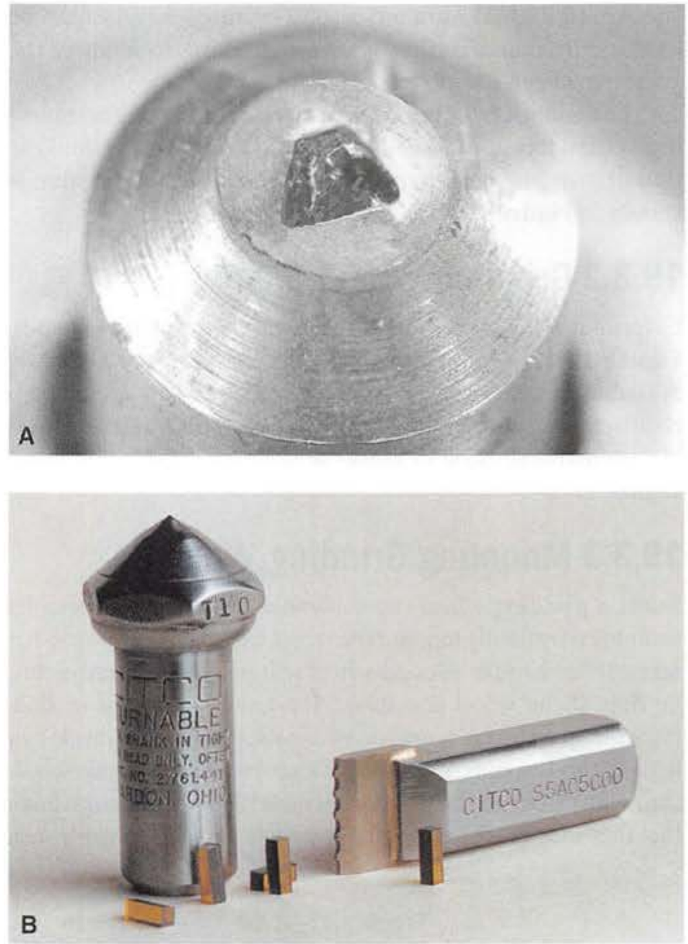

Goodheart-Willcox Publisher

**Figure 19-8.** Double-faced masking tape is used to mount thin, nonferrous material for grinding.

National Standards Institute (ANSI). Called ANSI Standard B74.13, it is used by all grinding wheel manufacturers. Five factors were considered:

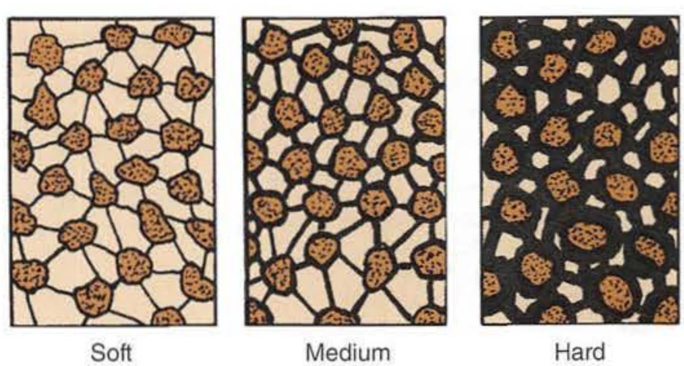
- **Abrasive type.** Classifies the abrasive material in the grinding wheel. Manufactured abrasives fall into two main groups, identified by letter symbols:
  - A = aluminum oxide
  - C = silicon carbide

  An optional prefix number may be used to designate a particular type of aluminum oxide or silicon carbide abrasive.
- **Grain size.** Indicated by a number, usually from 8 (coarse) to 600 (very fine).
- **Grade.** The strength of the bond holding the wheel together, ranging from A (soft) to Z (hard).
- **Structure.** Grain spacing or the manner in which the abrasive grains are distributed throughout the wheel. It is numbered 1 to 16. The higher the number, the more "open" the structure (wider the grain spacing). The use of this number is optional.
- **Bond type.** The type of material that holds the abrasive grains (wheel) together. Eight types are used:
  - B = Resinoid
  - BF = Resinoid reinforced
  - E = Shellac
  - O = Oxychloride
  - R = Rubber
  - RF = Rubber reinforced
  - S = Silicate
  - V = Vitrified




CITCO Div., Western Atlas, Inc.

**Figure 19-9.** Diamond wheel dressing tools. A—Close-up of a natural diamond chip on a grinding wheel dresser. The diamond should be rotated a partial turn each time it is used to put a new edge of the diamond into position. B—Dressing tools manufactured from manmade diamonds. These diamonds do not have the irregularities of natural diamonds, resulting in consistent diamond exposure and longer wear.




Goodheart-Willcox Publisher

**Figure 19-10.** Wheel hardness is determined by the type and percentage of bond and grain spacing.

An additional number or one or more letters may be used as the manufacturer's private marking to identify the grinding wheel. Its application is optional.

The adoption of this standardized grinding wheel marking system has guaranteed, to a reasonable degree, duplication of grinding performance. The wheel marking system is shown in **Figure 19-11**.

## 19.3.2 Grinding Wheel Shapes

Grinding wheels are made in many standard shapes, **Figure 19-12**. Only twelve basic face shapes are generally available, but these faces may be changed to suit specific job requirements, **Figure 19-13**. Wheels used for internal grinding are manufactured in a large selection of shapes and sizes, **Figure 19-14**.

## 19.3.3 Mounting Grinding Wheels

Select a grinding wheel recommended for the job. Check its soundness by lightly tapping the wheel with a plastic or wooden screwdriver handle. A good wheel will produce a clear metallic ring. If the wheel is cracked, the tone will be flat or dull, rather than a clear ringing sound. Cracked grinding wheels can fly apart as the rpm of the wheel increases to operating speed, throwing pieces off the wheel in all directions with enough force that they may cause injury even to people outside the work area.

**SAFETY NOTE**

Always discard cracked grinding wheels. If possible, break them into several pieces to ensure that they are not used.

Unbalanced wheels cause irregularities on the finished ground surface. They should be statically balanced as shown in **Figure 19-15A**. On CNC grinders, automatic wheel balancing systems can lengthen the life of the wheel and provide improved surface finishes. Automatic systems like the one shown in **Figure 19-15B** use vibration sensors and ultrasound wheel contact sensors to monitor operation of the wheel. A microprocessor-based controller signals a flange or spindle-mounted balancing head to make necessary adjustments.

Mount the wheel on the spindle. It should fit snugly. Never force a grinding wheel onto a shaft. The blotter rings or compressible washers should be large enough to extend beyond the wheel flanges, **Figure 19-16**. It is essential that the wheel be mounted properly. If it is not, excessive strains will develop during the grinding operation and the wheel may shatter.

**SAFETY NOTE**

Avoid standing in line with the grinding wheel, especially during the first few passes across the work.

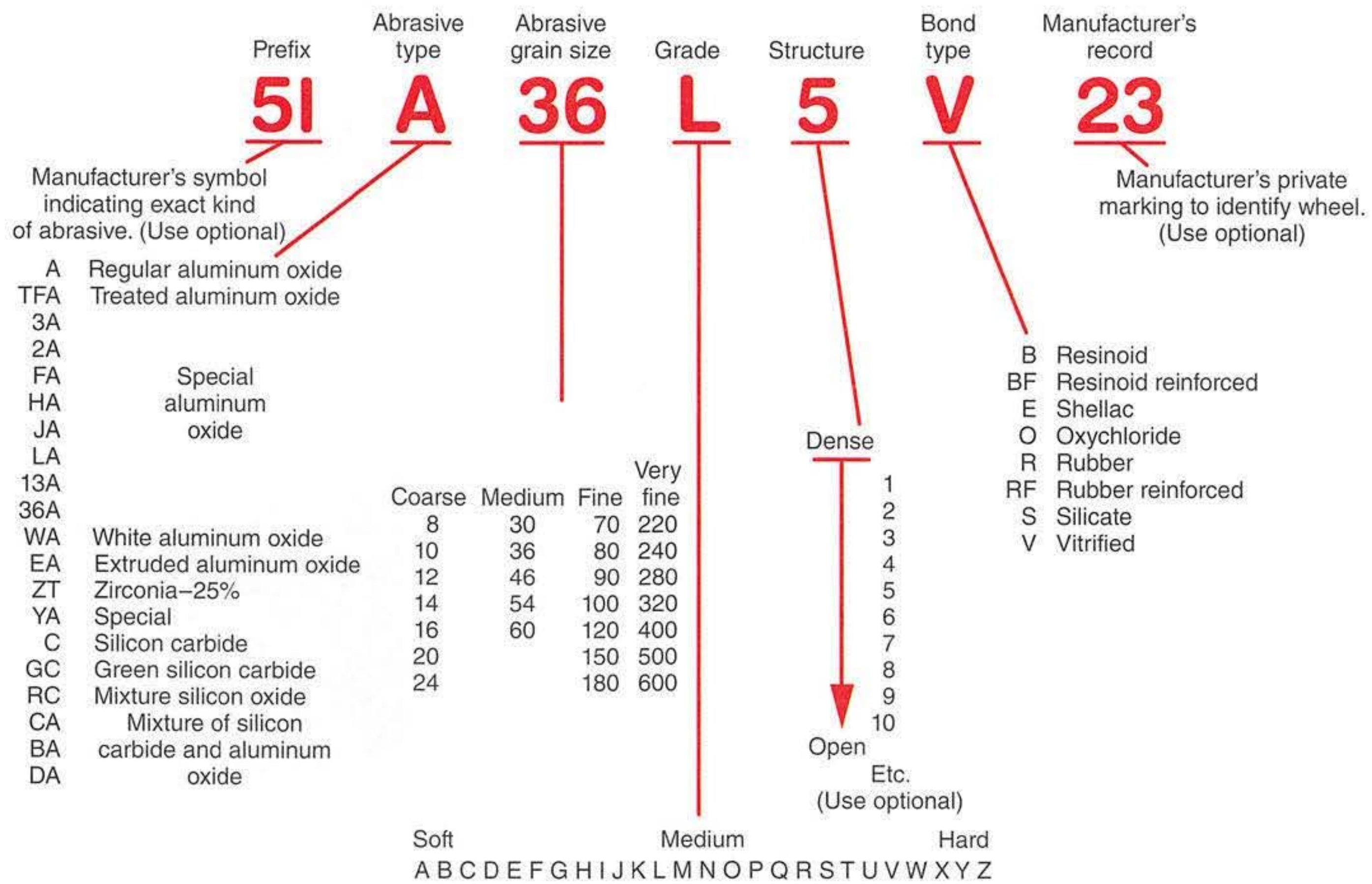
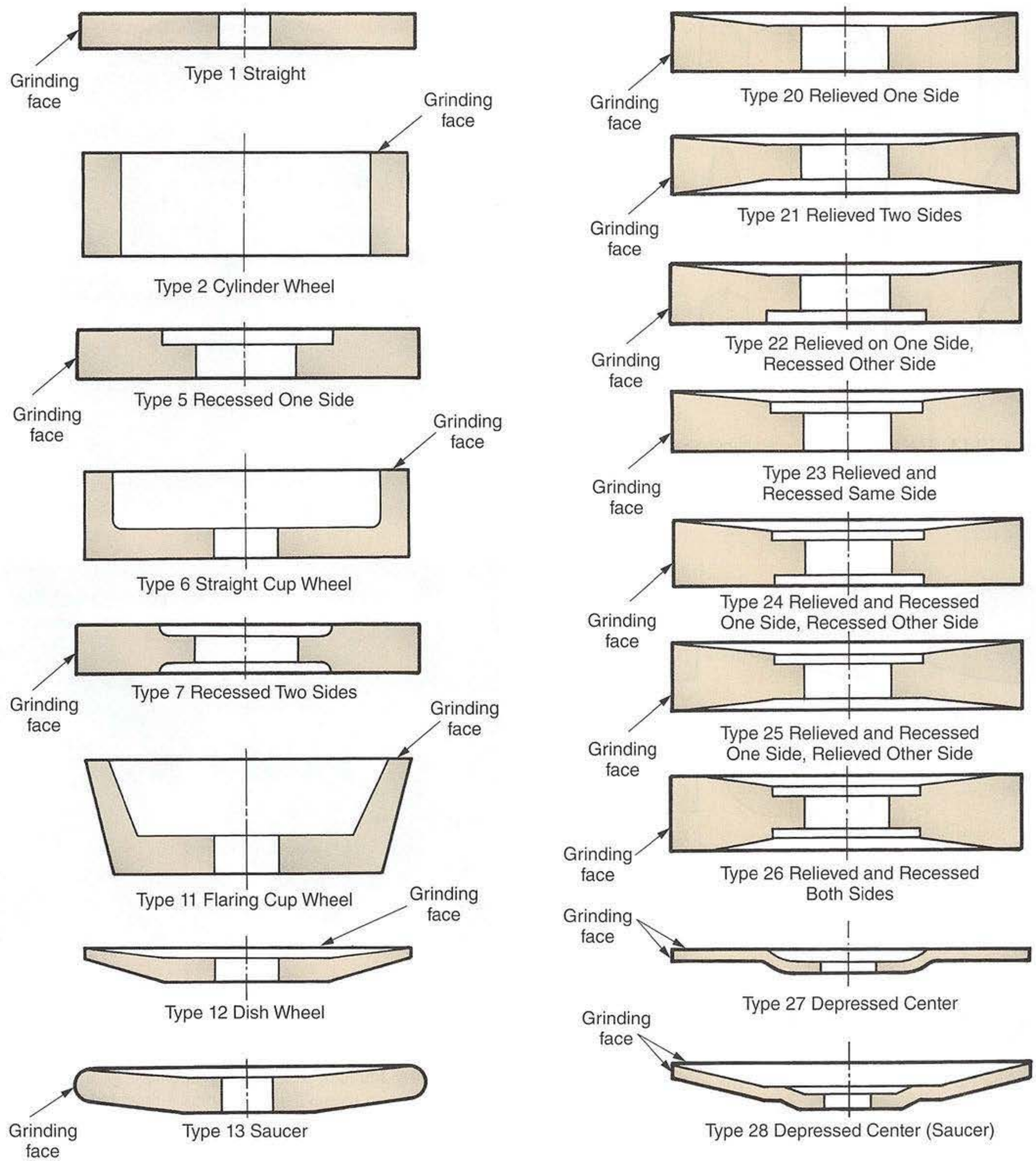
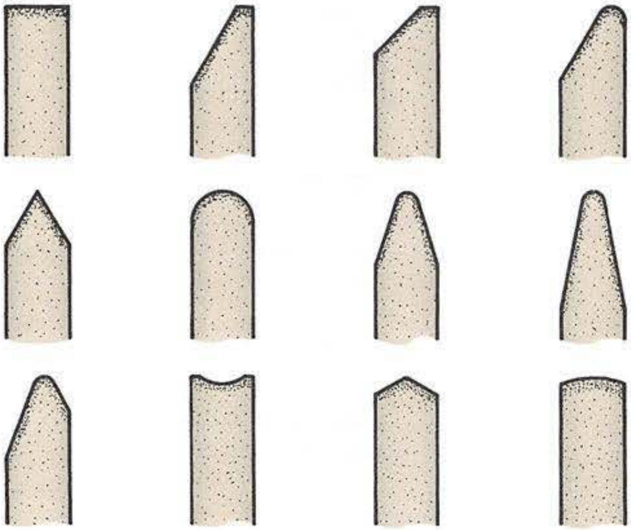



**Figure 19-11.** Standard system for marking grinding wheels.



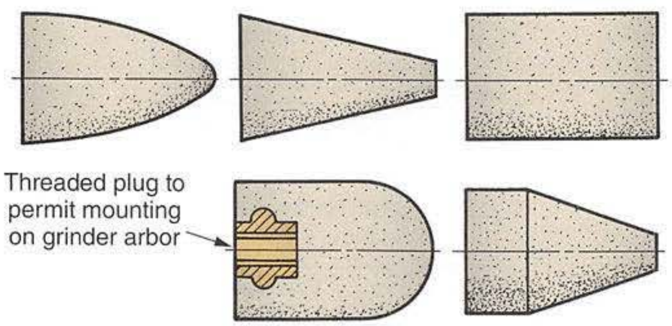

Goodheart-Willcox Publisher

**Figure 19-12.** Standard grinding wheel shapes.



Goodheart-Willcox Publisher

**Figure 19-13.** The twelve basic face shapes that are generally available.

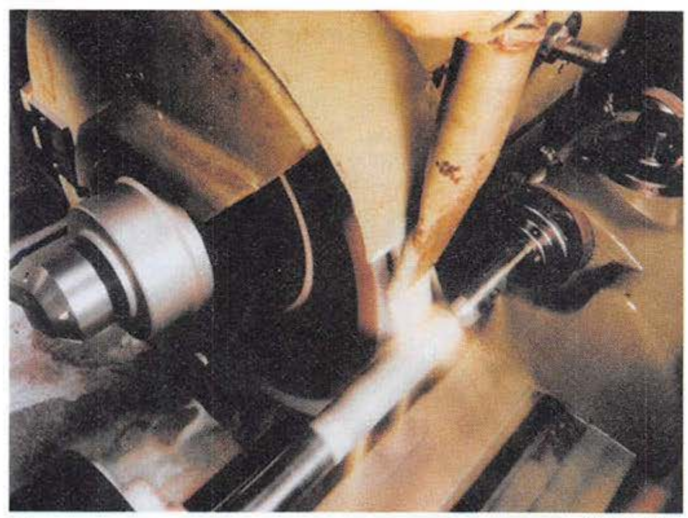



Goodheart-Willcox Publisher

**Figure 19-14.** A few of the many grinding wheel shapes available for internal grinding.

A

Revolution Tool Company



B

Marposs Corp.

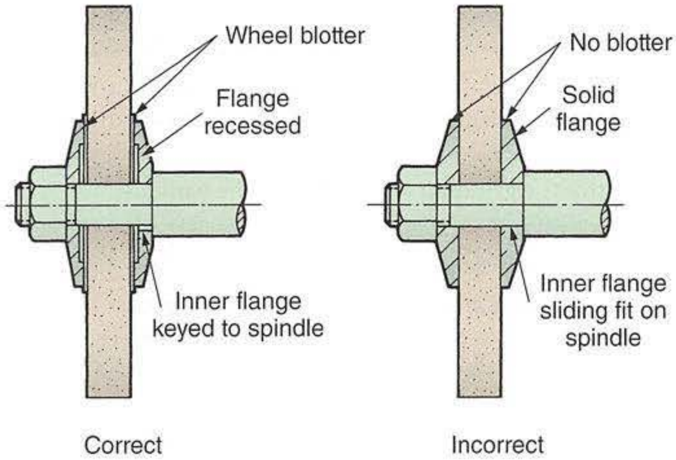
**Figure 19-15.** Grinding wheel balancing. A—Static balance method. The wheel nut shown features a series of threaded holes on a bolt circle. The wheel is statically balanced by adding or removing setscrews of different lengths opposite the wheel's heavy and light sections. B—Automatic grinding wheel balancing system uses a flange- or spindle-mounted balancing head, vibration and ultrasound sensors, and a microprocessor-based controller to keep the wheel in balance.

## 19.4 Cutting Fluids

Cutting fluids are an important factor in reducing wear on the grinding wheel. They help maintain accurate dimensions and are important to the quality of the surface finish produced. As a coolant, the cutting fluid must remove the heat generated during the grinding operation. Heat must be removed as fast as it is generated.

Several types of cutting fluids are used in grinding operations:

- Water-soluble chemical fluids take advantage of the excellent cooling ability of water. They are usually transparent and include a rust inhibitor, water softeners, detergents to improve the cleaning ability of the water, and bacteriostats (substances that regulate and control the growth of bacteria).
- Polymers are added to water to improve lubricating qualities.




Goodheart-Willcox Publisher

**Figure 19-16.** Do not operate a grinder unless the wheel is properly mounted.

- Water-soluble oil fluids are usually a milky white because they consist of a mixture of oil and water. They are less expensive than most chemical fluids. Bacteriostats are added to control bacteria growth.

Coolant can be applied by flooding the grinding area, **Figure 19-17.** The fluid recirculates by means of a pump and holding tank built into the machine. A mist system forces the coolant over the wheel or applies it to the work surface under air pressure. It cools by evaporation. A coolant can also be applied manually by pumping the fluid from a pressure-type oil pump can.

**SAFETY NOTE**

If coolant is applied manually, keep the tip of the oil pump can a safe distance from the wheel.

For safety, long equipment life, and quality control, a coolant system should be cleaned at regular intervals. To clean the coolant system, remove all dirt and sludge from the holding tank. Chips and grinding wheel residue in the coolant can mar the ground surface of the workpiece. Discard the fluid when it becomes contaminated.

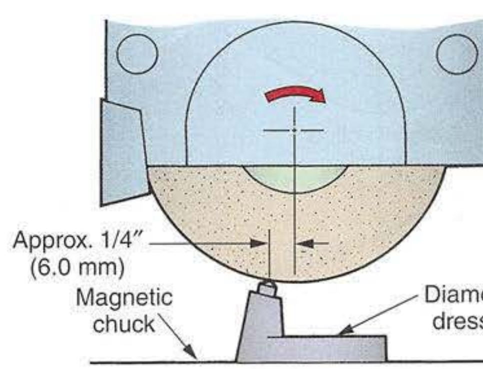
Stana/Shutterstock.com

**Figure 19-17.** Coolant must flood the area being ground.

## 19.5 Grinding Applications

The following procedure is recommended to produce a surface that is flat (free of waviness):

1. Select and mount a suitable grinding wheel.
2. True and dress the wheel with a diamond dressing tool, **Figure 19-18.**
3. Mount the work-holding device. If a magnetic chuck is used, it should be "ground in" to ensure a surface that is true and parallel to table travel. Grind off as little material as possible from the chuck in order to true the surface. Also, be sure to flood the surface with coolant during the procedure. For high-precision work, the magnetic chuck should be ground in each time it is remounted on the machine.
4. Check the coolant system to be sure it is operating satisfactorily.
5. Position the work and energize the chuck. If the work is already ground on one surface, protect it and the chuck surface by fitting a piece of oiled paper between the machined surface and the chuck before energizing the chuck, **Figure 19-19.**
6. Adjust the table stops, **Figure 19-20.**
7. Check the holding power of the magnetic chuck by trying to move the work.
8. Down-feed the grinding wheel until it just touches the highest point on the work surface. The grinding wheel can be set to the approximate position by down-feeding until it just touches a sheet of paper placed between the wheel and the work surface.
9. Turn on the coolant, spindle, and hydraulic pump motors.




Goodheart-Willcox Publisher

**Figure 19-18.** For best results when cleaning or truing a grinding wheel, position the diamond wheel dresser as shown.

10. Set the cross-feed to move the table in or out about 0.020″ (0.5 mm) at the end of each cycle.
11. With the wheel clear of the work, down-feed about 0.001″ to 0.003″ (0.025 mm to 0.076 mm) per pass for average roughing cuts.

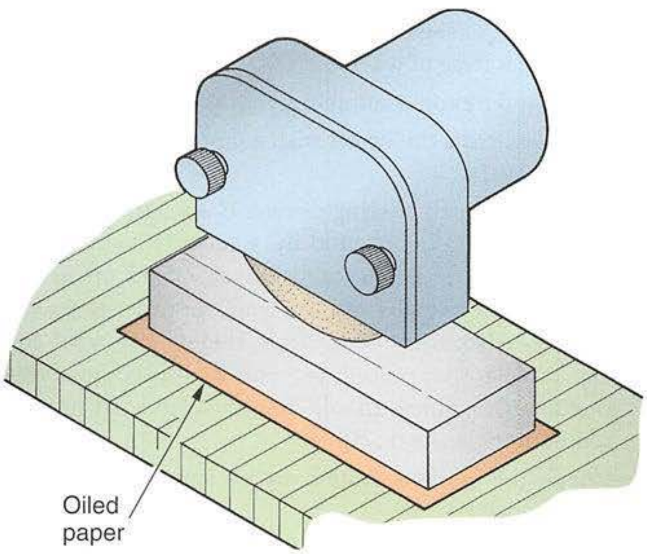



**Figure 19-19.** A piece of oiled paper placed between the magnetic chuck and a newly ground surface will protect the finish of the work and the surface of the chuck.

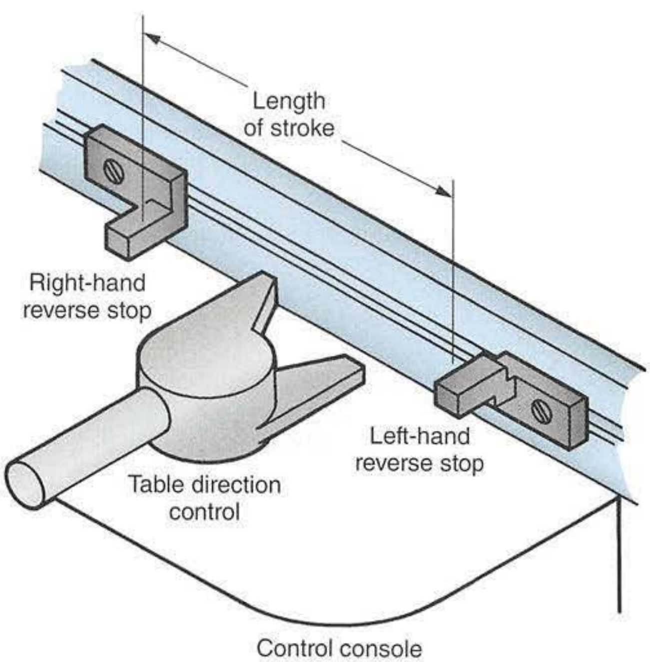



**Figure 19-20.** Adjustable stops regulate the length of the table stroke. Take care to ensure that the stop adjustment permits the entire work surface to be ground.

12. Use light cuts of 0.0001″ (0.0025 mm) for finishing the surface. It is wise to redress the wheel for finishing cuts.

When the work surface has been ground to the required dimension and finish, use the following procedure to turn off the machine:

1. Move the grinding wheel clear of the work.
2. Turn off table travel.
3. Turn off the coolant.
4. Let the grinding wheel run for a few moments after the coolant has been turned off to remove all traces of fluid. Otherwise, the wheel may absorb some of the coolant and become out of balance.
5. Use a squeegee to remove excess coolant from the work. De-energize the chuck and remove the work.

**SAFETY NOTE**

Be careful of the sharp edges on newly ground work when removing it from the machine.

6. Clean the machine. Apply a light coating of oil on the chuck's work surface to prevent possible rusting.
7. Place all tools in proper storage.

## 19.5.1 Grinding Edges Square and Parallel with Face Sides

Most rectangular work requires the edges to be parallel to each other and square with the finished face sides. In one commonly used technique, **Figure 19-21**, edge 1 is ground while being held in a precision vise. After burrs are removed, the adjacent edge 2 is ground. Its squareness is checked vertically with a dial indicator.

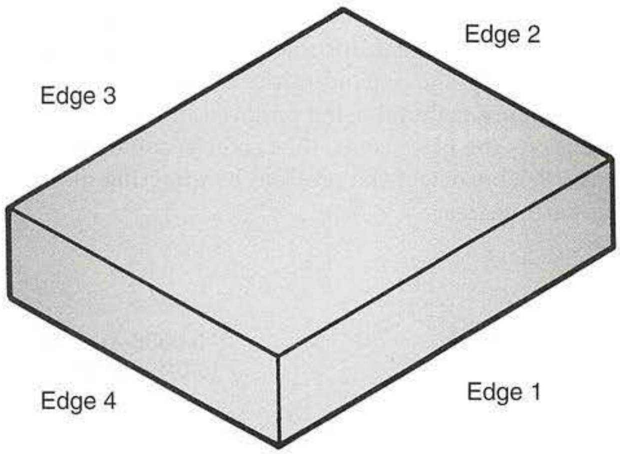
After edges 1 and 2 are ground square with each other, they serve as reference planes to grind edges 3 and 4 to the required dimensions. Use oiled paper in the vise to protect the ground faces and edges from stray metal and abrasive particles. Carefully wipe the vise clean and remove all burrs after grinding each edge.

An angle plate can also be used to grind edges square and parallel with the finished faces. See **Figure 19-22**. A parallel may be used to set the work in approximate position. The same positioning and grinding sequences are followed as previously described.

## 19.5.2 Creep Grinding

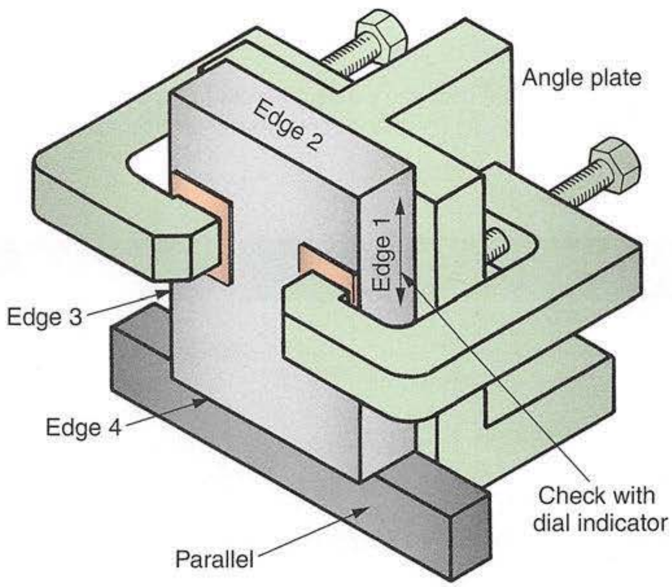
***Creep grinding*** is a production-type surface grinding operation that makes a deep cut into the work, often performed in a single pass, **Figure 19-23**. It is also sometimes known as *deep grinding*. Special grinding machines are required for this type of work.

In comparison to conventional surface grinding, creep grinding increases the depth of cut 1000 to 10,000 times and reduces the work speed in the same proportion. Machining




Goodheart-Willcox Publisher

**Figure 19-21.** The sequence for squaring edges of a rectangular workpiece after the faces have been ground flat and parallel.




Goodheart-Willcox Publisher

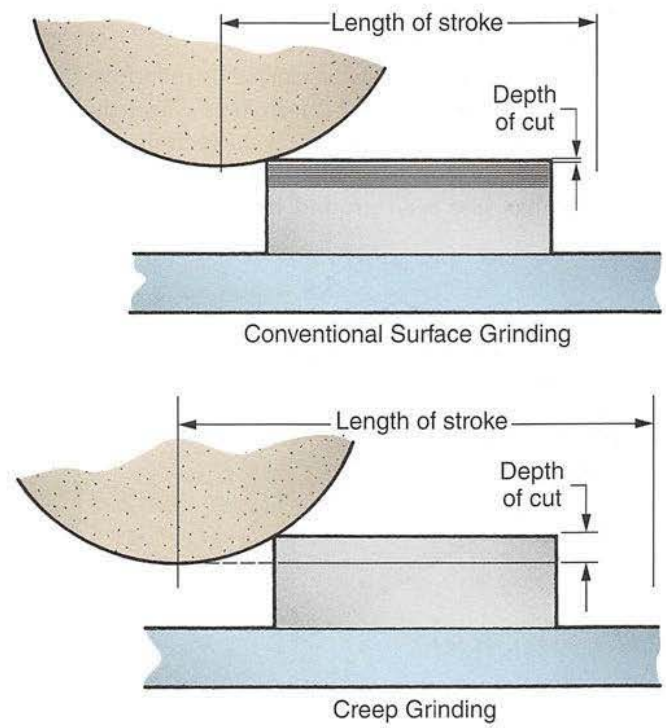
**Figure 19-22.** An angle plate can also be used to hold work for grinding the edges square and parallel.

time can be reduced by 50% to 80%. The tools (such as grinding wheels and work-holding devices) must be designed for this heavy-duty work.

# 19.6 Grinding Problems

You may encounter several problems specific to precision surface grinding. The following paragraphs address a few of the more common difficulties and provide suggestions for their solution.

Irregular table movement or no table movement on hydraulic machines can be caused by clogged hydraulic lines, insufficient hydraulic fluid, a hydraulic pump that is




Goodheart-Willcox Publisher

**Figure 19-23.** The difference between conventional and creep grinding. Creep grinding equipment must be specially designed for this heavy-duty work.

not functioning properly, or inadequate table lubrication. A cold hydraulic system can also cause these symptoms. Let the machine warm up for at least 15 minutes before use. Air in the hydraulic lines can cause erratic table movement. Make corrections as recommended by the manufacturer of the machine.

Irregular scratches, of no identifiable pattern, are frequently caused by a dirty coolant system, or by particles becoming loosened in the wheel guard. Scratches may also occur if the grinding wheel is too soft, and the abrasive particles are carried to the wheel by the coolant system. Deep, irregular marks on the work surface may be caused by a loose grinding wheel.

Work surface waviness can be caused by a wheel being out of round. This can be corrected by truing the wheel.

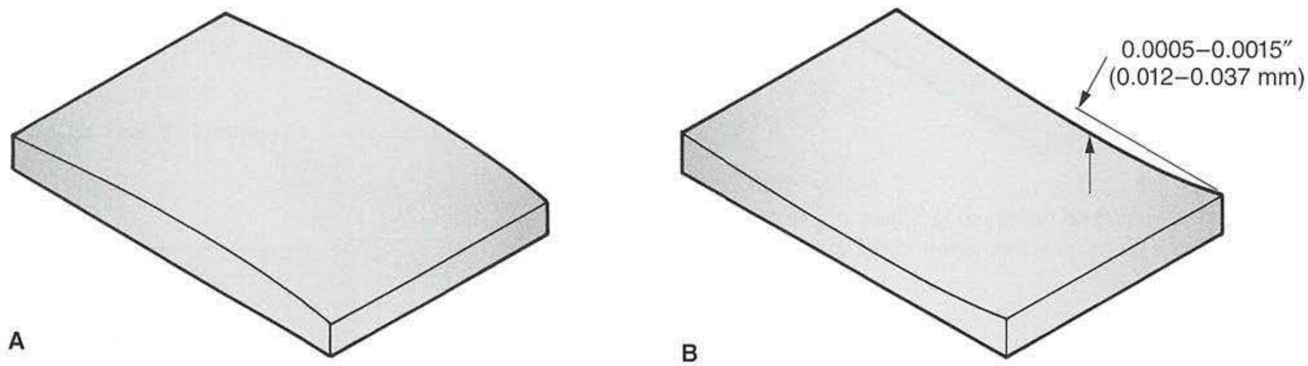
Wheel glazing or loading often indicates that the wrong coolant is being used. A dull diamond on the wheel dresser can also cause this problem.

Chatter or vibration marks can be caused by a glazed or loaded grinding wheel. There is a slipping action between the wheel and the work. The wheel cuts until the glazed section comes into position and then slides over the work instead of cutting. Correct the problem by redressing the grinding wheel. Vibration marks can also be caused by a grinding machine that is not mounted solidly or by a wheel that is loose on the spindle. Check for these conditions and make corrections if necessary.

Burning or work surface checking may be the result of too little coolant reaching the work surface, a wheel that is too hard, or a wheel with grain that is too fine. Make needed corrections as indicated by inspection.

Work that is not flat may be caused by insufficient coolant, a nicked or dirty chuck surface, or a wheel that is too hard. Check and make any necessary corrections.

Work that is not parallel is frequently caused by a chuck that has not been ground in since the last time it was mounted on the machine. A nicked or dirty chuck can cause the same problem. Insufficient coolant can allow the work to heat up and expand in the center of the cut. This results in more material being removed in that area than at each end. As the piece cools, the center becomes depressed, **Figure 19-24**. Correct the problem by directing more fluid to the cutting area.




Goodheart-Willcox Publisher

**Figure 19-24.** Effect of insufficient coolant. A—If not enough coolant is used, frictional heat can cause the work to expand in the center of cut, causing more material to be removed in the center than at each end. B—As the piece cools, its center becomes depressed.

# CAREER CONNECTION

## Aerospace Engineer

### What does an aerospace engineer do?

Aerospace engineers design aircraft, spacecraft, satellites, and other aerospace products. Depending on their organization, they may also coordinate the manufacture and testing of their designs. Aerospace engineers specialize in one of two types of engineering:

- Aeronautical engineering, which focuses on the theory and technology of aircraft and their performance inside the earth's atmosphere.
- Astronautical engineering, which focuses on the theory and technology of spacecraft and their performance inside and outside the earth's atmosphere.

### What education and skills are needed to be an aerospace engineer?

Aerospace engineers hold bachelor's degrees in aerospace engineering, engineering, or another science related to aerospace systems. They often specialize in more than one field and use aerospace engineering principles alongside other sciences, such as aerodynamics, celestial mechanics, or thermodynamics. Students interested in aerospace engineering should study chemistry, physics, and mathematics.

### What is it like to be an aerospace engineer?

More than a third of aerospace engineers work in the manufacturing industry for aerospace products and parts. They often work in offices but may go elsewhere to test and refine designs. Aerospace engineers earn median wages of $107,000 annually, according to the *Occupational Outlook Handbook*. Those with the highest wages often work for the federal government and companies that manufacture navigational control equipment.

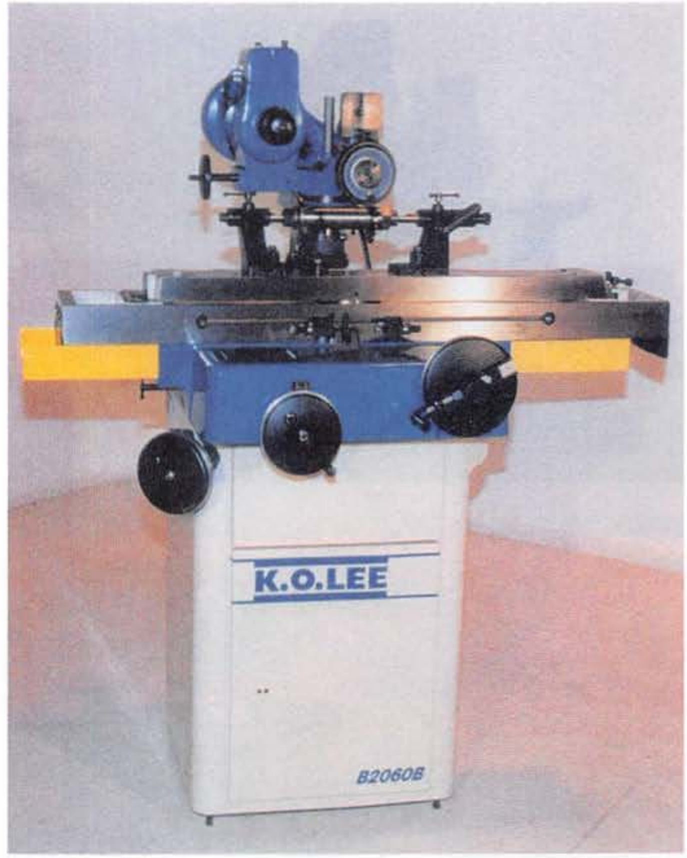
# 19.7 Grinding Safety

Follow these guidelines to work safely with a surface grinder:

- Never attempt to operate a grinder until you have been instructed in its proper and safe operation. When in doubt, consult your instructor.
- Do not use a grinder unless all guards and safety devices are in place and securely attached.
- Never try to operate grinding machines while your senses are impaired by medication or other substances.
- Always wear proper eye protection when performing any grinding operation.
- Never place a wheel on a grinder before checking it for soundness. Destroy faulty wheels so they cannot be used.
- Check the wheel often and dress it when required to prevent it from becoming glazed or loaded.
- Make sure the grinding wheel is clear of the work before starting the machine.
- Never operate a grinding wheel at a speed higher than specified by the manufacturer.
- Change coolant fluid before it becomes contaminated. It is good practice to set up a schedule for replacing the fluid at regular intervals or adding chemicals to control bacterial growth.
- Have any cuts, burns, or abrasions treated promptly—major infections can result from untended minor injuries.
- Immediately wipe up any spilled coolants from the floor around the machine.
- Stop the machine before making measurements or performing machine and work adjustments.
- If you are using a magnetic chuck, make sure it is holding the work solidly before starting to grind.
- Remove any jewelry, including watch and rings, before using a magnetic chuck to prevent them from becoming magnetized or being pulled toward the machine.
- If you are using automatic feed, run the work through one cycle by hand to be sure there is adequate clearance and that the dogs are adjusted properly.
- Keep all tools clear of the worktable.

# 19.8 Universal Tool and Cutter Grinder

The ***universal tool and cutter grinder*** is a grinding machine designed to sharpen cutters (primarily milling cutters) to specified tolerances. See **Figure 19-25**. Attachments permit straight, spiral, and helical cutters to be sharpened accurately. Other attachments are available to adapt the machine for all types of internal and external cylindrical grinding. See **Figure 19-26**.




K.O. Lee Co.

**Figure 19-25.** Universal tool and cutter grinder.

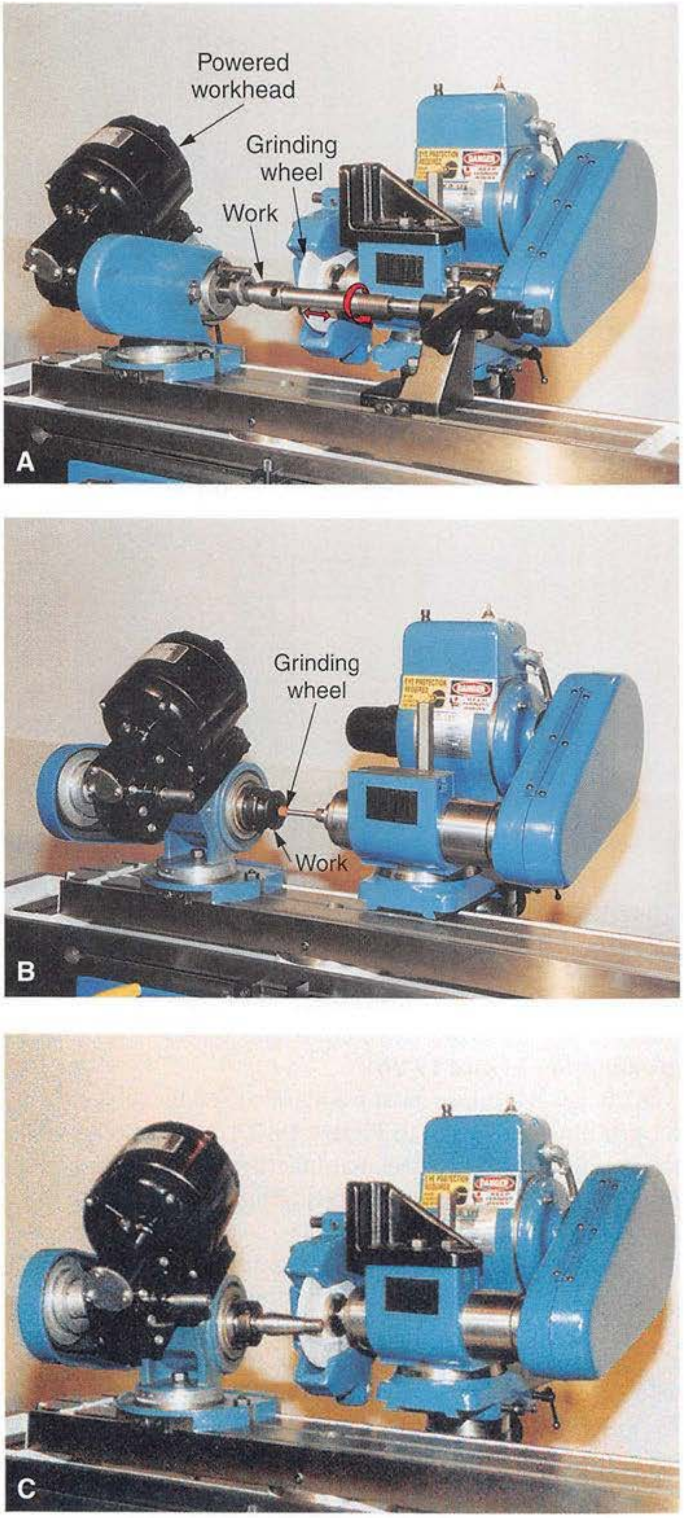
The wheel shapes most frequently used for tool and cutter grinding are shown in **Figure 19-27**. Charts prepared by the various grinding wheel manufacturers are used to determine the correct wheel composition (abrasive, grain size, and bond) for the job at hand.

Keep the grinding wheel clean and sharp by frequent dressing with a diamond tool. Use light cuts to avoid drawing the temper out of the tooth cutting edge.

Crowding the wheel into the cutter is a common mistake when grinding cutters. The cutters are made from materials such as HSS and cemented carbides, which do not give off a brilliant shower of sparks when in contact with a grinding wheel. This creates the illusion that the cut being made is too light.

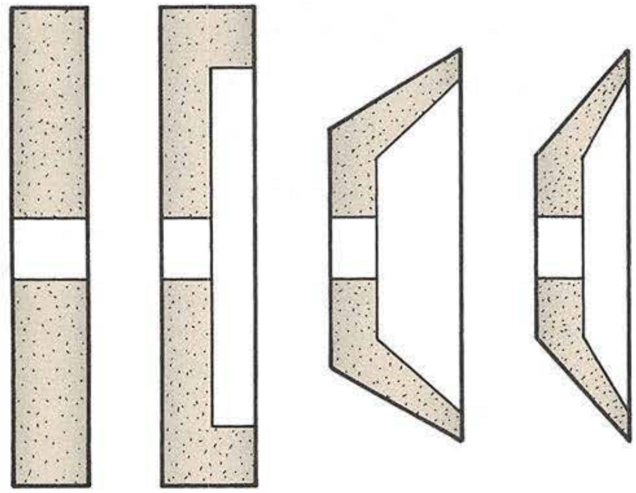
# 19.9 Sharpening Cutters

A ***tooth rest*** places each tooth of a cutter quickly and accurately into position for sharpening. Several types are used to permit different cutter types to be sharpened. The bracket




K.O. Lee Co.

**Figure 19-26.** Tool and cutter grinder applications. A—Limited cylindrical grinding can be done on a universal tool and cutter grinder. B—A universal tool and cutter grinder can also be used for internal grinding. C—The center of a spindle is being trued using a universal tool and cutter grinder. The work is rotated by a powered workhead.



Goodheart-Willcox Publisher

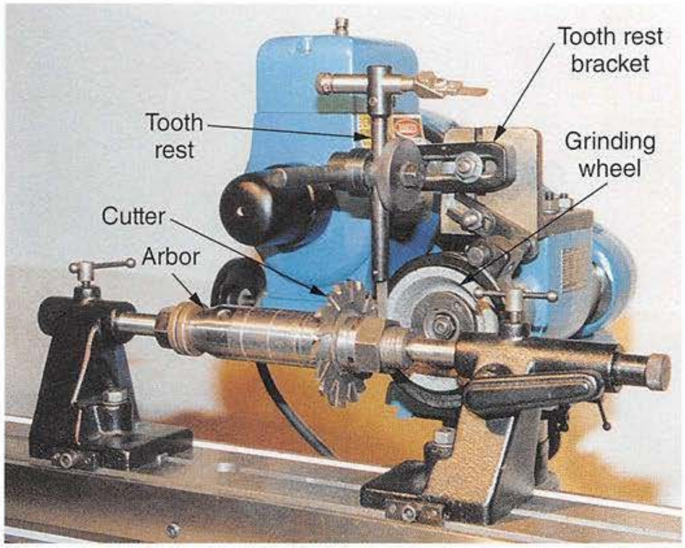
**Figure 19-27.** Wheel shapes typically used for grinding cutters.

that supports the tooth rest can be mounted to the worktable or on the grinding wheel housing. See **Figure 19-28**.

## 19.9.1 Grinding Plain Milling Cutters

For this procedure, proper eye protection is a must. If the machine is not equipped with a vacuuming system, you should also wear a respirator mask.

1. Select the correct wheel for the job. True it with a diamond tool.
2. Mount the cutter on a suitable arbor and place the unit between centers.
3. Mount the tooth rest to the wheel head. Position the edge about 1/4″ (6.0 mm) above the centerline of the grinding wheel, **Figure 19-29**. This creates a 5° to 6° clearance angle on the tooth cutting edge of a 6″ (150 mm) diameter cutter. Adjust to suit the cutter being ground.
4. Set up the cutter so that the wheel grinds away from the tooth cutting edge. While requiring more machining care than grinding into the cutting edge of the tooth, this method has less chance of drawing the temper. Also, it prevents the formation of a burr, which would need to be taken off with an oilstone in order to secure a sharp edge. See **Figure 19-30**.
5. If you are using a flare cup wheel, set up the wheel as shown in **Figure 19-31**. Since there is a greater area of contact when using a flare cup wheel, take lighter cuts than with straight grinding wheels.
6. Apply a bit of thinned layout bluing to the back of the tooth. Start the machine and feed the cutter into the wheel. Take a light cut. The bluing will allow a visual check of how the grinding operation is progressing and whether the setup is producing the proper clearance angle.



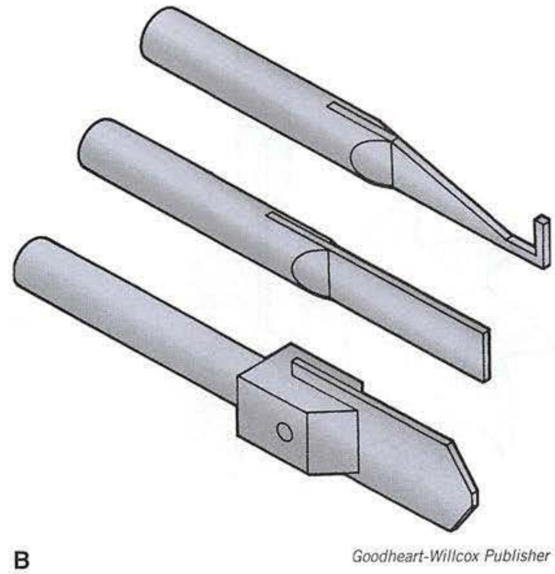




**Figure 19-28.** Tooth rest. A—A tooth rest is used to position the teeth of a cutter. Note the support bracket and the cup-shaped wheel that does the grinding. B—Several types of tooth rests.

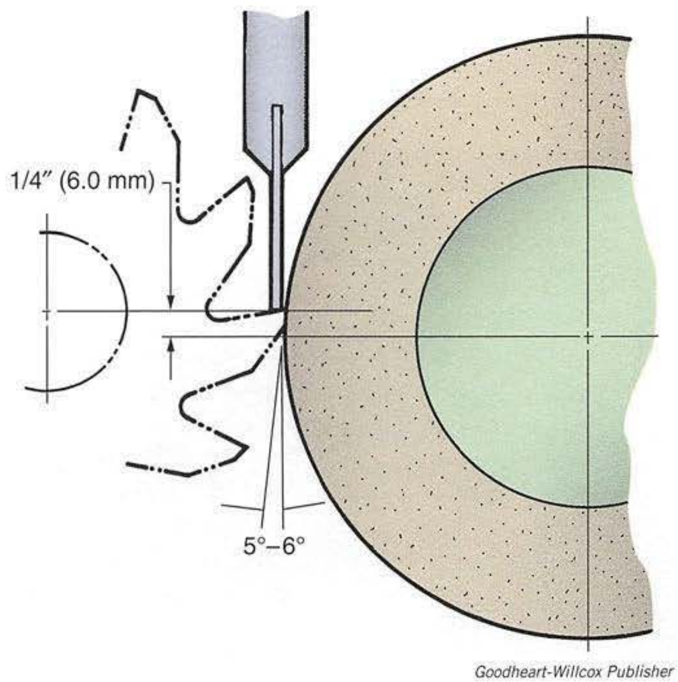



**Figure 19-29.** This setup is for grinding a 6" (150 mm) diameter cutter.

7. When you are satisfied with the setup, bring the next tooth into position on the tooth rest and grind that tooth.
8. Repeat the operation until all of the teeth are sharpened. Make necessary adjustments to ensure tooth concentricity. The cutting surfaces of all teeth must be the same distance from arbor hole centerline.

After a cutter has been sharpened several times, the clearance angle flat (land) will become too wide. Then it becomes necessary to grind in a secondary clearance angle.

If it becomes apparent that more material is being removed from some teeth than others, make a quick check to determine the cause:

- The grinding wheel may be too soft and wearing down too rapidly. As the wheel wears, less material is removed from the cutter tooth.
- The tooth rest may not be mounted solidly, allowing it to move during the grinding operation.
- The arbor may not be running true on the centers. Check the arbor runout with a dial indicator as the arbor is rotated.

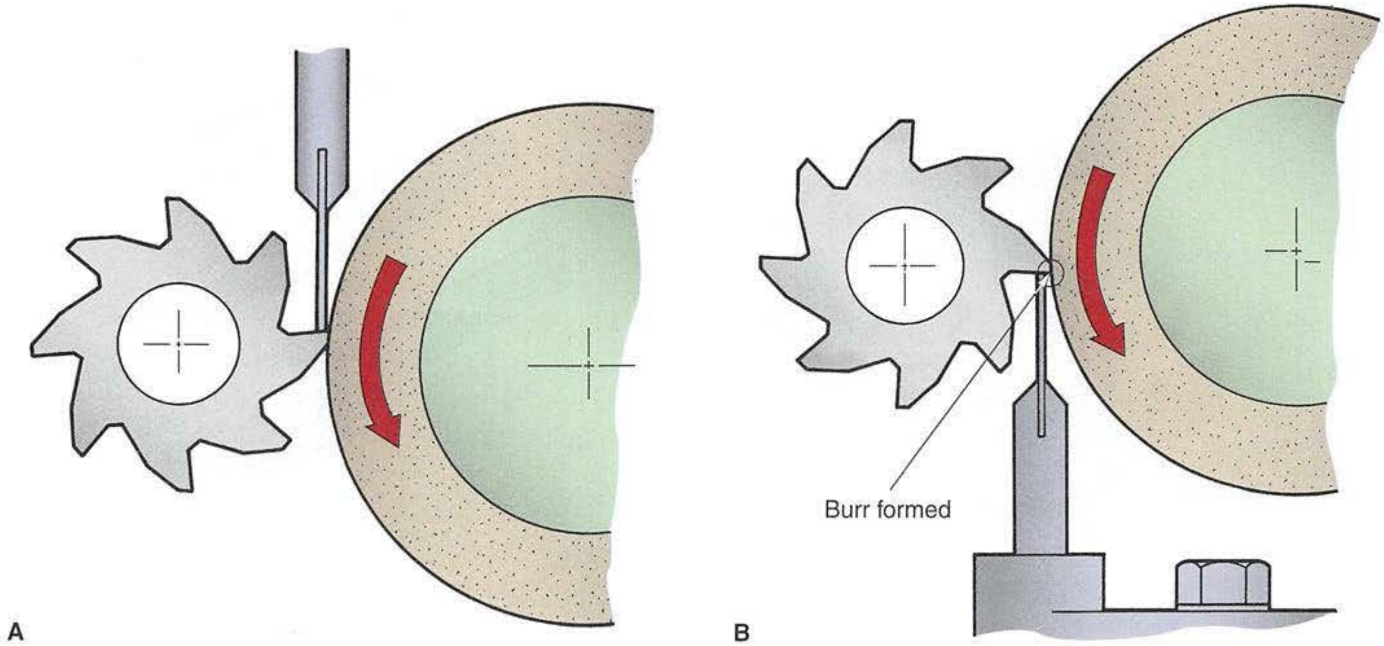
When you have identified the cause of the problem, make the necessary corrections and continue the operation.

An indexing disc may also be used to position each tooth for sharpening, **Figure 19-32**. It is mounted on the arbor. The divisions are normal to each other, plus or minus 4 minutes (1/15°). They are available in a range of graduations.

Teeth on a side-milling cutter must also be sharpened. This is done by mounting the cutter on a stub arbor and fitting the unit into a workhead, rather than positioning it between centers. Facing mills are sharpened in the same manner.

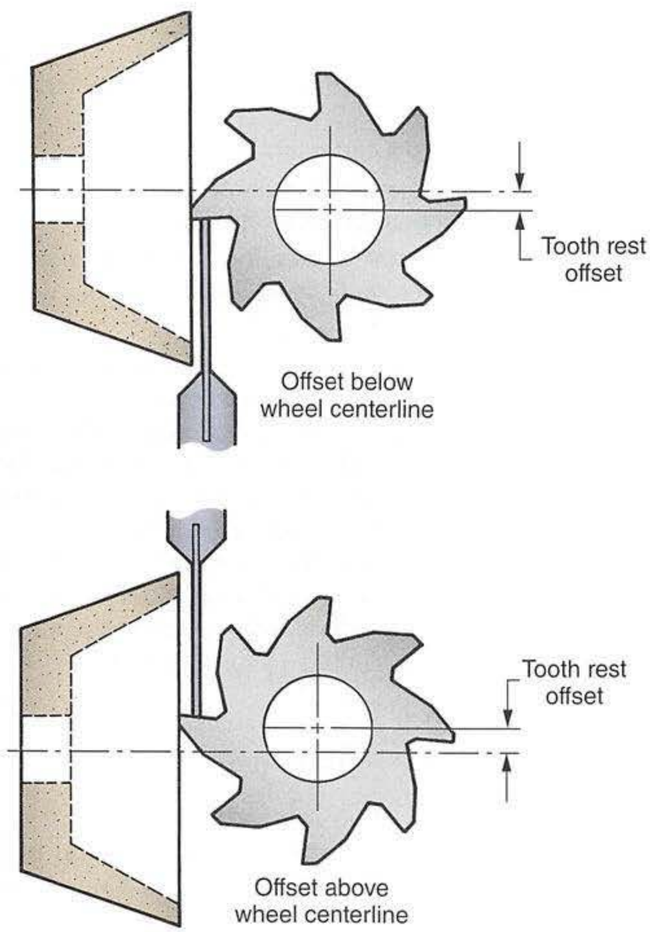
## 19.9.2 Grinding Cutters with Helical Teeth

Slabbing cutters and other cutters that have helical teeth are sharpened in much the same manner as plain milling



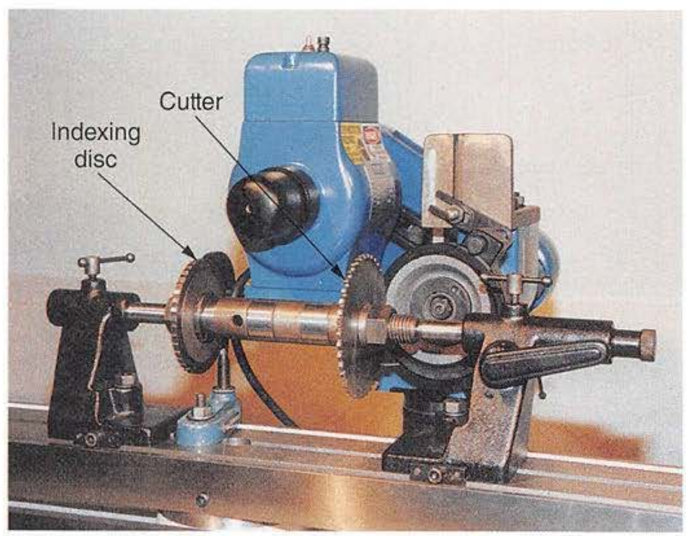

Goodheart-Willcox Publisher

**Figure 19-30.** Tooth grinding setup. A—The wheel grinds away from the cutting edge of the tooth. With this technique, there is less chance of drawing the temper out of the tooth, and no burr is formed. B—If the wheel grinds into the cutting edge of the tooth, there is a greater chance that a burr will form or the temper will be drawn.




Goodheart-Willcox Publisher

**Figure 19-31.** Milling cutter being ground with a flare cup wheel.



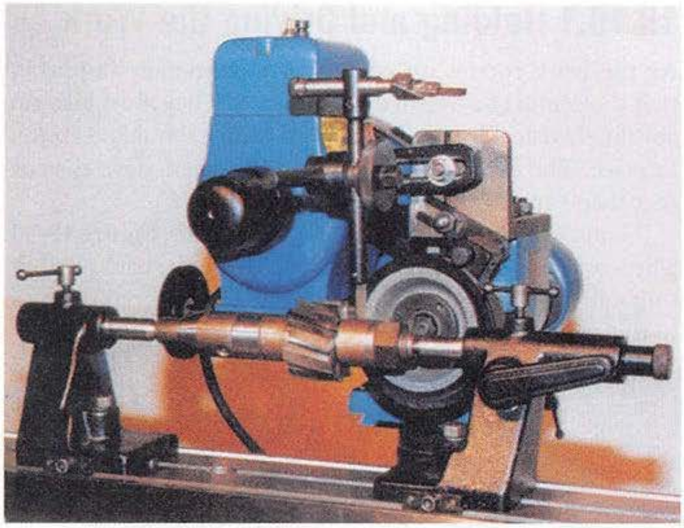

K.O. Lee Co.

**Figure 19-32.** An indexing disc is often used to position each tooth for sharpening.

cutters, **Figure 19-33**. However, these cutters must be held against the tooth rest as the table is traversed. This will create a twisting motion to keep the tooth correctly located against the grinding wheel.

## 19.9.3 Grinding End Mills

End mills are sharpened in basically the same way as helical teeth cutters, with the end mill mounted in a workhead rather than between centers. The end teeth are sharpened



K.O. Lee Co.

**Figure 19-33.** Setup for sharpening a cutter with helical teeth.

using the same technique used to sharpen the side teeth on a side milling cutter.

## 19.9.4 Grinding Form Cutters

Form tooth cutters must be ground radially to preserve the tooth shape, **Figure 19-34**. An index disc or a form cutter grinder can be used.

## 19.9.5 Grinding Taps

A universal tool and cutter grinder can also be used to resharpen taps. A tap becomes dull when the leading edges of the starting chamfer become worn. The chamfer can be reground by mounting the tap in a workhead, **Figure 19-35**. Flutes are reground using a straight wheel with an edge that has been shaped to fit the flutes.

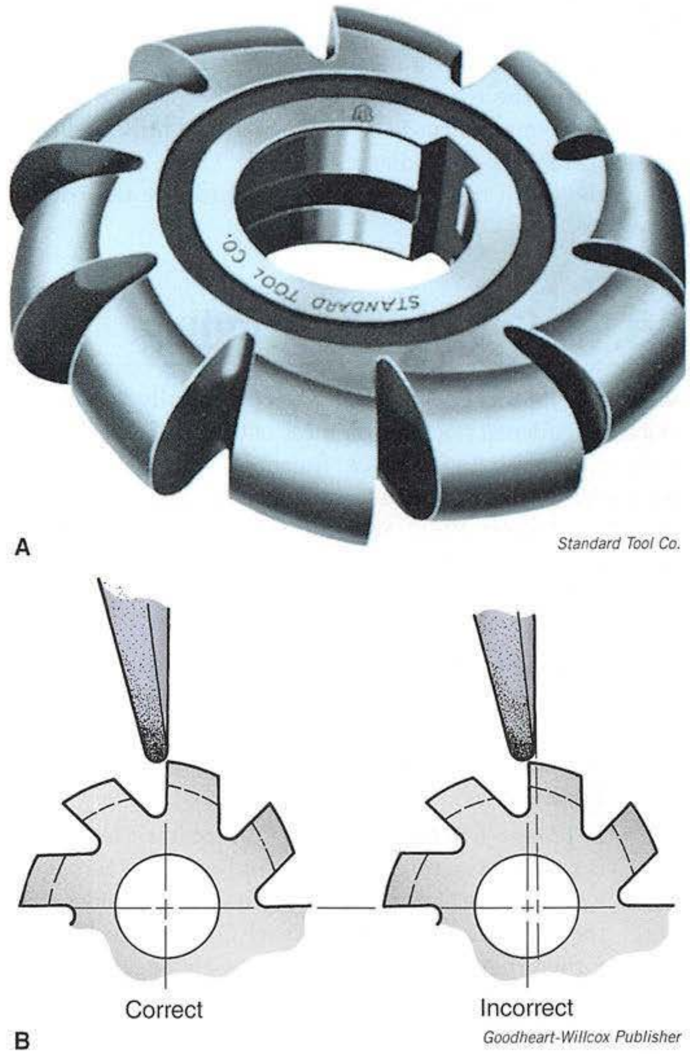
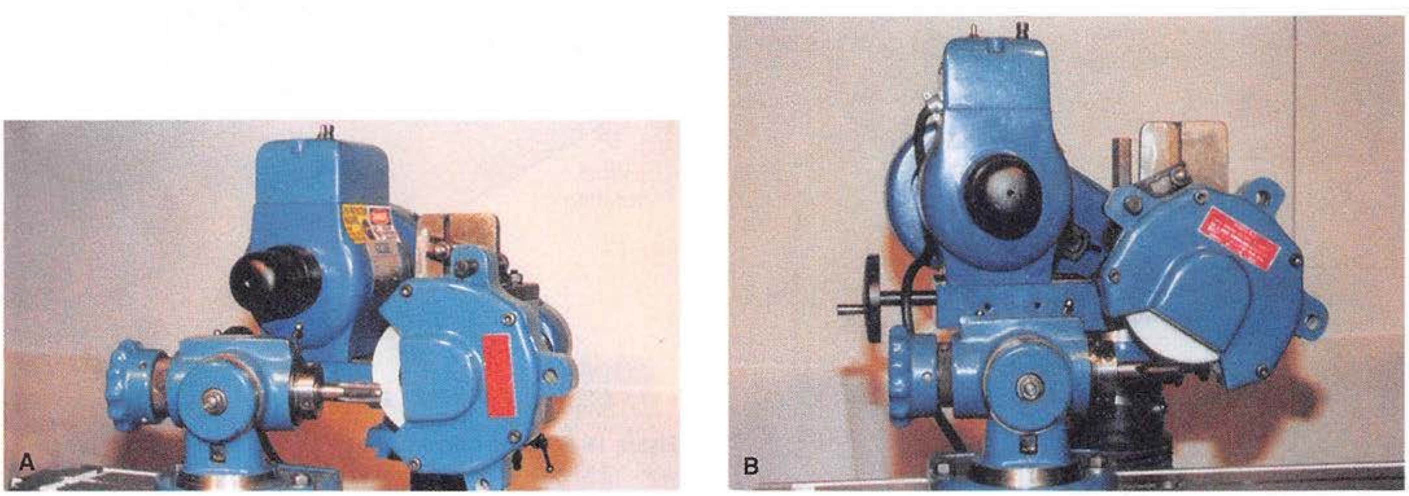



**Figure 19-34.** Form tooth cutters. A—This convex cutter is typical of form tooth cutters. B—Form tooth cutters must be ground radially. Otherwise, the form or shape that the cutter was designed to machine will be altered.




K.O. Lee Co.

**Figure 19-35.** Grinding taps. A—Setup for regrinding a chamfer on a tap. B—Flutes are being reground on a tap to renew the cutting edges of the teeth.

### 19.9.6 Grinding Reamers

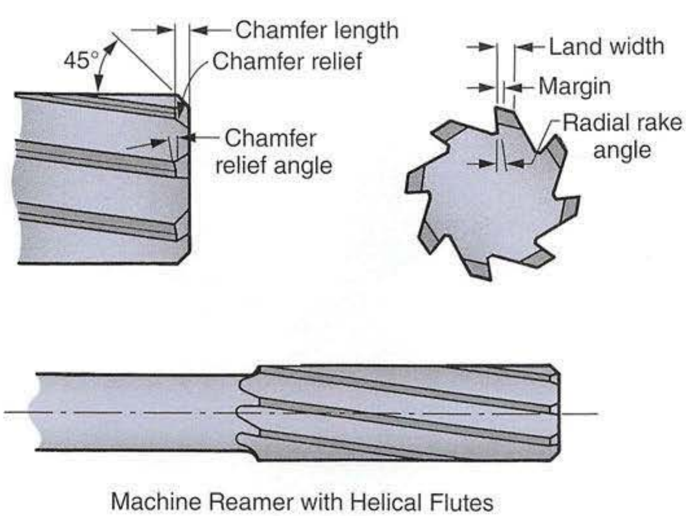
The cutting action of a machine reamer takes place at the front end of the teeth, **Figure 19-36**. Sharpen the reamer in the same manner used to sharpen a face milling cutter. The worktable is pivoted at a 45° angle. Using a cup wheel, adjust the tooth rest and grinding head to give the correct clearance.

## 19.10 Cylindrical Grinding

With a cylindrical grinder, it is economically feasible to machine hardened steel to tolerances of 0.00001″ (0.0002 mm) with extremely fine surface finishes. Work is mounted between centers and rotates while in contact with the grinding wheel, **Figure 19-37**. Straight, taper, and form grinding operations are possible with this technique. Two variations of cylindrical grinding are traverse grinding and plunge grinding.

- In ***traverse grinding***, a fixed amount of material is removed from the rotating workpiece as it moves past the revolving grinding wheel. Work wider than the face of the grinding wheel can be ground. See **Figure 19-38**.
- In ***plunge grinding***, the work still rotates. However, it is not necessary to move the grinding wheel across the work surface. The area being ground is no wider than the wheel face. Grinding wheel infeed is continuous rather than incremental (minute changes at end of each cut), **Figure 19-39**.

**Figure 19-40** shows both techniques being used to grind to a shoulder.




Goodheart-Willcox Publisher

**Figure 19-36.** Cutting edges of a machine reamer.

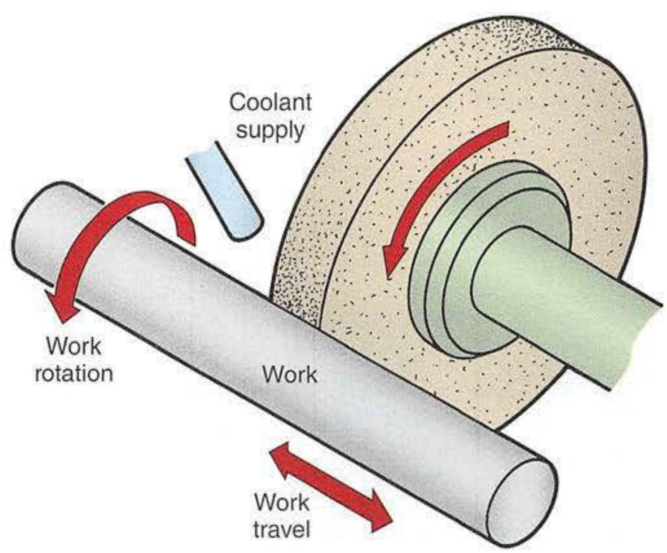
### 19.10.1 Holding and Driving the Work

As the work rotates on centers, it is extremely important that the centers be free of dirt and nicks. They must also run absolutely true. If possible, the head center should be ground in place. The center holes must also be clean, have the correct shape and depth, and be well-lubricated.

Long work is best supported by work rests, **Figure 19-41**. The work rests support the workpiece from the back and bottom and are adjustable to compensate for material removed in the grinding operation.

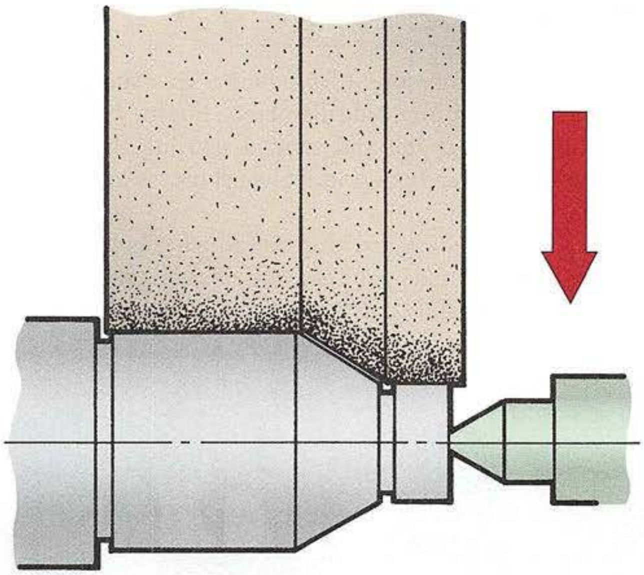
Landis Div. of Western Atlas

**Figure 19-37.** Close-up of a cylindrical grinding operation.




Goodheart-Willcox Publisher

**Figure 19-38.** The principle of traverse grinding. The rotating work moves past the rotating grinding wheel.



Goodheart-Willcox Publisher

**Figure 19-39.** In plunge grinding, the grinding wheel is fed into the rotating work. Because the work is no wider than the grinding wheel, reciprocating motion is not needed.

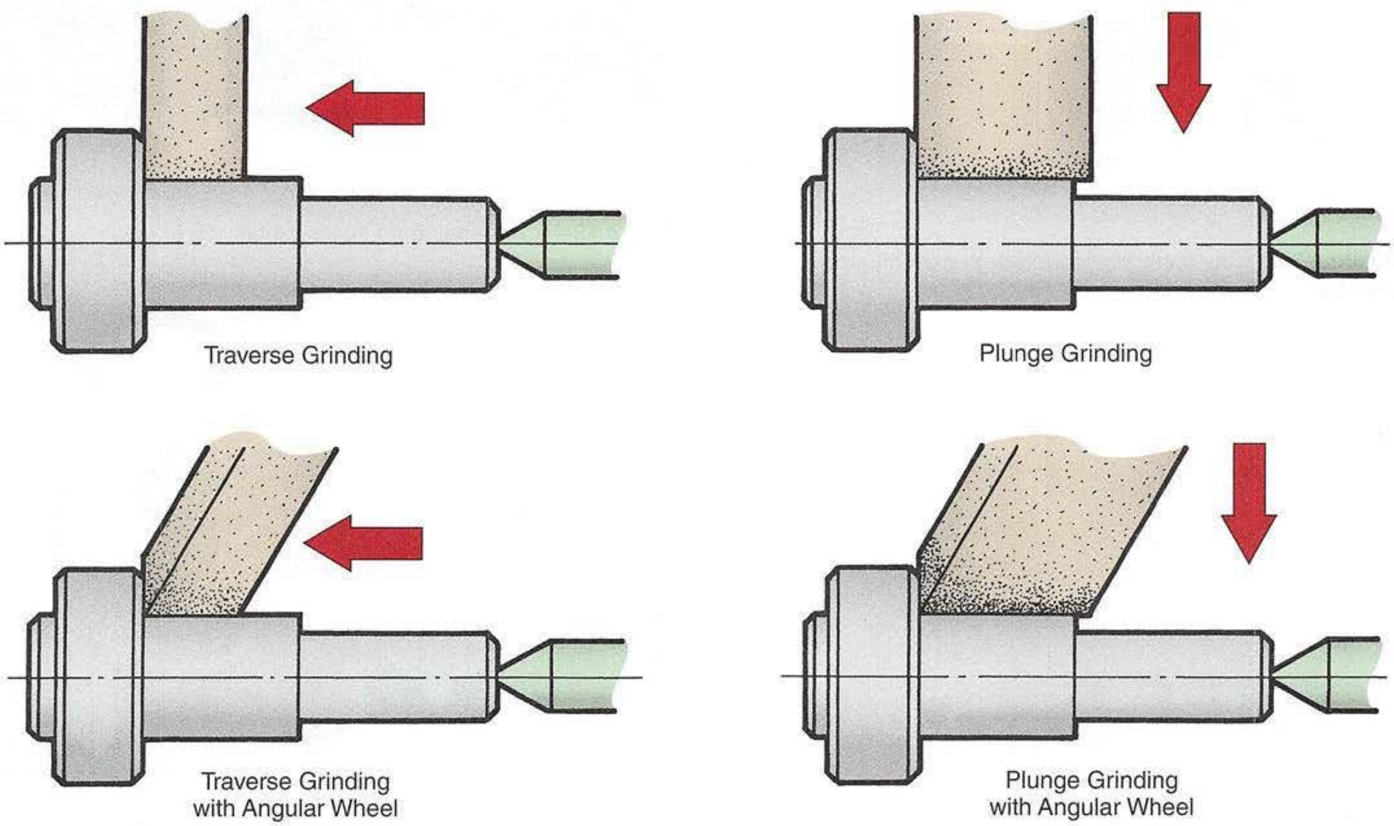
The work can be rotated using a drive plate that revolves around the headstock center and an adjustable drive pin and dog, **Figure 19-42**. Work can also be mounted in a chuck.

## 19.10.2 Machine Operation

To ensure a good finish and accurate size, it is vital that work rotation and traverse table movement (back and forth in front of the grinding wheel) be smooth and steady. Adjust table movement so that the wheel overruns the work end by about one-third the width of the wheel face, **Figure 19-43**. This permits the grinding wheel to do a more accurate grinding job. Insufficient runoff results in work that is oversize. Complete runoff of the grinding wheel causes the piece to be undersize.

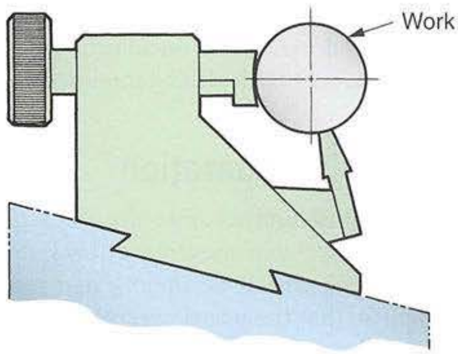
The grinding wheel must be trued and balanced. Otherwise, vibration will cause chatter marks on the work and may cause it to be out-of-round.

Cutting speeds and feeds can be determined from information available on charts furnished by the grinding machine and grinding wheel manufacturers. The charts also specify which coolant will give the best results.



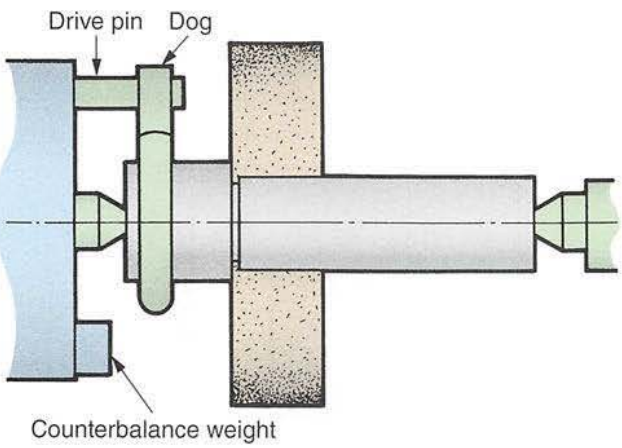

Goodheart-Willcox Publisher

**Figure 19-40.** Grinding to a shoulder using traverse and plunge grinding techniques.



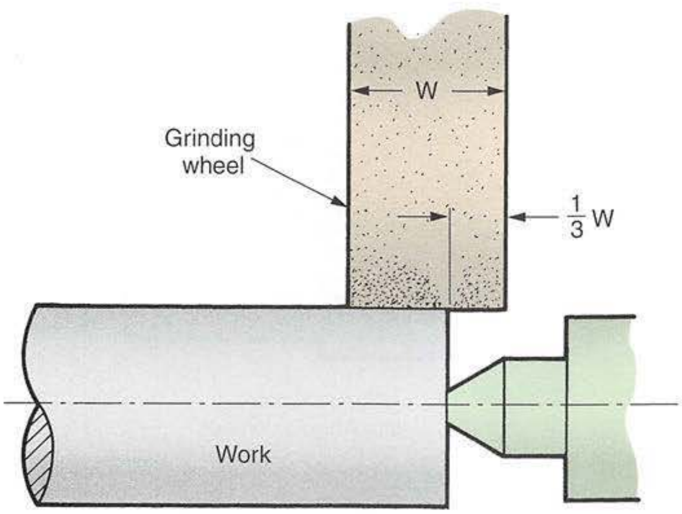

Goodheart-Willcox Publisher

**Figure 19-41.** Work rests should be placed every four or five diameters along the work for support. They must be adjusted after each grinding pass.




Goodheart-Willcox Publisher

**Figure 19-42.** One method used to rotate work on a cylindrical grinder.



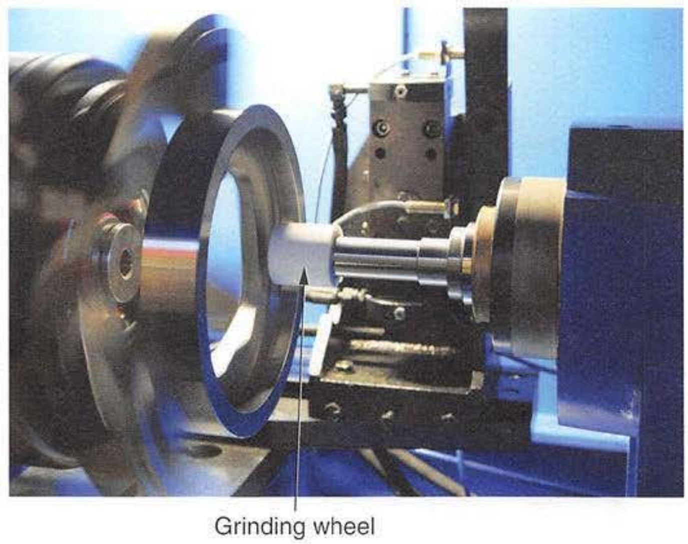

Goodheart-Willcox Publisher

**Figure 19-43.** Table movement should permit the wheel to extend about one-third of its width beyond the end of the work. This ensures that the wheel removes the proper amount of metal, improving the accuracy of the job.

# 19.11 Internal Grinding

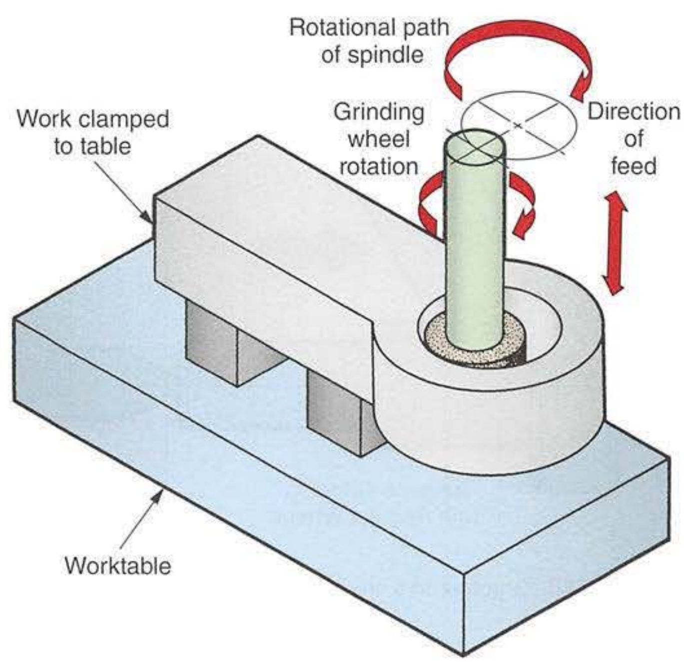
***Internal grinding*** is done to produce a fine surface finish with high accuracy on inside diameters, **Figure 19-44**. Work is mounted in a chuck and rotated. During the grinding operation, the revolving grinding wheel moves in and out of the hole.

A type of grinding machine that finishes holes in pieces too large to be rotated by the conventional machine is shown in **Figure 19-45**. Hole diameter is controlled by regulating the diameter of the circle in which the grinding head moves.




sspopov/Shutterstock.com

**Figure 19-44.** Internal grinding operation.




Goodheart-Willcox Publisher

**Figure 19-45.** Internal grinding technique used when work is too large or odd-shaped to be rotated.

## 19.12 Centerless Grinding

In *centerless grinding*, the work does not have to be supported between centers because it is rotated against the grinding wheel. Instead, the piece is positioned on a work support blade and is fed automatically between a regulating or feed wheel and a grinding wheel. See **Figure 19-46**. The regulating wheel causes the piece to rotate, and the grinding wheel does the cutting. Feed through the wheels is obtained by setting the regulating wheel at a slight angle.

There are four variations of centerless grinding. See **Figure 19-47**.

- **Through-feed grinding.** This method can be used only to produce simple cylindrical shapes. The work is fed continuously by hand, or from a feed hopper, into the gap between the grinding wheel and the regulating wheel. The finished pieces drop off the work support blade.

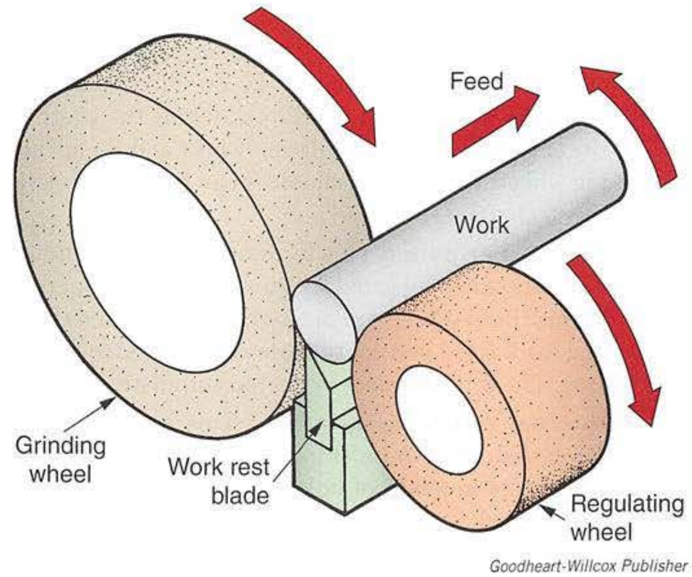



**Figure 19-46.** Basic arrangement for centerless grinding.

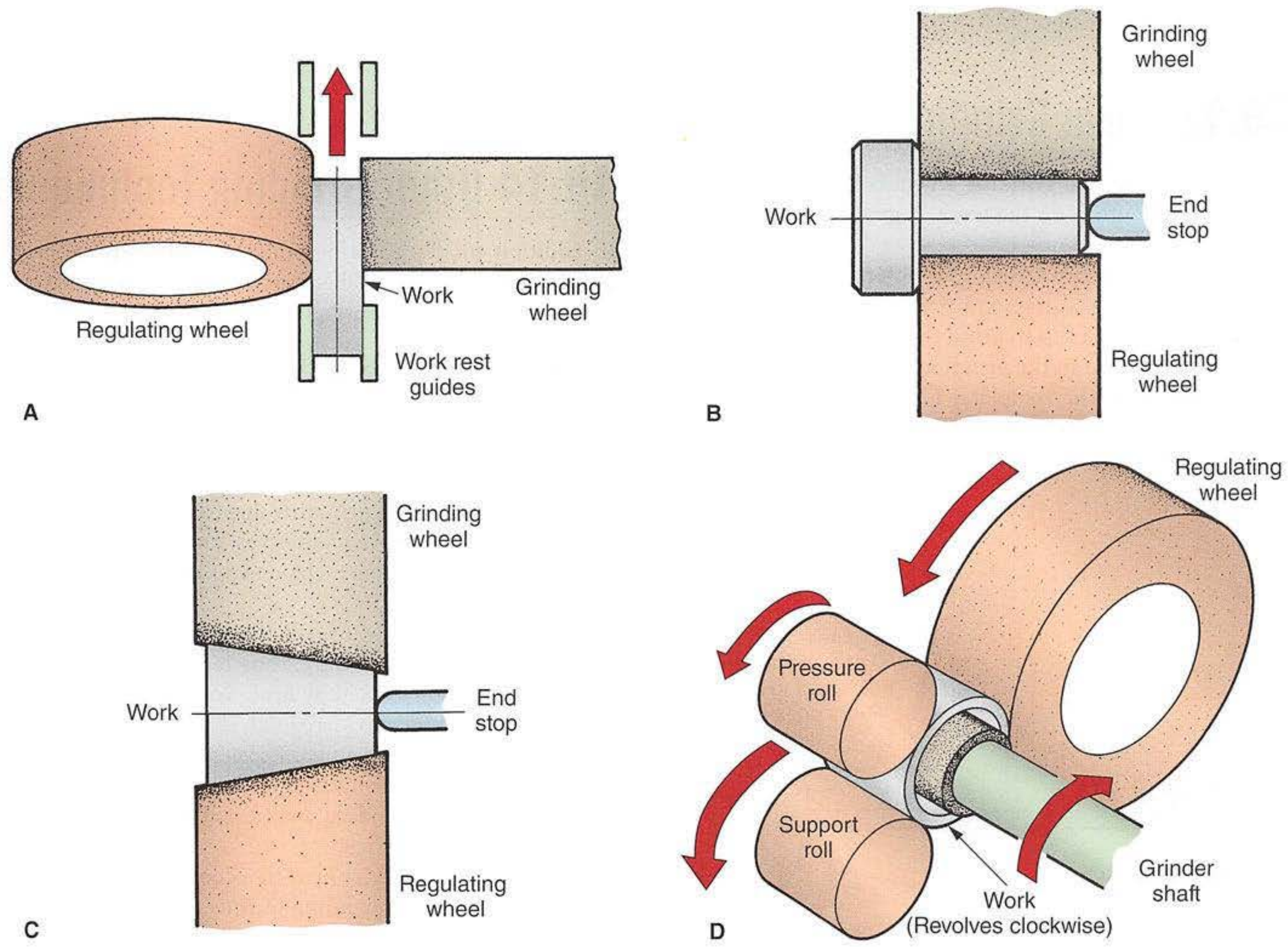



**Figure 19-47.** Centerless grinding variations. A—Through-feed centerless grinding. The angle of the regulating wheel pulls the work over the grinding wheel. B—Infeed centerless grinding. The work is fed into the wheel gap until it reaches a stop. The piece is ejected when the grinding operation is complete. C—End-feed centerless grinding is best suited for grinding short tapers and spherical shapes. D—Setup for internal centerless grinding.

- **Infeed grinding.** This technique feeds the work into the wheel gap until it reaches a stop. The piece is ejected at the completion of the grinding operation. Work diameter is controlled by adjusting the width of the gap between the regulating wheel and the grinding wheel. Work with a shoulder can be ground using this technique.
- **End-feed grinding.** This form of centerless grinding is ideally suited for grinding short tapers and spherical shapes. Both wheels are dressed to the required shape and work is fed in from the side of the wheel to an end stop. The finished piece is ejected automatically.
- **Internal centerless grinding.** This method minimizes distortion in finishing thin-wall work and eliminates reproduction of hole-size errors and waviness in the finish.

Centerless grinding is used when large quantities of the same part are required. Production is high and costs are relatively low, because there is no need to drill center holes or to mount the work in a holding device. Almost any material can be ground by this technique.

# 19.13 Form Grinding

In ***form grinding***, the grinding wheel is shaped to produce the required contour on the work. **Figure 19-48** shows this principle.

Thread grinding is an example of form grinding. A form or template guides a diamond dressing wheel that shapes the grinding wheel used to grind the required thread shape. The pattern formed in the grinding wheel is a mirror image of the pattern in the template, **Figure 19-49**. The grinding machine automatically compensates for the material removed from the grinding wheel when it is dressed.

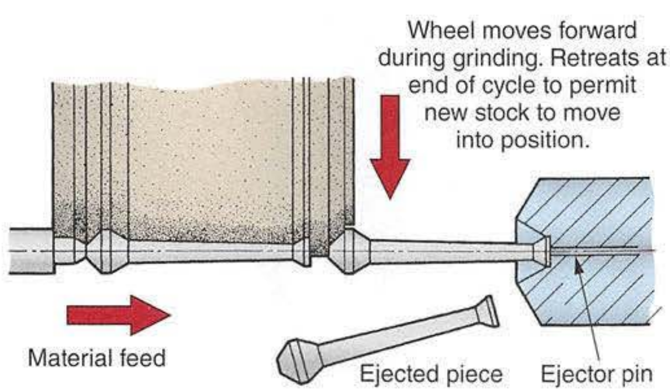



**Figure 19-48.** Form grinding of this engine part is done at rate of 200 pieces an hour. The material was heat-treated before grinding.

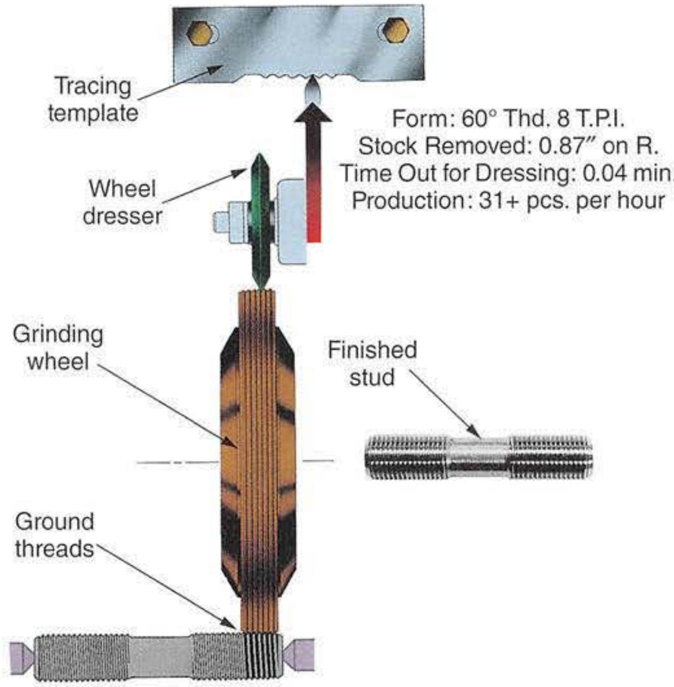



**Figure 19-49.** Precision threads are being form-ground on a special stud.

# 19.14 Other Grinding Techniques

In addition to the grinding techniques already described, industry makes considerable use of other abrasive processes. These processes are described in the following paragraphs.

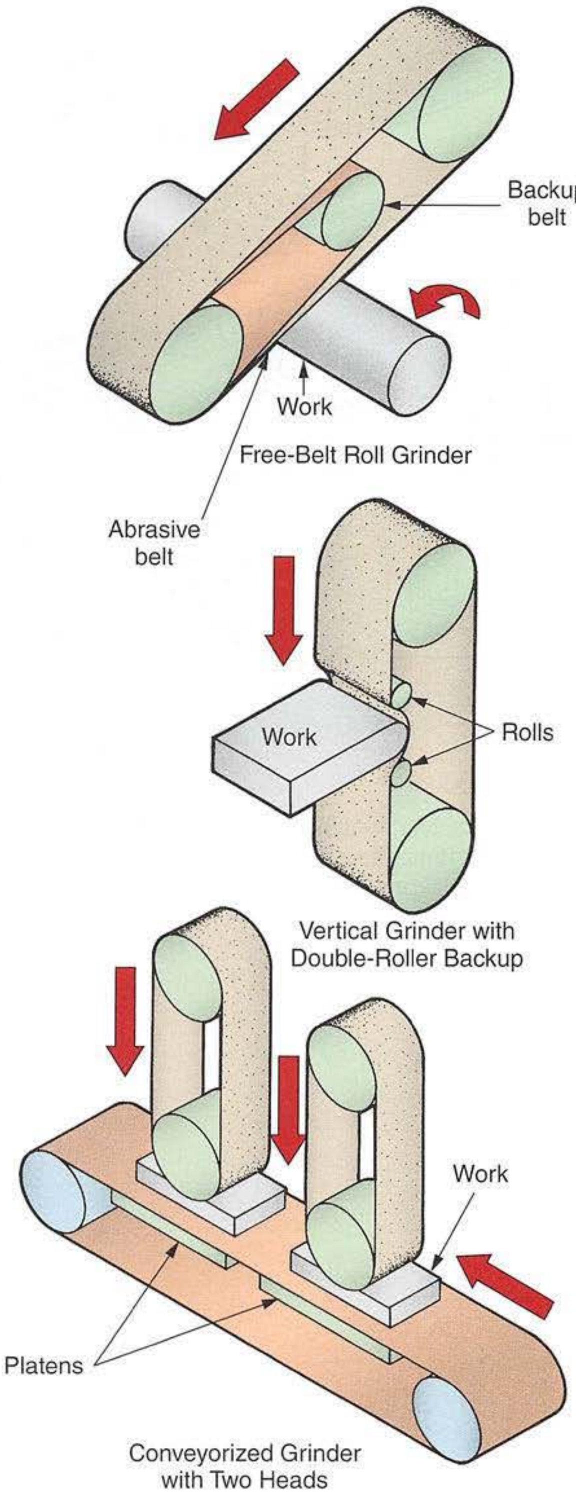
## 19.14.1 Abrasive Belt Machining

Abrasive belt grinding was first used for light stock removal and polishing operations. However, the technique has advanced so that high-rate metal removal to close tolerances is now possible. This is primarily due to tougher and sharper abrasive grains, improved adhesives, and stronger backings. Several abrasive grinding machine applications are shown in **Figure 19-50**.

Abrasive belts, because of their length, run cool and require light contact pressure, thus reducing the possibility of metal distortion caused by heat. Soft contact wheels and flexible belts conform to irregular shapes. A major advantage of abrasive belt grinding is its versatility. A machine can be converted quickly from heavy stock removal to finishing operations, or for grinding a different material, by simply changing the abrasive belt.

Belts may be used dry or with a coolant. The most satisfactory belt speed for grinding ferrous and nonferrous metals is between 5000 and 9000 surface feet per minute (sfm). Slower speeds of 1500 to 3000 sfm are required for tougher materials such as titanium.

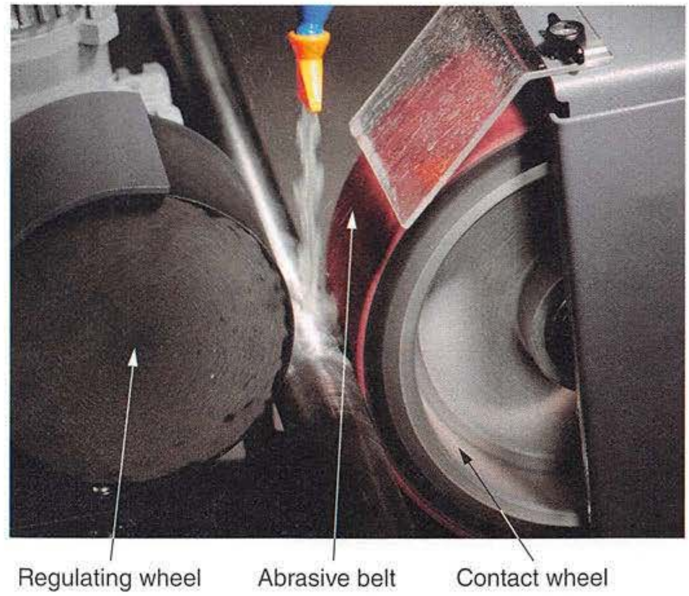
Abrasive belt grinding usually requires support behind the belt, **Figure 19-51**. This may be in the form of contact




Goodheart-Willcox Publisher

**Figure 19-50.** A few of the many abrasive belt grinding techniques.

wheels or platens. Contact wheels are usually made of cloth or rubber. The hardness and density of the contact wheel affects stock removal and finish. Serrated or slotted wheels improve cutting action and prolong abrasive belt life.




C. & E. FEIN GmbH

**Figure 19-51.** The contact wheel supports the abrasive belt to prevent it from deflecting when it contacts the work.

***Platens*** are made of metal (some have cemented carbide inserts) and are usually not as effective as contact wheels. They are flat, but can be shaped to conform to the contour required on the work. Jets of air or water may be applied between the belt and platen to reduce friction.

## 19.14.2 Electrolytic Grinding

***Electrolytic grinding*** is actually a form of electrochemical machining. Applications of this technique include rapid removal of stock from alloy steel parts, sharpening carbide tools, and machining heat-sensitive work.

An electric current is passed between a metal-bonded grinding wheel (cathode) and the work (anode) through a conductive electrolyte, **Figure 19-52**. The surface of the work is attacked electrochemically and is dissolved in a process similar to electroplating, but in reverse.

The dissolved material is removed by the wheel. No burr is developed, making it possible to machine materials such as stainless steel and exotic metal honeycomb sections. No heat is generated, and there is no metallurgical change in the metal.

## 19.14.3 Computer-Controlled (CNC) Grinders

Many types of computer numerical control (CNC) grinders are available. These machines are designed to operate automatically. Functions such as positioning, spindle start and stop, vertical feed motion, and linear feed rates are programmed into the machine's computer. This relieves the operator of the responsibility for controlling and monitoring the numerous coordinate settings and related machine functions.