Study Unit

# Toolholding Systems

Preview

You've studied the process of machining and the various types of machine tools that are used in manufacturing. In this unit, you'll take a closer look at the interface between the machine tools and the work piece: the toolholder and cutting tool. In today's modern manufacturing environment, many sophisticated machine tools are available, including manual control and computer numerical control, or CNC, machines with special accessories to aid high-speed machining. Many of these new machine tools are very expensive and have the ability to machine quickly and precisely. However, if a careless decision is made regarding a cutting tool and its toolholder, poor product quality will result no matter how sophisticated the machine. In this unit, you'll learn some of the fundamental characteristics that most toolholders have in common, and what information is needed to select the proper toolholder.

**When you complete this study unit, you'll be able to**

- Understand the fundamental characteristics of toolholders used in various machine tools
- Describe how a toolholder affects the quality of the machining operation
- Interpret national standards for tool and toolholder identification systems
- Recognize the differences in toolholder tapers and the proper applications for each type of taper
- Explain the effects of toolholder concentricity and imbalance
- Access information from manufacturers about toolholder selection

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# Contents

# Toolholding Systems

## OVERVIEW OF MACHINE TOOLS

### Types of Machine Tools

Many different types of machine tools are used in manufacturing environments. Each of these machine tools has its own special capabilities. Some of the more common machining operations include turning, milling, drilling, and boring, but many more are possible. Figure 1 shows a schematic depiction of machining operations. In some machines, the work piece is moved while the cutting tool remains stationary. In others, the tool is moved while the work piece remains stationary. On some machines, such as various grinding machines, both the cutting tool and the work piece are moving.

In addition to the operations shown in Figure 1 that cut metal, also known as *chip-making* operations, some specialized machines are used for hole punching, riveting, welding, flame cutting, tubing bending, stamping, and even inspection.

Machine tools have been around for more than a hundred years and have become more sophisticated as knowledge of materials and machining techniques have advanced. Lathes for turning wood and metal were used as early as the 1600s. As knowledge of materials, especially steels, increased, machine tools were developed that were capable of performing cutting and shaping operations on a wide variety of materials with great precision. Machine tools that could cut metal quickly and accurately were in great demand during and after World Wars I and II. With the advent of *numerical*

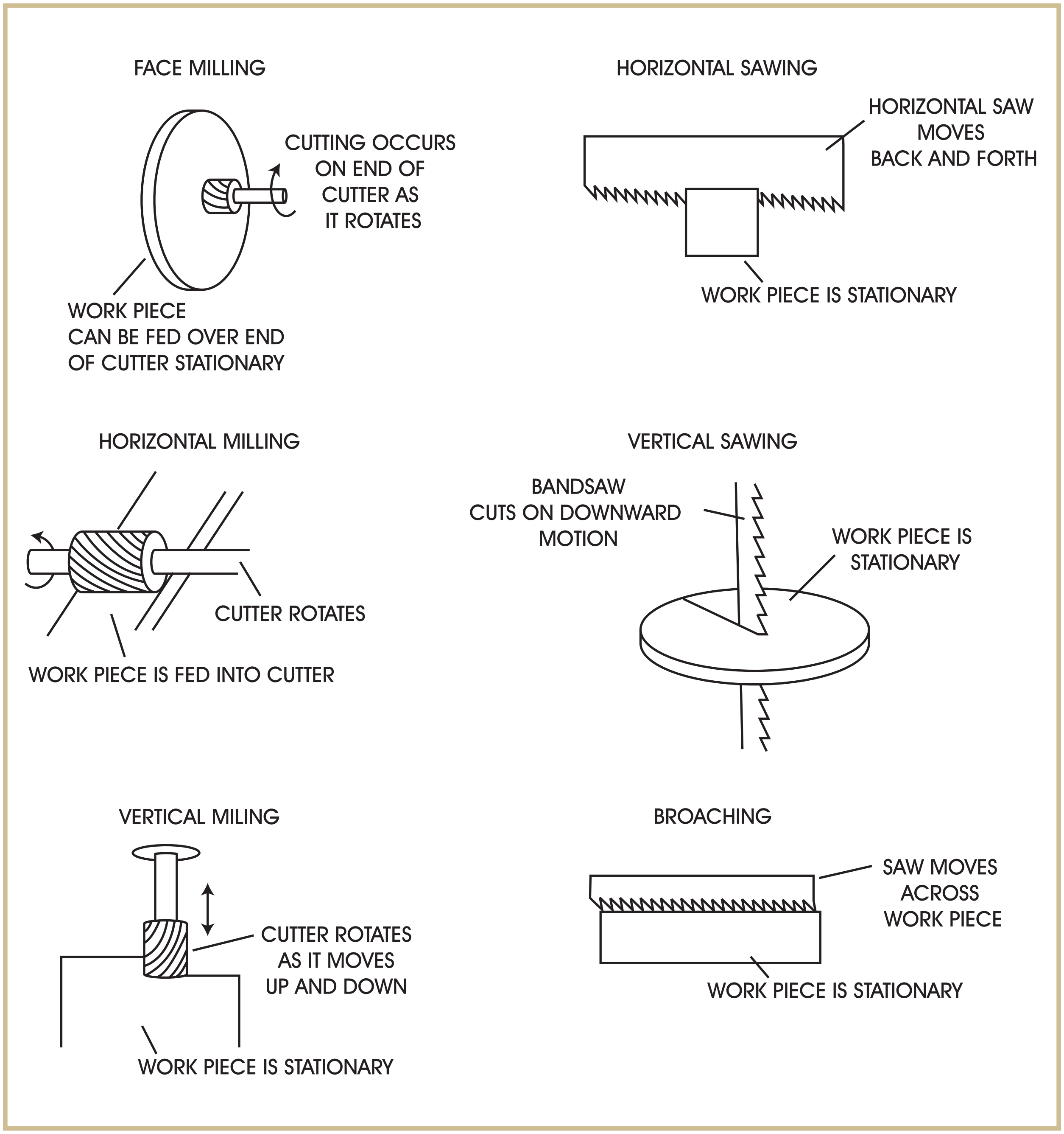



***FIGURE 1—Machining processes use a combination of tool work and piece motions to achieve the desired final geometries.***

*control*, machine tools were made that could be controlled automatically by means of a paper tape with punched holes, much like a player piano. Eventually, these numerically controlled, or *NC* machines, gave way to *computer numerical control*, or *CNC*, machines, in which an electronic computer controlled the operations of the machine tool.

These early CNC machines have now evolved into what are known as *machining centers*, where numerous operations are completely automatic. Modern machining centers can automatically load one or more work pieces, perform a complex sequence of machining operations, change cutting tools, and unload the finished work from the machine. These operations can all be accomplished without the assistance of a human operator. Often the only operation the machinist must perform is to prepare the work for the automatic work handler, and then to turn on the machine. The responsibilities of a modern machinist involve writing the program that tells the machine what operations to perform and in what sequence. Figure 2 shows an example of a modern machining center. Machining centers are so advanced that it's now possible for a computer aided drafting (CAD) operator to draw a part on a computer and send it electronically to the CNC machine to be


***FIGURE 2—A modern machining center includes a computer to control the machining process. The doors lock in the closed position during machining to ensure operator safety.***

made into a real component! Computer software is able to interpret the shape of the part, decide how the tool should travel, and send the electronic machining instructions to the machining center.

Some of the most common types of machine tools include lathes, drilling machines, and milling machines. The basic operations of these machines, and the methods used to mount the cutting tools, are the same whether the machine is a manually operated or CNC machine.

## Lathes

A *lathe* is a machine tool used for turning or facing operations. In these operations, the work piece is rotated, and a cutting tool is used to remove metal from an inside or outside diameter. Lathes are used for production of parts that are symmetrical about an axis of rotation. Figure 3 shows a conventional lathe and a toolholder.

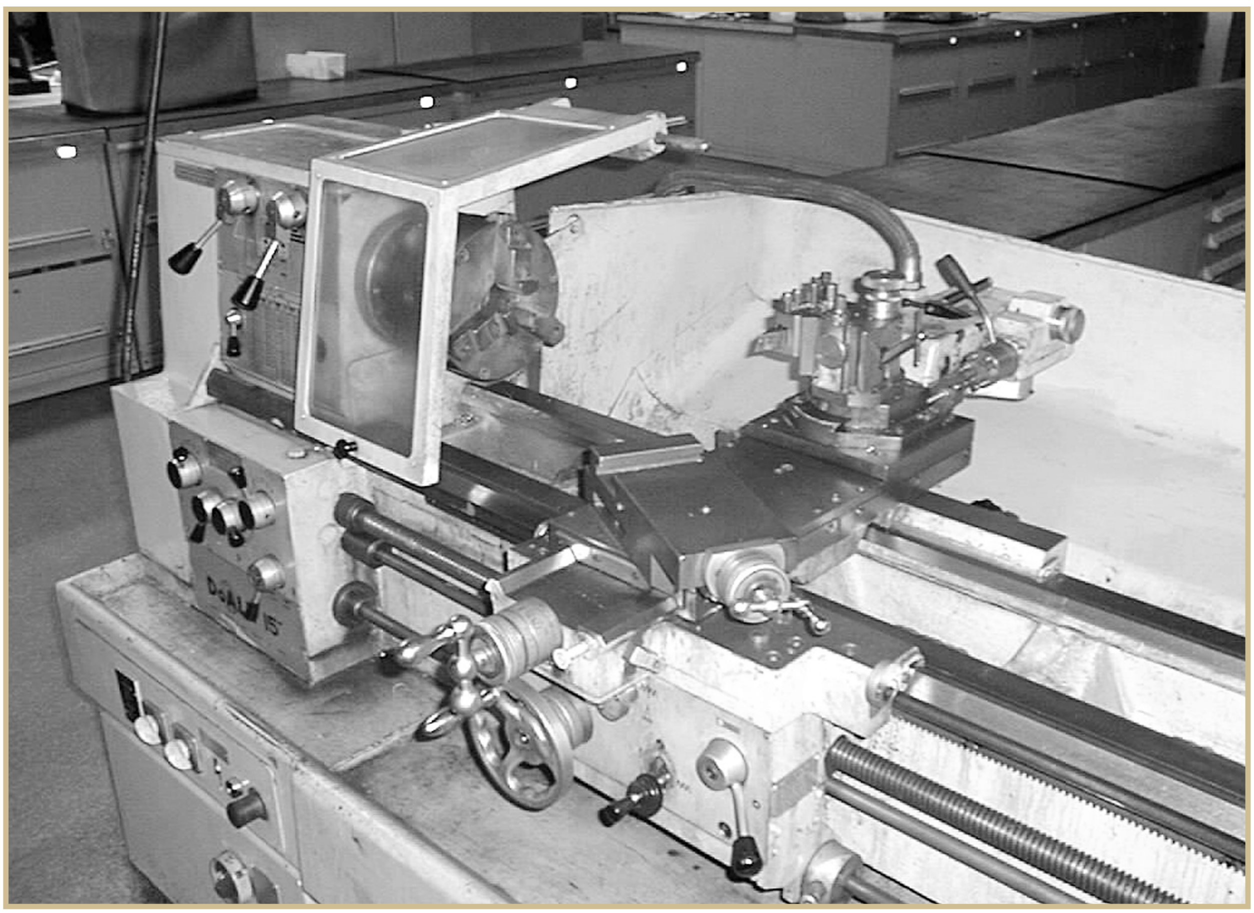



***FIGURE 3—Cutting tools can be changed rapidly in manually controlled lathes.***

The operations of *parting*, or cutting off, facing, turning, threading, grooving, chamfering, profiling, and boring can all be done on a lathe, as illustrated in Figure 4.

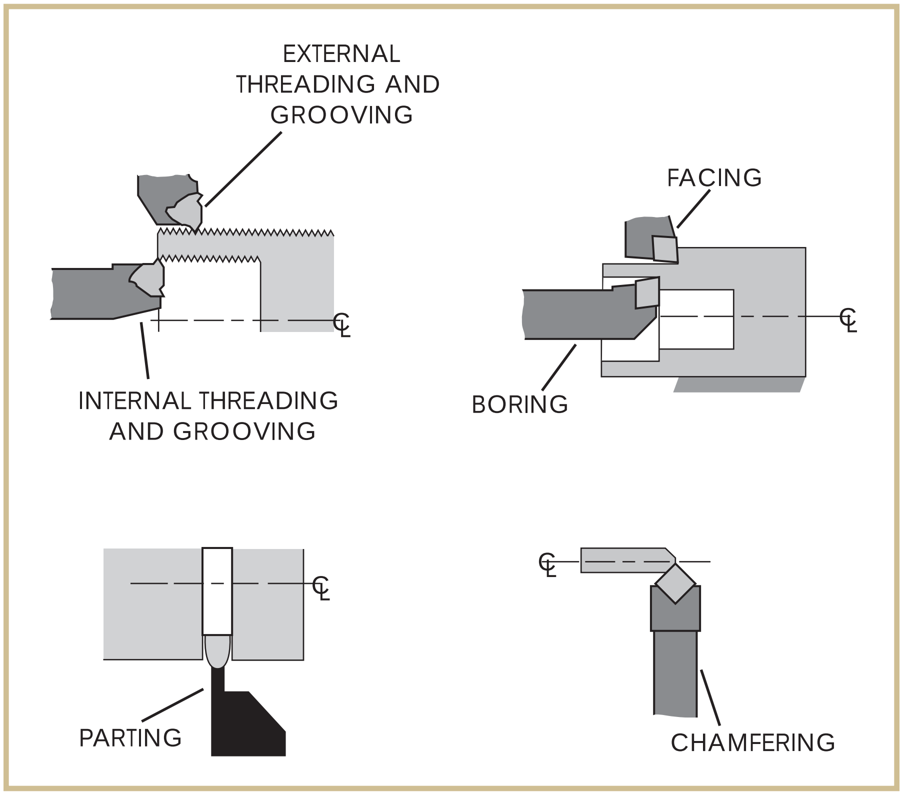



***FIGURE 4—These are some of the many different machining processes performed with a lathe.* (Courtesy of Sandvik Coromant Company)**

## Drilling Machines

A *drilling machine* removes metal from the rotation of either a rotating cutting tool or a rotating work piece. The toolholder advances its position to increase the depth of the hole. Drilling machines are used to perform cutting operations such as drilling holes, reaming, thread tapping, boring, and countersinking. Figure 5 shows a drill and its toolholder. Machines used exclusively for drilling are sometimes called *drill presses*.

## Milling Machines

*Milling machines* are similar to drilling machines, but the cutting tool is usually mounted in the vertical or horizontal axis and the work piece is mounted on a table that can be moved along the x-, y-, or z-axis. Milling machines are often used to produce contoured surfaces, flat surfaces, slots, and

***FIGURE 5—The drill press is dedicated to drilling operations.* (Reprinted with permission from Sears Craftsman)**

countersinks. Figure 6 shows a typical milling machine and a toolholder.

In our study of toolholders, we'll look at the basic characteristics of toolholders that are used in these machines. Many other types of machine tools will have very similar requirements for tools and tool-holders, so your knowledge can be applied to many different situations.

## Toolholders

The basic function of any toolholder is to provide a means of securely and rigidly mounting the cutting tool to the machine. Each of the machine operations shown in Figure 1 has its

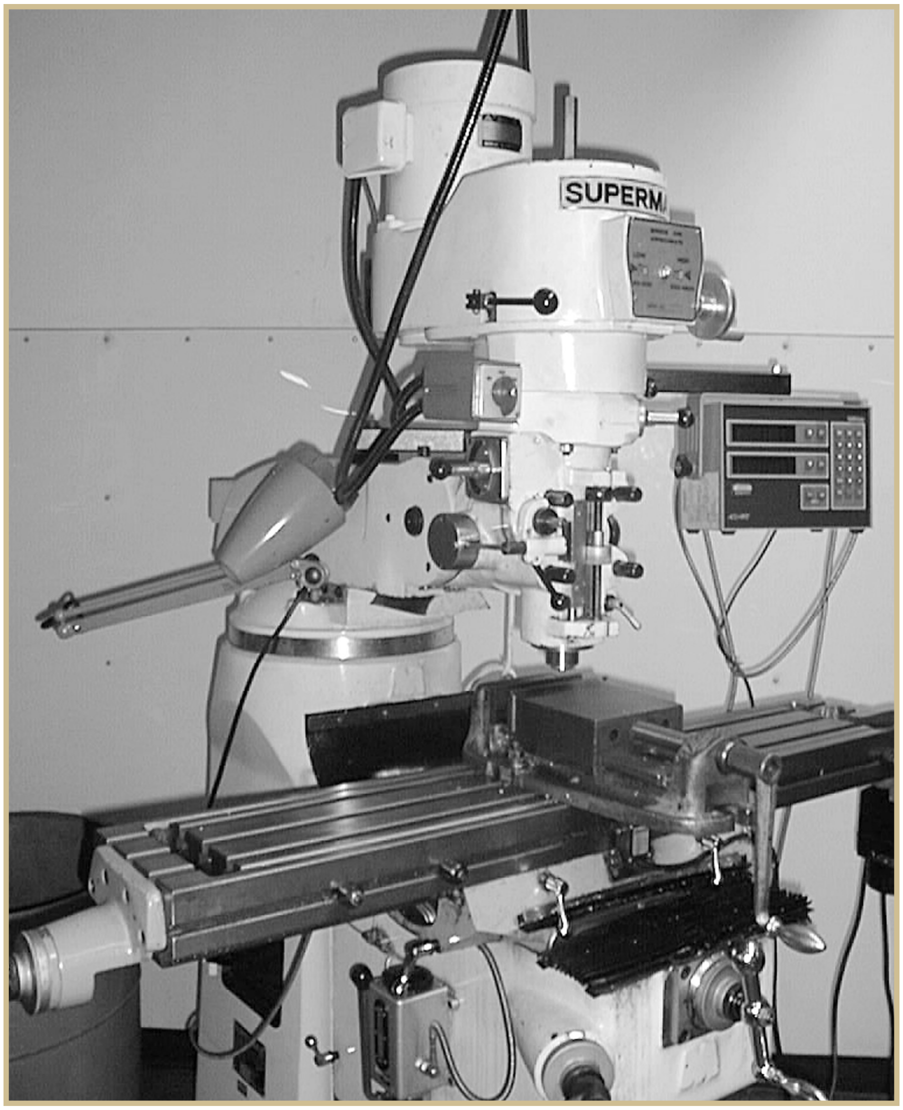



***FIGURE 6—A conventional vertical milling machine is a staple of many machine shops.***

own special requirements for cutting tools and toolholders. No matter what design is required, the combination of the cutting tool, toolholder, and machine spindle must provide three characteristics for effective machining: accuracy, repeatability, and reliability.

## Accuracy

Many machine tools are able to hold tolerances within tenths of thousandths of an inch. For example, a diameter of a cylinder rod may be specified as 1.250 inches, but the allowable tolerance may be only plus or minus 0.0005 inches. Also, the tolerance may have to be held over many inches of part length. Any degradation of the tool rigidity or mounting position prevents the machine tool from achieving its inherent accuracy.

## Repeatability

When the first part is complete and the next one is placed in the machine, it's critical that the second part be machined to the same dimension with the same accuracy as its predecessor. For example, assume that a machine tool is set up to produce a part that's 1.250 inches long, plus or minus 0.0005 inches. A shift in machine settings that would produce a subsequent part that's machined to 1.252, plus or minus 0.0005 inches, has the same accuracy, but isn't acceptable because the basic dimension of 1.250 inches hasn't been maintained. All parts must be machined to the same required dimensions every time that operation is specified.

## Reliability

Over the course of hundreds or thousands of parts, a machine must perform reliably without the assistance of the machine operator. A machine tool or toolholder system that requires constant adjustment or maintenance isn't effective or efficient. In modern machining centers, tools are often changed so that many different operations can be performed. Each time a tool is selected and mounted on the machine for a subsequent operation, the toolholder must be designed to allow for consistent positioning and retention in the machine. This allows the cutting tool to maintain the required accuracy and repeatability. Tool life for the various machining operations should be consistent so that maintenance of the machine can be reliably and efficiently scheduled.

## Toolholder Design

In this study unit, we'll discuss toolholder designs that apply primarily, but not exclusively, to the general class of machine tools in the lathe and milling machine family. There are many other types of machine tools such as grinders, broaches, planers, and other specialized equipment. However, the principles of holding a cutting tool are all similar. Lathes and milling machines are by far the most common, and a well-developed system of toolholder classification has evolved over the years.

The lathe operations we'll discuss mostly involve the use of a stationary cutting tool that's mounted either in a tool post or a turret. A *turret* is an attachment that consists of a block that holds the cutting tools. The operator controls the position of the tool post or turret either manually or automatically by a computer program. The typical lathe toolholder-and-cutting-tool assembly consists of a cutting edge or point mounted in a steel shank, which is in turn attached to a tool post or turret. The turret can be rotated so that any of the tools can be positioned towards the workpiece. Figure 7 shows a typical lathe toolholder-andcutting-tool assembly ready for a turning operation.

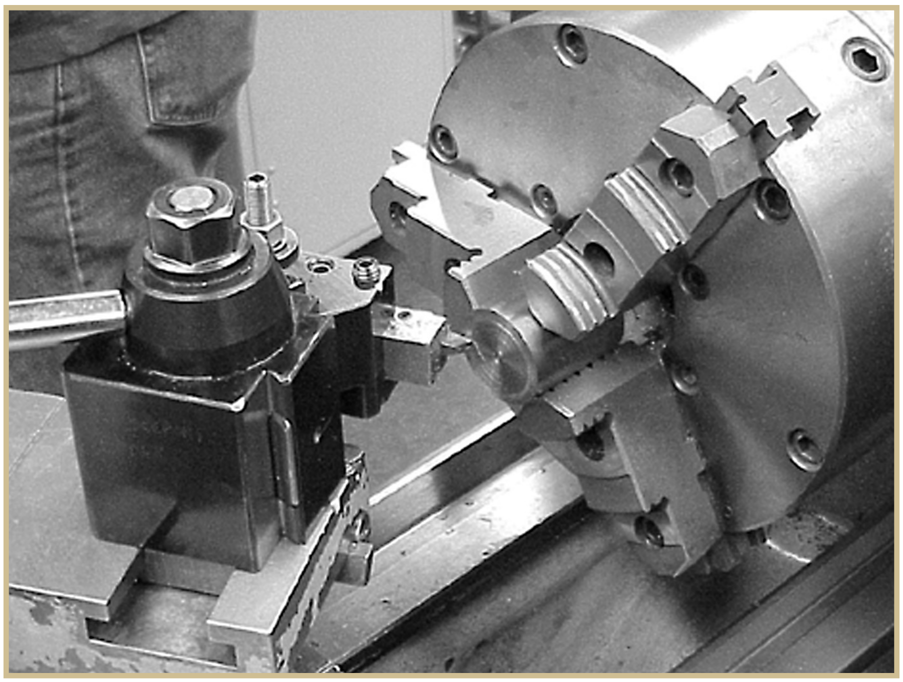


***FIGURE 7—Manually operated lathes are still an invaluable part of the equipment in a machine shop.***

Milling machines are classified as one of two types: a horizontal or vertical design. In both cases, the *spindle* holds the cutting tool, and the work piece is fastened on a table that can be moved in three axes. A spindle is a device that locates a toolholder and serves as an attachment point in the machine tool. Cutting tools are usually mounted in toolholders that are pulled into the spindle by a *draw bar*. The draw bar attaches to the toolholder, often by threading into the back, and seats the toolholder in the proper position. A matching taper on the spindle and toolholder ensures a concentric fit and enough frictional force to withstand machining loads. Figure 8 shows several types of toolholders intended for use in milling machines.

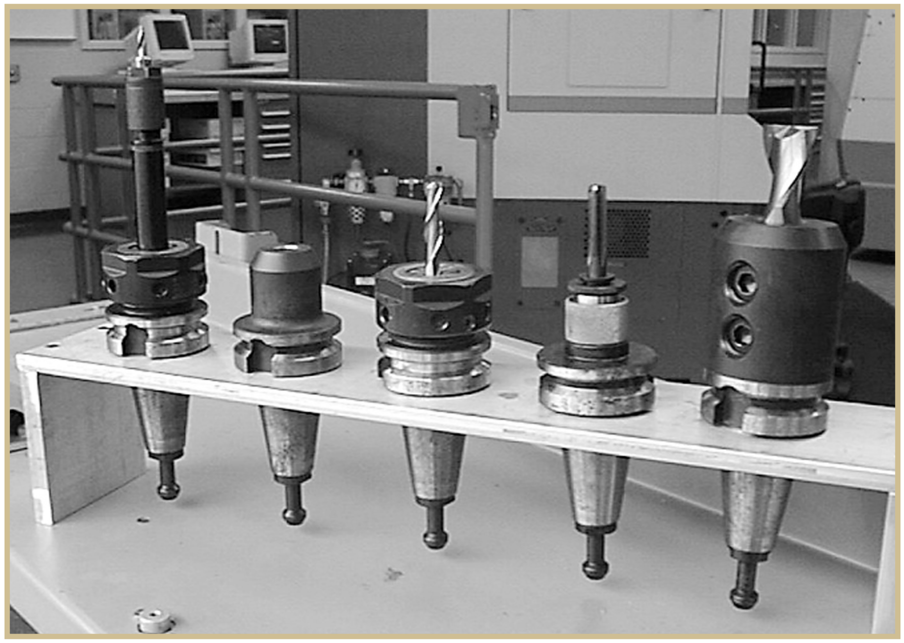


***FIGURE 8—These milling machine toolholders can be loaded for automatic changing. Note that each toolholder has a different tool for a variety of machining capabilities in one machining center.***

Many methods are used to mate the actual cutting tool to the toolholder. *Collets* are often used for this purpose. Collets are a type of *chuck*, a clamplike device that holds the tool. There are two general kinds of collets: spring collets and solid collets. These collets have cylindrical or tapered ends that are used to hold circular pieces. Figure 9 shows some examples of collets. There are many varieties of collets, which are also used in lathes to hold both cylindrical work pieces and cutting tools such as drills or reamers.

In lathes, collets are used both in the spindle and the tailstock. Figure 10 shows a lathe tailstock that's intended to hold a collet.

## Cutting Tools for Turning and Milling Operations

In your study of toolholders, you'll learn about the many different types and styles of toolholders. The first consideration in the selection of the proper toolholder is to understand the

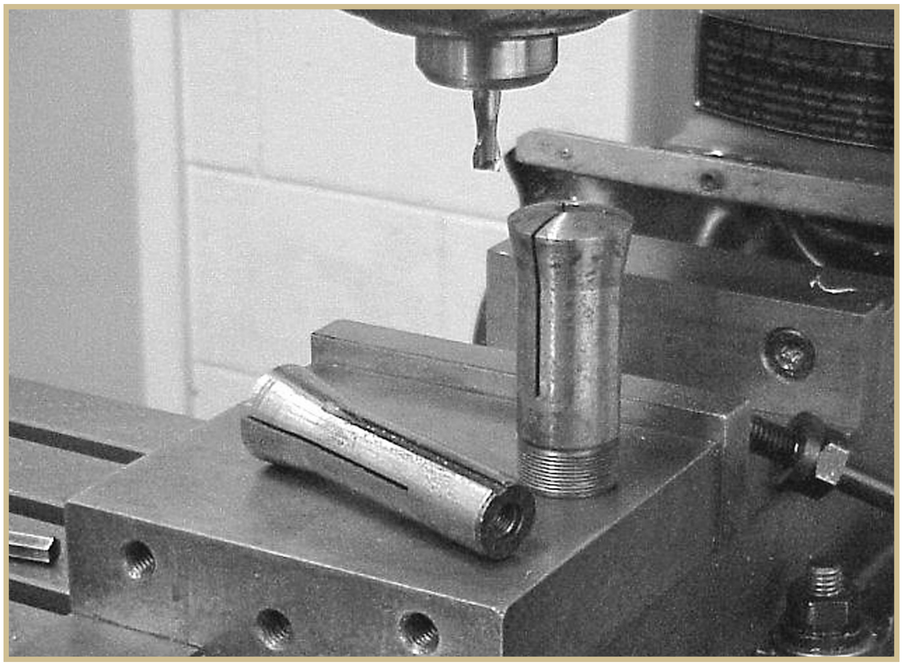


*FIGURE 9—These spring-type collets can be used in both lathes and milling machines. The precision spring fingers provide good concentricity with cutting tool changes.*

cutting tool necessary for the desired machining operation. In this unit we'll be primarily concerned with the more usual chip-making processes of turning, drilling, and milling. We'll take a close look at the typical cutting tools required for these machines. Later, we'll look at how these cutting tools are mounted in toolholders.

## High-Speed Steel

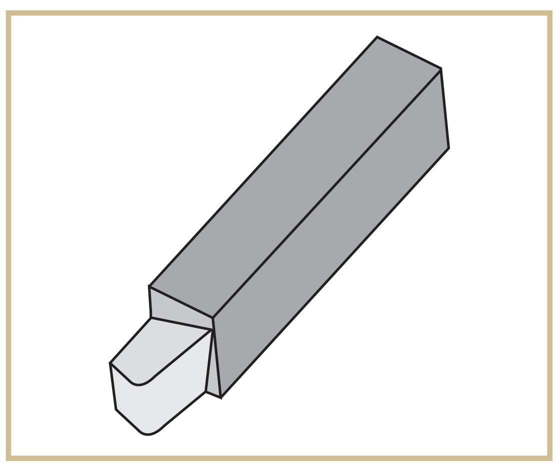
The simplest cutting tool/toolholder is the square or rectangular bar made of high-speed (HS) steel. Figure 11 shows a sample cutting tool, which is made from a hardened steel bar that has been ground to the proper shape. These tools, while simple to make, usually aren't suitable for high-speed, high-precision applications, and are only for machining softer materials at low speeds. The more commonly encountered type of cutting tool uses a steel holder with a much harder insert made of carbide and often coated with an even harder material.

## Cemented Carbides

Because HS steel isn't usually a durable cutting tool, other types of very hard materials were developed to efficiently cut metals. One of the earliest types was known as *cemented*

***FIGURE 10—Collets and tapered cutting tools can be inserted into this lathe tailstock, which has a taper that matches the one found on the cutting tool or toolholder.***

***FIGURE 11—One-piece cutting tools like this are useful only for machining soft materials at low speed.***



*carbide*. A *carbide* is a chemical combination, or compound, of an element (usually a metal) with carbon. Because of the strength and stability of the chemical bond, the resulting material is very stable and very hard. A disadvantage to using these materials is that because they are so hard, they're resistant to normal material manufacturing techniques, making it complicated to form reliable tooling materials. Some of the problems were overcome by using powdered-metal techniques, as discussed in the next section.

The term *cemented carbide* appeared in the 1930s to describe a material that was made of *tungsten carbide* (chemical symbol, WC) particles held together by cobalt metal. Cemented carbide is made using powder metallurgy techniques that involve melting the material and casting it into molds.

Modern cemented carbides are produced by mixing various metal carbides from tungsten, tantalum, vanadium, niobium, chromium, or molybdenum with a binder material that's usually cobalt, nickel, or a combination of nickel and cobalt. This mixture is held together by an organic binder and formed into a desired shape. After forming, the material is sintered in a furnace. The sintering melts the binder material around the carbide particles. After sintering, the material is ground to the final dimensions. Also, these carbide cutting materials are coated with an additional thin coating of titanium nitride (chemical symbol, TiN) to extend the wear life of the tool. This coating is now very often applied to many cutting tools, such as drills and mills. You may see its yellowish coating on the cutting edges of the tools. TiN coatings can extend the life of a typical drill or end mill to many times that of an uncoated tool, making the coating cost well worthwhile.

The American National Standards Institute (ANSI) has standard sizes and designations for eight styles of cemented carbide blanks, which can be purchased in large quantities. The tool consists of a square bar of plain carbon steel, which has been machined to accept an insert made of a hard carbide. The insert is brazed to the holder with a highmelting-temperature braze alloy. The insert is then ground to the desired shape. The machinist must grind the proper tool angles, rake angle, and chip-breaker for the desired application. Cutting tools made in this fashion are often used for custom and one-of-a-kind applications.

Also, many generic tools can be made and used for a variety of common machining jobs that arise in nonproduction applications. Brazed tools can be reground several times until the carbide tip is almost entirely consumed, and a new insert can be brazed. However, improper brazing can lead to lowered hardness or shattering of the tip.

One of the simpler types of cutting tools for turning operations that use a specialized cutting edge is the *single-point cutting tool*. Figure 12 shows one of the many configurations of a tool designed and made for turning parts on a lathe.

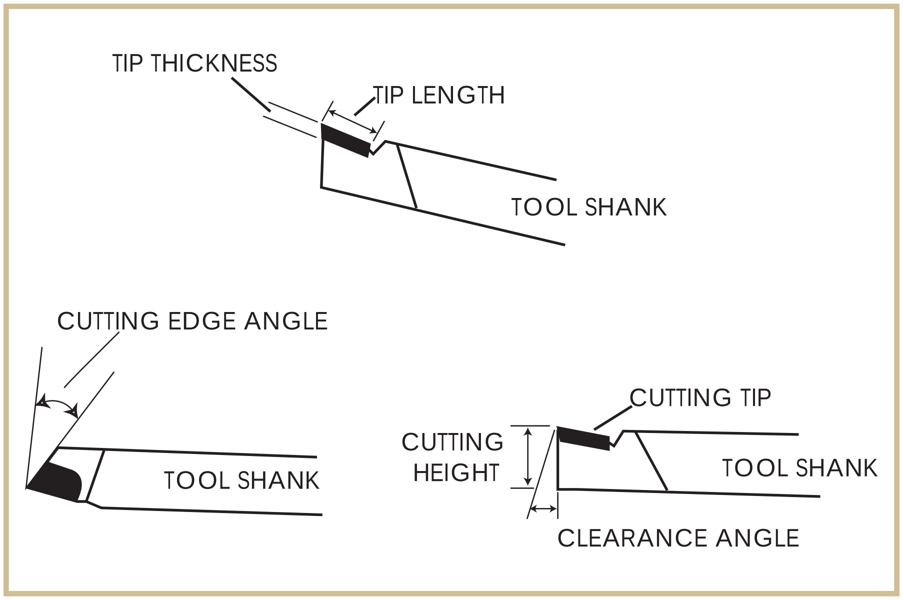



***FIGURE 12—The carbide-tipped cutting tool's cutting edges can be reformed several times after wear, and a replacement insert can be brazed on the steel shank.***

## Indexable Inserts

Because of the problems encountered with brazed-on carbide inserts, most production machining now uses replaceable inserts, or *indexable inserts*. These inserts are tool tips of a precise size, which can be replaced in a toolholder without loss of accuracy and without resetting the tool-holder with respect to the work piece. Figure 13A shows several examples of indexable inserts, and Figure 13B shows how these inserts are mounted in a toolholder. Indexable inserts have multiple cutting edges that are indexed from one edge to another after an edge becomes dull. Tool life (on any cutting edge) is normally between 10 and 20 minutes. It's important to index the insert before a catastrophic failure occurs.

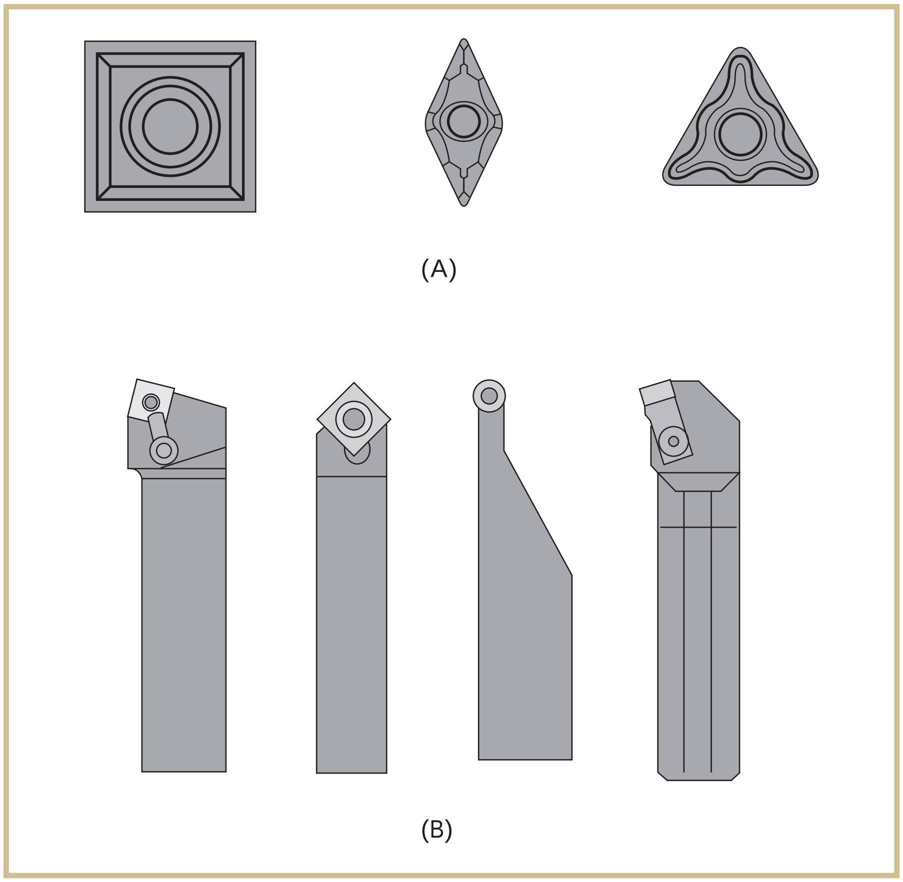



***FIGURE 13—(A) Indexable inserts are available in a wide variety of shapes for special machining tasks. They're stronger when they have larger included angles between the cutting edges. Indexable inserts are mounted on (B) tool-holder shanks in a variety of ways.*** **(Courtesy of Sandvik Coromant Company)**

Inserts are generally divided into three categories that are labeled with a letter designator and a color code. Straight tungsten carbide types are designated with the color red, letter K, and are used for machining cast irons, nonferrous metals, and nonmetallic materials. Highly alloyed grades are designated with the color blue, letter P and are used for machining steel. Less alloyed types are designated with the color yellow, letter M. This grade has less titanium carbide (TiC) than the P type, and is used for machining steels, stainless steels, nickel alloys and ductile cast irons. Within each grade are subgrades that reflect variations in hardness and toughness. Table 1 shows a summary of ISO 513 classifications. Manufacturers' catalogs for inserts are often color-coded for easy reference.

## Ceramics

For more severe applications, ceramic inserts are used. Ceramics are nonmetallic materials that are nonconductive and withstand heat and abrasion better than the cemented

**Table 1**

**ISO CLASSIFICATIONS OF HARD METALS BY APPLICATION**

| Symbol and Color | Designation (Subgrade) | Use and Working Conditions |
|---|---|---|
| P<br>Blue<br>(Machined with ferrous long chips) | P01 | Finish turning and boring; high cutting speeds, small chip sections, accurate dimensions, fine finish, vibration-free operations |
| | P10 | Turning, copying, threading, milling; high cutting speeds; small or medium chip sections |
| | P20 | Turning, copying, milling; medium cutting speeds and chip sections, planing with small chip sections |
| | P30 | Turning, milling, planing; medium or large chip sections, unfavorable machining conditions |
| | P40 | Turning, planing, slotting; low cutting speeds, large chip sections, with possible large cutting angles, unfavorable cutting conditions, and work on automatic machines |
| | P50 | Operations demanding very tough carbides; turning, planing, slotting; low cutting speeds, large chip sections, with possible large cutting angles, unfavorable conditions and work on automatic machines |
| M<br>Yellow<br>(To be machined with ferrous metals with long or short chips, and non-ferrous metals.) | M10 | Turning; medium or high cutting speeds, small or medium chip sections |
| | M20 | Turning, milling; medium cutting speeds and chip sections |
| | M30 | Turning, milling, planing; medium cutting speeds, medium or large chip sections |
| | M40 | Turning, parting off; particularly on automatic machines |
| K<br>Red<br>(To be machined with ferrous metals with short chips, non-ferrous metals and nonmetallic materials.) | K01 | Turning, finish turning, boring, milling, scraping |

(*continued*)

| Table 1 | | |
|---|---|---|
| **ISO CLASSIFICATIONS OF HARD METALS BY APPLICATION (*Continued*)** | | |
| **Symbol and Color** | **Designation (Subgrade)** | **Use and Working Conditions** |
| | K10 | Turning, milling, drilling, boring, broaching, scraping |
| | K20 | Turning, milling, planing, boring, broaching, demanding very tough carbide |
| | K30 | Turning, milling, planing, slotting, unfavorable conditions, and possibility of large cutting angles |
| | K40 | Turning, milling, planing, slotting, unfavorable conditions, and possibility of large cutting angles |

(*Machinery's Handbook,* 25th Edition, pages 750, 751, Table 2, ISO Classifications of Hard Metals)

carbide inserts. Ceramic inserts can be made of alumina, silicon nitride, yttria, and other oxides and nitrides. A *nitride* is a compound of nitrogen and an electropositive element such as boron or silicon. An *oxide* is a chemical compound of an element plus oxygen; for example, silicon dioxide is $SiO_2$, the combination of silicon and oxygen. Oxides are very stable because the bond is very strong. Many oxides of metals are very hard, and much harder than pure or alloyed metals. Alumina ($Al_2O_3$) is a combination of aluminum (normally a very soft metal) and oxygen. It's a ceramic material with a hardness of RC50 or more. Other ceramic materials used are alumina with titanium nitride, and silicon nitride ($Si_3N_4$).

## Superhard Materials

Another class of materials, known as *superhard materials*, is now available for critical applications. Polycrystalline synthetic diamond (PCD) and cubic boron nitride (PCBN, or CBN) are the only two materials in this category, but research continues in the area of superhard cutting tools. Superhard materials are able to machine hard metals and cast iron at high speeds for long periods of time. These materials, however, aren't used extensively due to high cost compared to the other readily available inserts.

## Identification System for Inserts

Because of the great variety of sizes and shapes of inserts, standards organizations, such as ANSI, have developed an identification system to describe the geometry of the inserts.

The ANSI standard B212.4–1986 is an identification system consisting of a series of numbers and letters that designate the features of the insert. Figure 14 shows a chart that describes the function of each digit in the alphanumeric

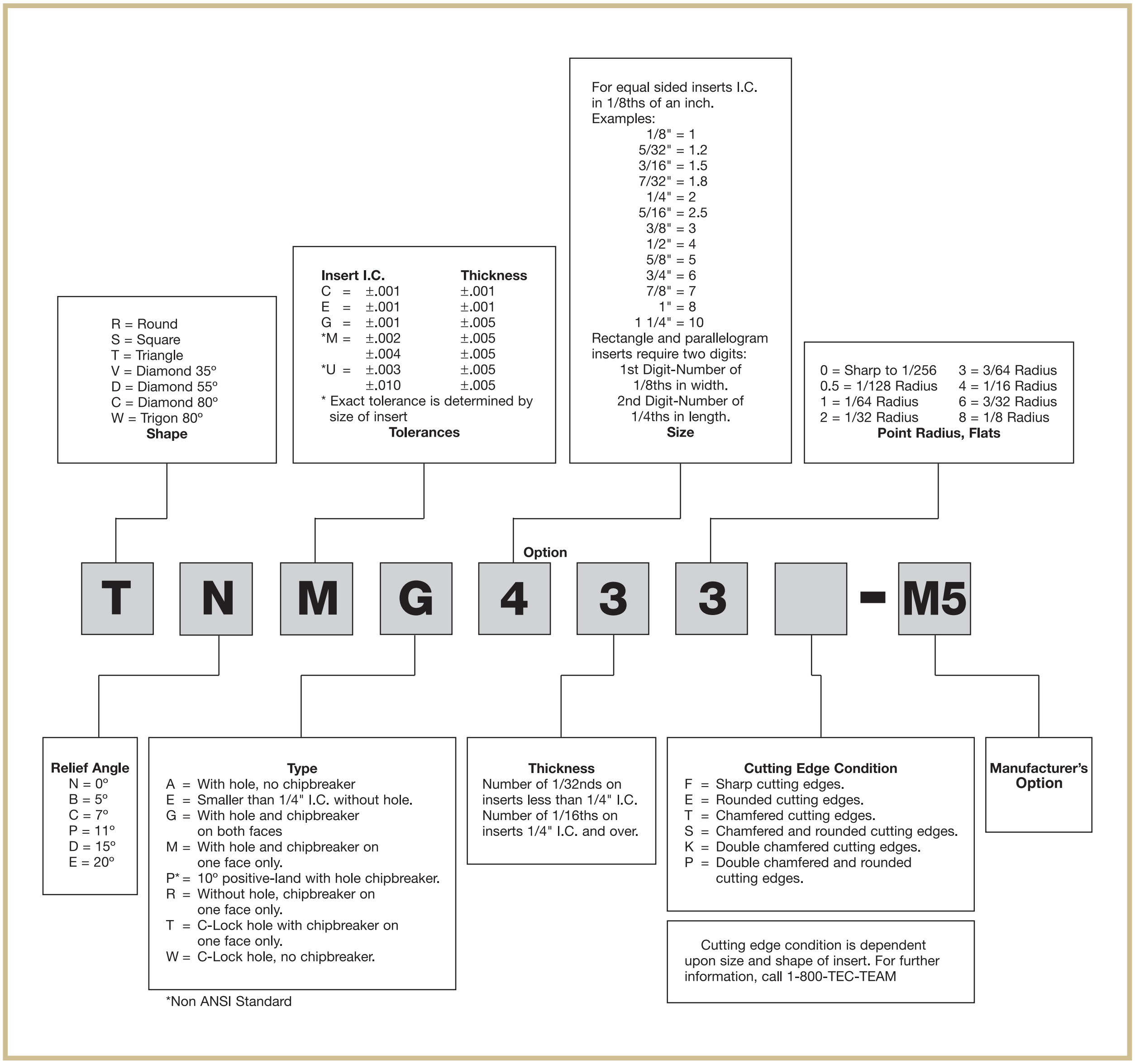



***FIGURE 14—The insert identification system allows the machinist to identify and select the proper insert based on the required cutting process.*** **(Courtesy of Carboloy Inc., www.carboloy.com)**

sequence. Each position describes a characteristic of the insert as follows:

- Shape
- Relief angle
- Tolerance
- Type of insert
- Size
- Thickness
- Cutting-point configuration (radius or flat)
- Special cutting-point condition
- Hand of insert
- Other condition

Different manufacturers may have slight variations of this identification system to incorporate proprietary features of their products, so you should consult their catalogs to be sure of the exact insert required for any machining job.

Now, before you continue your studies, take a few moments to complete *Self-Check 1*.

# Self-Check 1

**At the end of each section of *Toolholding Systems*, you'll be asked to pause and check your understanding of what you've just read by completing a "Self-Check" exercise. Writing the answers to these questions will help you to review what you've studied so far. Please complete *Self-Check 1* now.**

1. A ________ holds tools and can be mounted in a lathe's tailstock.

2. Three requirements of toolholders for effective and efficient machining are ________, ________, and ________.

3. A ________ on a collet assures concentricity of the cutting tool in the spindle.

4. A simple single-point cutting tool for a lathe may use a ________ insert brazed to a steel shank.

5. A TPMT insert has a ________ shape and a(n) ________ degree relief angle.

6. PCD and PCBN are the two types of ________ materials, which are used in critical cutting-tool applications.

**Check your answers against those on page 71.**

# TOOLHOLDERS FOR MANUALLY CONTROLLED MACHINE TOOLS

This section discusses some aspects of toolholders for manually controlled machine tools, such as lathes and milling machines. However, many of the considerations we discuss will apply to CNC machines, since the mechanics of machining are the same whether or not a computer controls the process, and whether there's a single tool or many. You should also be aware that many of the following considerations of toolholders, even though grouped for turning or milling, apply to many processes. For example, when discussing toolholders for boring, which is a turning process, the concepts may apply as well to milling machines, where boring is often done.

## Toolholders for Turning Operations

Toolholders for indexable inserts are made from steel that's machined to the desired configuration and hardened to add strength, toughness, and rigidity. Hardness values of a finished toolholder may be in the range of RC 44 to RC 48. Toolholders can be either external or internal types, as well as right- or left-handed. *External* types are used for machining outside diameters of a rotating part, while *internal toolholders* are used to remove material from inside diameters, such as boring operations. Figure 15 shows some typical examples of external toolholders.

The selection of the toolholder depends almost entirely on the insert chosen, which is, in turn, determined by the machining operation to be carried out. The required feed, speed, depth of cut, and surface finish determines the type of insert. Once this is known, a toolholder design can be selected. Manufacturers' catalogs give very detailed information about selection of inserts and toolholders, and there's such a variety available that a standard configuration is usually available for almost any application.

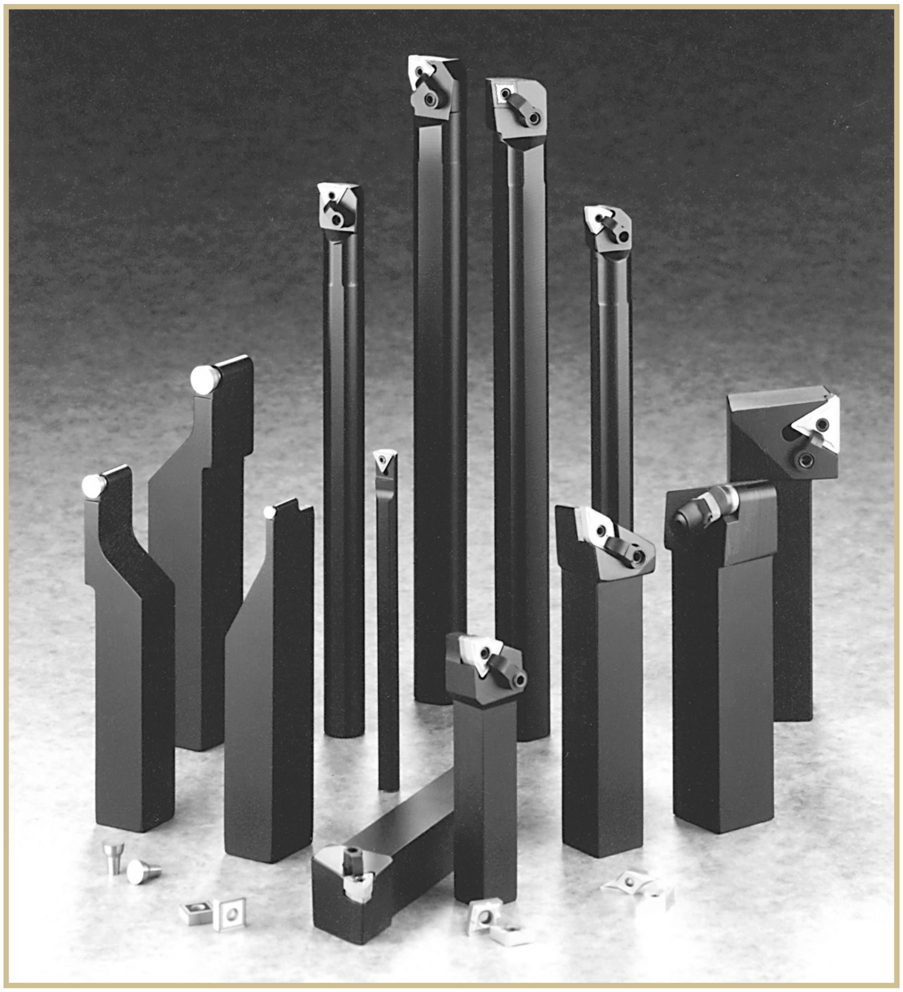


***FIGURE 15—External toolholders are available from manufacturers in a wide variety of configurations to meet almost every machining need.* (Courtesy of Carboloy Inc., www.carboloy.com)**

## Clamping Methods

A machined shape, or *pocket*, at the end of the toolholder is used to accurately locate the insert, which is held in place with four basic types of clamping methods. The insert is usually placed on a cemented carbide seat to increase the ability of the insert to withstand the cutting load. Figure 16 shows a cross section of the arrangement of the seat, insert, and toolholder pocket. Angles of the insert seat vary depending on the type of clamping methods used.

The clamping method used to firmly keep the insert in the toolholder can be any or all of the following basic types:

- *Top clamping.* A top clamp uses a screw through the top of a clamp that forces the clamp against the insert, which keeps it seated firmly in the holder.

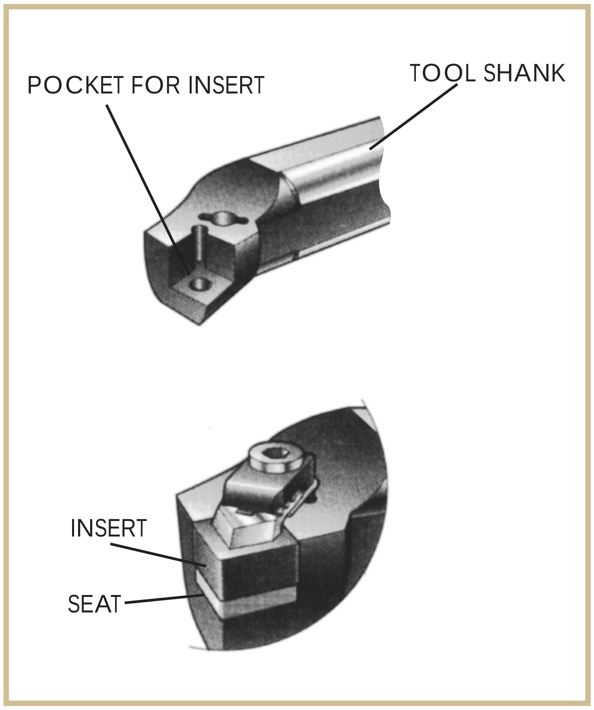



***FIGURE 16—Inserts are usually mounted on seats that fit within pockets in the end of the toolholder.***
**(Courtesy of Sandvik Coromant Company)**

- *Pin-lock clamping.* This type of clamping uses a pin with tapered sides that wedge against the walls of an insert that has a hole in it.
- *Multiple clamping.* Usually, a pin-lock and top clamp are used in combination. Multiple clamping methods are used when the machining load is high or when vibration is a problem.
- *Screw locks.* This method uses a machine screw directly through a hole in the insert to fasten the insert to the toolholder.

Figure 17 shows examples of the different types of clamping methods. Often, combinations of the above methods are used for reliability and when machining loads are high.

Manufacturers also have proprietary methods for specialized applications. Carboloy® Inc. has a clamping system called the *taper stem* that uses a special insert with a tapered stem that fits in a tapered hole in the end of the toolholder. The machining forces push the insert into the tapered hole, and the wedging action of the taper keeps the insert in place. Figure 18 shows an example of the tapered insert.

*FIGURE 17—Inserts may be attached to the toolholder by one or more methods, depending on the severity of the machining loads.* **(Courtesy of Sandvik Coromant Company)**

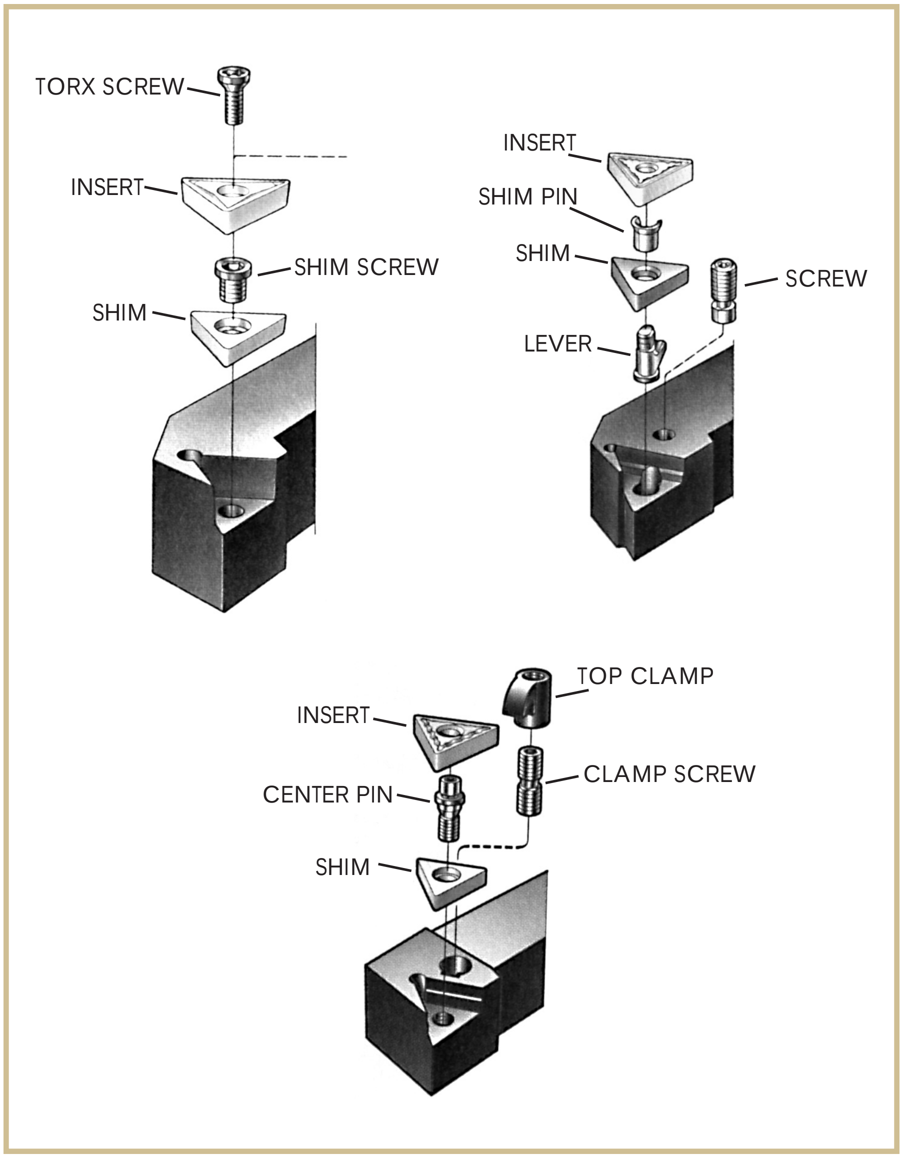
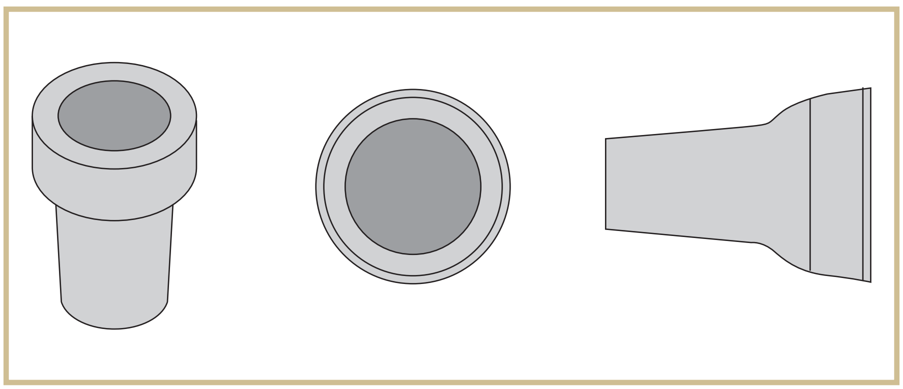



*FIGURE 18—Manufacturers may have special insert configurations that are proprietary, such as this Carboloy tapered insert. This design is especially useful when high machining loads are present.* **(Courtesy of Carboloy Inc., www.carboloy.com)**



## Insert Shape and Thickness

Another consideration in toolholder design is the shape of the insert. Inserts come in a variety of shapes, as shown in Figure 19. The pocket in the toolholder accommodates only certain shapes. Typically available insert shapes are round, square, triangle, 35-degree, 55-degree, and 80-degree diamond, and a combination of a triangle and a polygon shape, called a *trigon*.

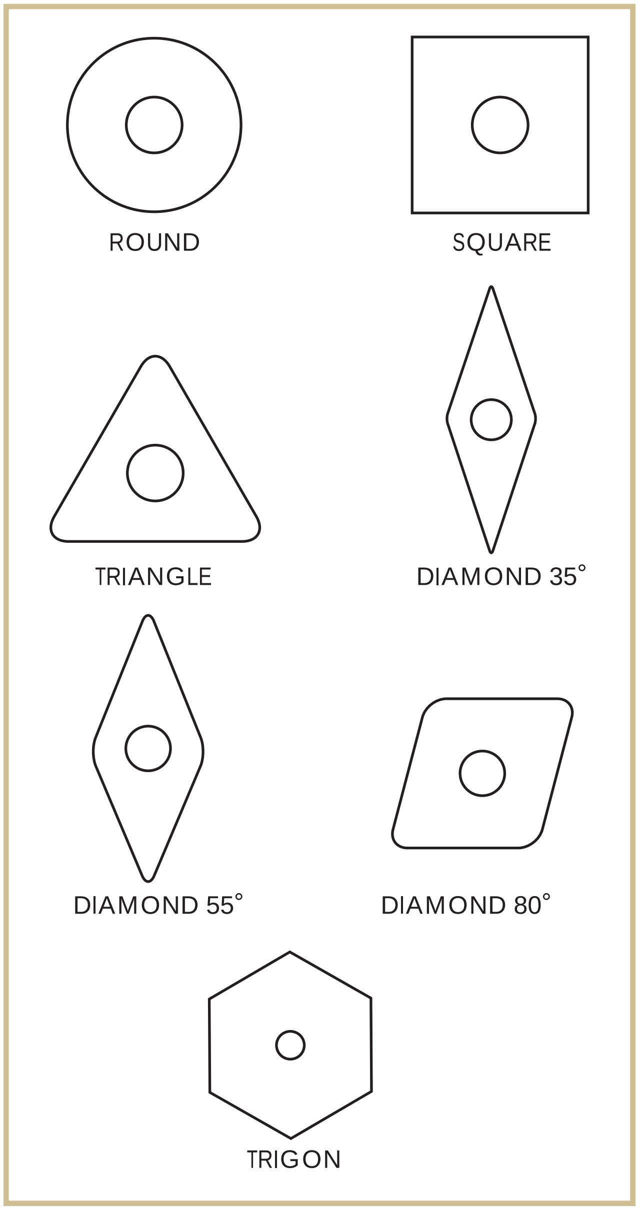



***FIGURE 19—Inserts are classified by their shape.***

A key property of the insert shape is the strength. Figure 20 shows how the strength of the insert changes in relation to shape.

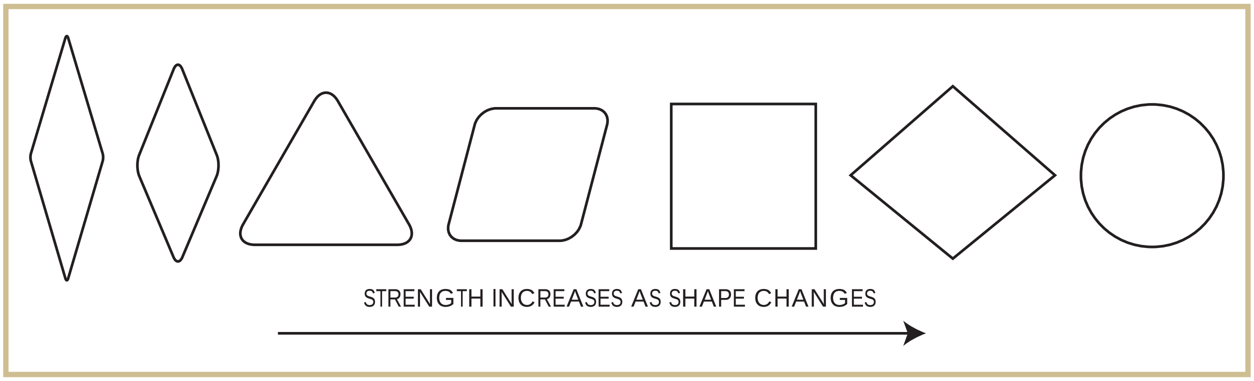
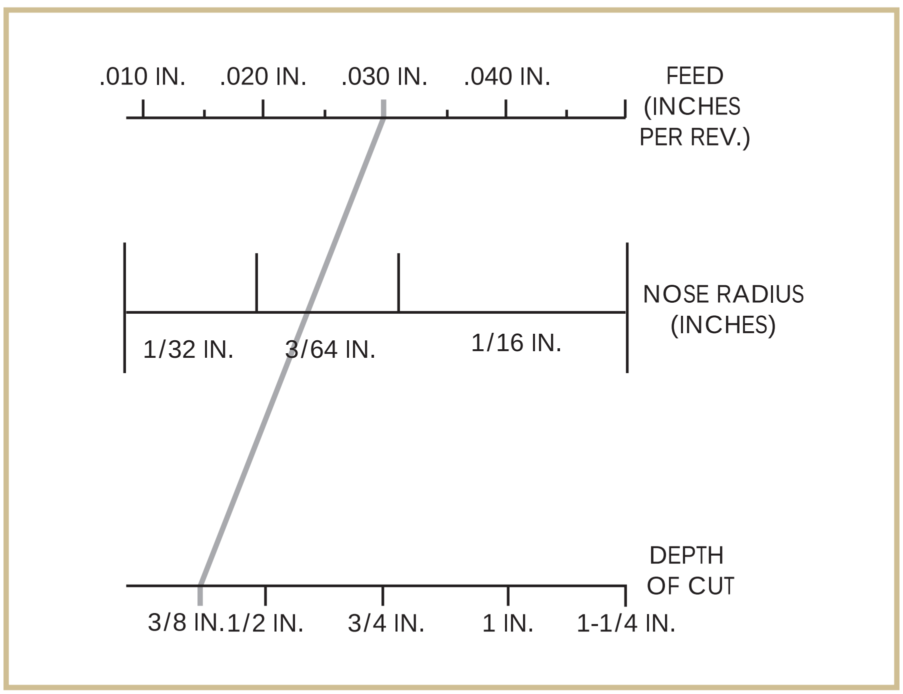



***FIGURE 20—The shape of the insert determines its strength.***

The strength of the insert is also dependent on the *nose radius*. The nose radius is the radius at the cutting tip of the insert. Figure 21 shows a chart for determining the minimum nose radius for a given machine feed and depth of cut. The minimum radius will determine, in turn, the shape of the insert chosen and the characteristics of the toolholder you must use for the particular operation.

***FIGURE 21—The minimum nose radius of the insert may be determined from the feed rate and the depth of cut.***



Closely related to the shape and radius of the insert is the thickness. Figure 22 shows a chart for determining the minimum insert thickness based upon feed rate and cutting-edge engagement. Cutting-edge engagement refers to the length of the insert that contacts the work piece. The thickness of the insert determines the design of the toolholder you must use for the machining operation.

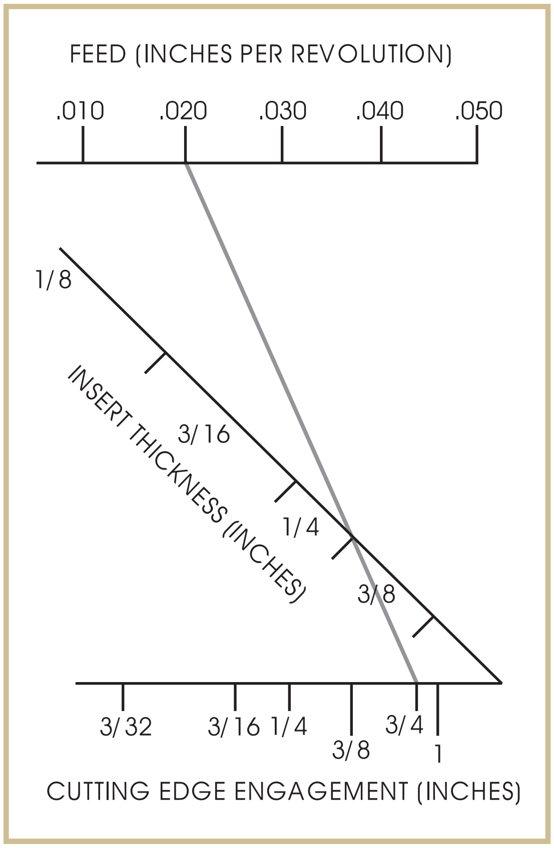



***FIGURE 22—The minimum insert thickness can be determined from the feed rate and the length of the cutting-edge engagement in the metal. In the case shown, a cutting tool configuration that allows for ¾ inch cutting-edge engagement, with a .020 inch-per-revolution feed rate, will require an insert thickness between ¼ and ⅜ inch.***

The selection of the nose radius depends on the shape of the work piece and the type of machining operation to be done. The nose radius has a great effect on the surface finish of the part. A larger nose radius results in a better surface finish and a stronger cutting edge. Also, a large radius allows greater feed rates. However, larger radii also have a tendency to induce chatter and vibration. Manufacturers generally recommend that the depth of cut should be larger than the nose radius. Figure 23 shows a chart that allows you to find either a nose radius, feed rate, or surface finish, if you know the other two values.

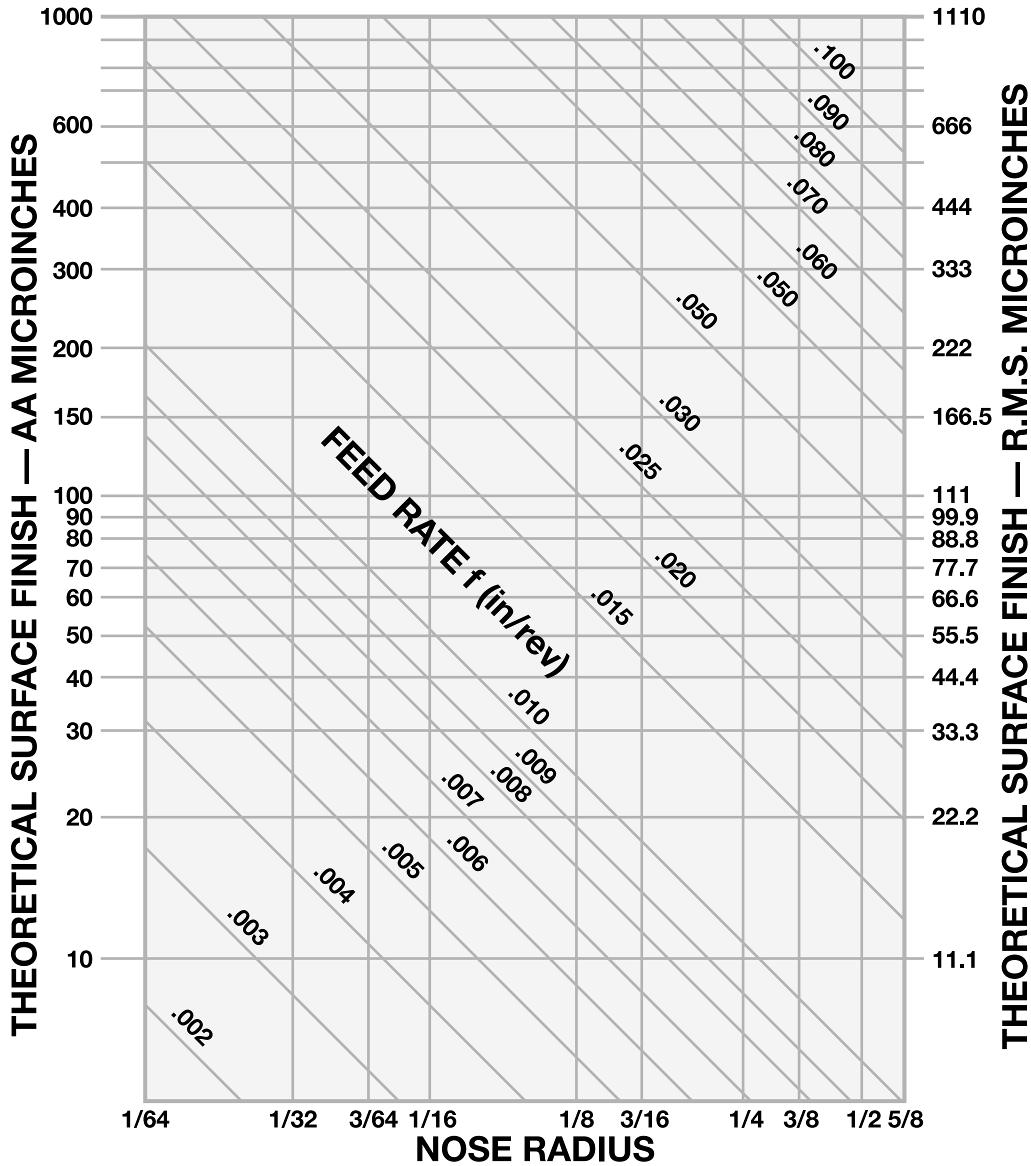



***FIGURE 23—The nose radius and the feed rate determine the surface finish of the work piece.***
**(Courtesy of Carboloy Inc., www.carboloy.com)**

## Toolholder Style

Toolholders are available with a wide variety of shank styles. The *shank* is the back portion of the bar, which attaches to the toolholder's mounting device. Shanks are available in various widths, thickness, and materials, and with different head configurations for locating the insert. Shanks can be straight or offset, and with different cutting edge angles (side or end) determined by the geometry of the insert pocket.

Because of the wide variety of cutting operations and insert shapes, a standard for identifying toolholder styles has evolved that's similar to the insert identification system. A toolholder identification system for both internal and external toolholders can be used to precisely identify a toolholder for a specific machining operation. The identification number is a 10-position alphanumeric string where each position is used to describe the feature of the toolholder. There are recognized standards for identification systems, such as ANSI, but you should always consult manufacturers' catalogs for ordering information, as modifications are often made to accommodate proprietary features of individual brands of toolholders and inserts. Figure 24 shows the meaning of each letter or number in the alphanumeric system for external toolholders.

Figure 25 shows an identification system for internal toolholders. Note that the second letter of the external-toolholder code (fourth letter for internal toolholders) specifies the insert shape that must be used. The toolholder style and insert shape determine the side or end cutting edge angles, which determine the bending forces on the toolholder and work piece.

Figure 26 shows how the toolholder and insert combinations affect the cutting edge angles.

## Rake Angle

The angle at which the insert meets the work piece is called the *rake angle*. Toolholders are designed to hold the insert at the desired rake angle for the most efficient cutting action. Rakes can be positive, neutral, or negative, as shown in Figure 27. The seat of the toolholder and the insert design determine the final rake angle.

*Positive top rake angles* usually produce the smoothest surface finishes because of reduced cutting forces and friction. This lowers the amount of horsepower required for machining and the amount of heat generated, which, in turn, lead to longer tool life. Inserts with positive top rake angles are weaker and are usually used only on softer metals. Machining small-diameter parts, and applications where chatter may occur, or where low cutting forces are necessary, require the use of positive rake angles.

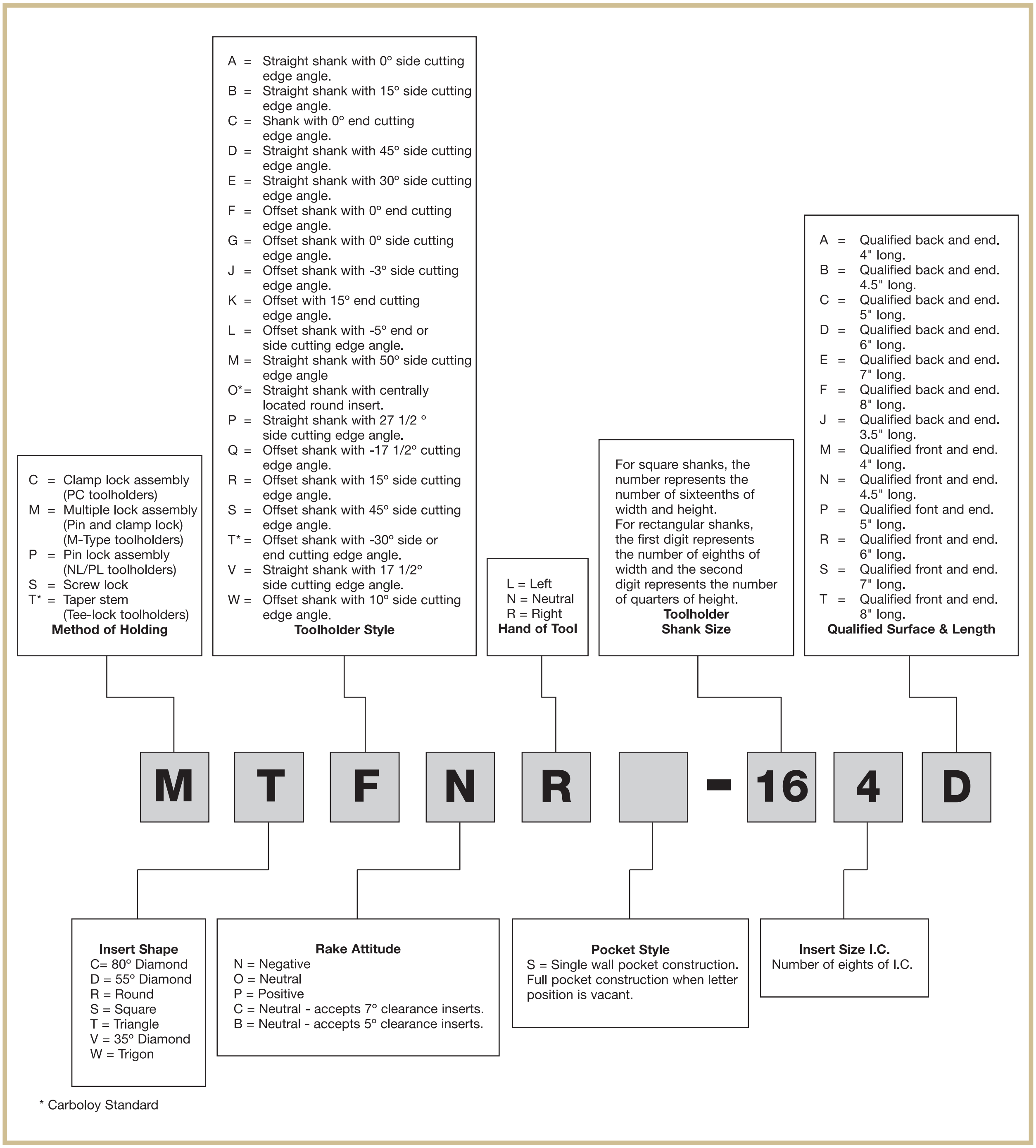



***FIGURE 24—As with inserts, ANSI has an identification system to aid the machinist in selecting the proper external toolholder for each application.*** **(Courtesy of Carboloy Inc., www.carboloy.com)**

*Neutral*,or *flat*, *top rake angles* produce higher cutting forces, and, therefore, require more horsepower from the machine. These insert types produce mid-grade surface finishes with chips that often flow in a continuous ribbon. These types of chips can pose a safety hazard for the operator.

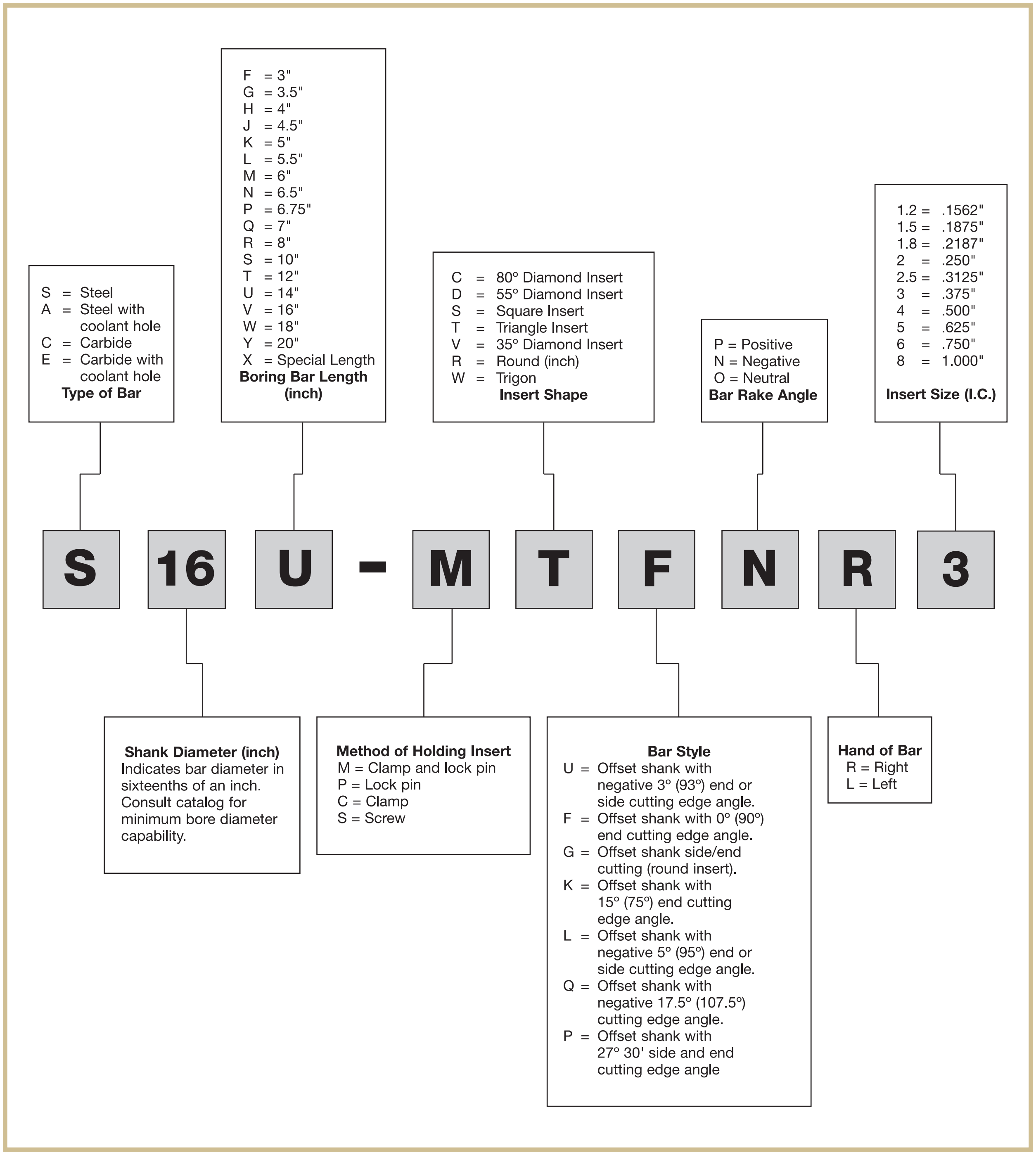



***FIGURE 25—In a way similar to external toolholders, internal toolholders are identified using this alphanumeric system.*** **(Courtesy of Carboloy Inc., www.carboloy.com)**

*Negative top rake angles* produce the highest cutting forces and, therefore, require the most horsepower from the machine. Surface finish is the lowest quality of the three choices, and negative angles are usually used for tougher and/or harder materials. However, insert strength is the

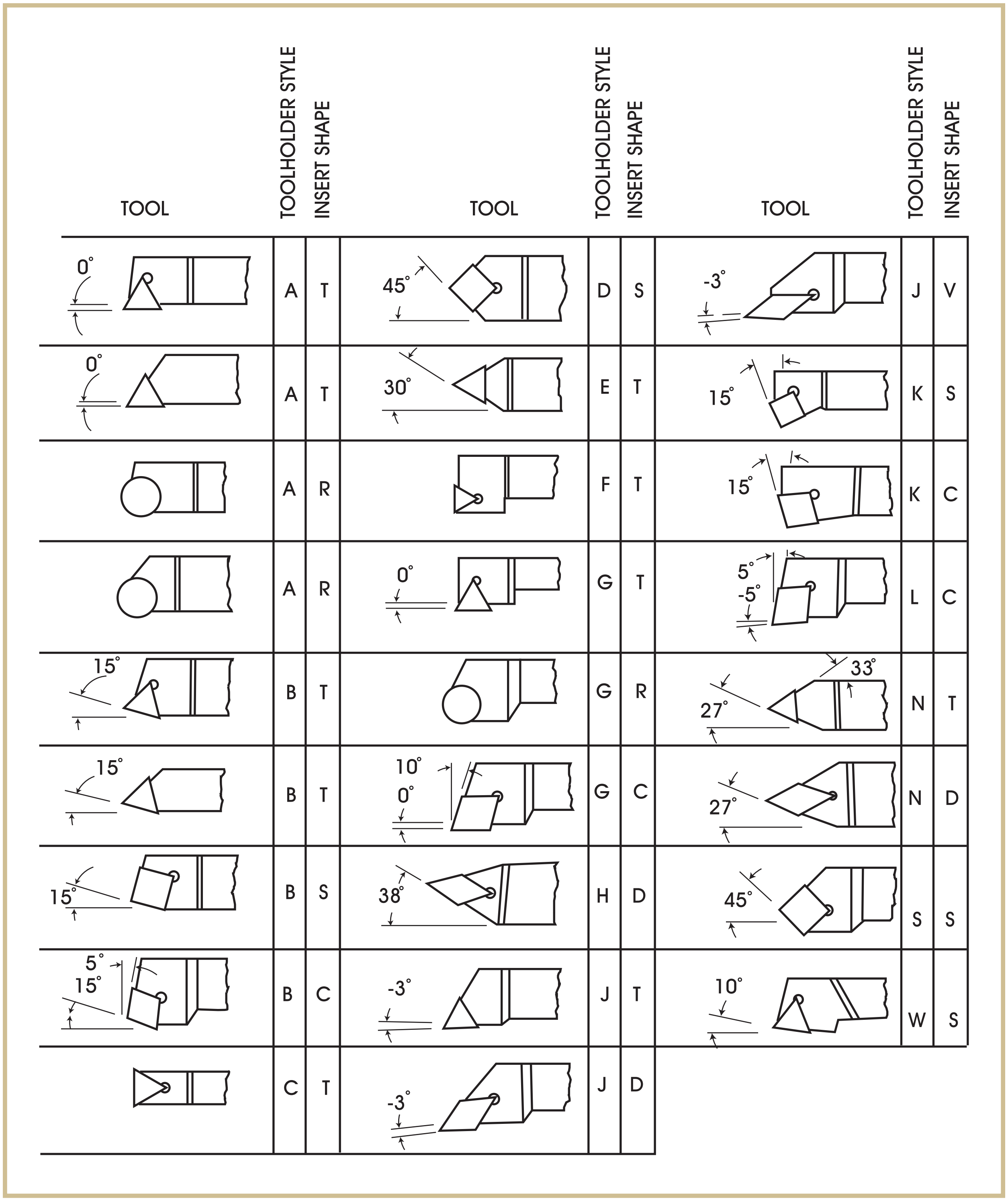



***FIGURE 26—Toolholder and insert geometries can form a variety of cutting edge configurations.*** **(*Machinery's Handbook,* 25th Edition, pages 734, 735, Table 3B, Indexable Insert Holder Application Guide)**

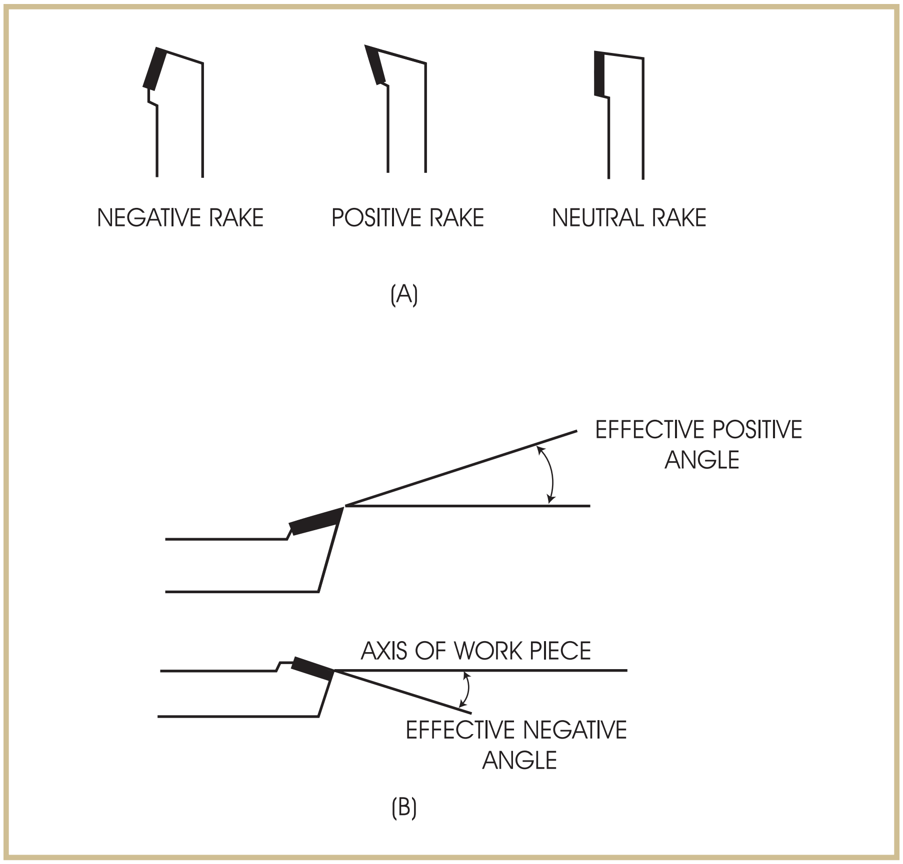



***FIGURE 27—Cutting edge rake angles can be positive, neutral, or negative. It's the combination of insert and shank geometries that determines the actual rake angle.***

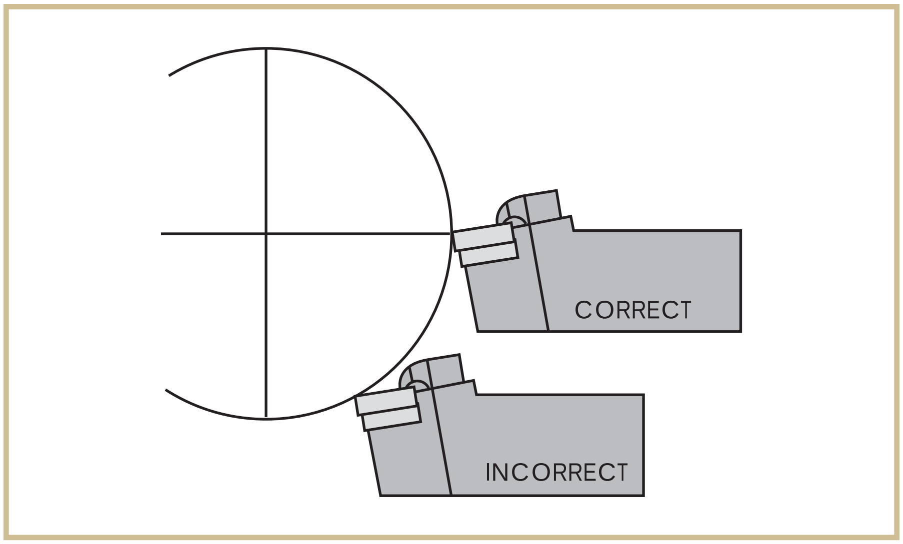
greatest and tool life is much greater when negative rake angles are used, even when large depth of cuts is necessary for efficient metal removal.

Toolholders give the correct rake angles and tool clearances only when the cutting point of the insert is at the same height as the axis of rotation of the work piece. If the tool point is above or below the axis line, the rake angles aren't correct, which may result in poorer finishes, tool chatter, or even breakage. Figure 28 shows the correct orientation of a toolholder for a turning operation.

## Cutting Angles and Rigidity

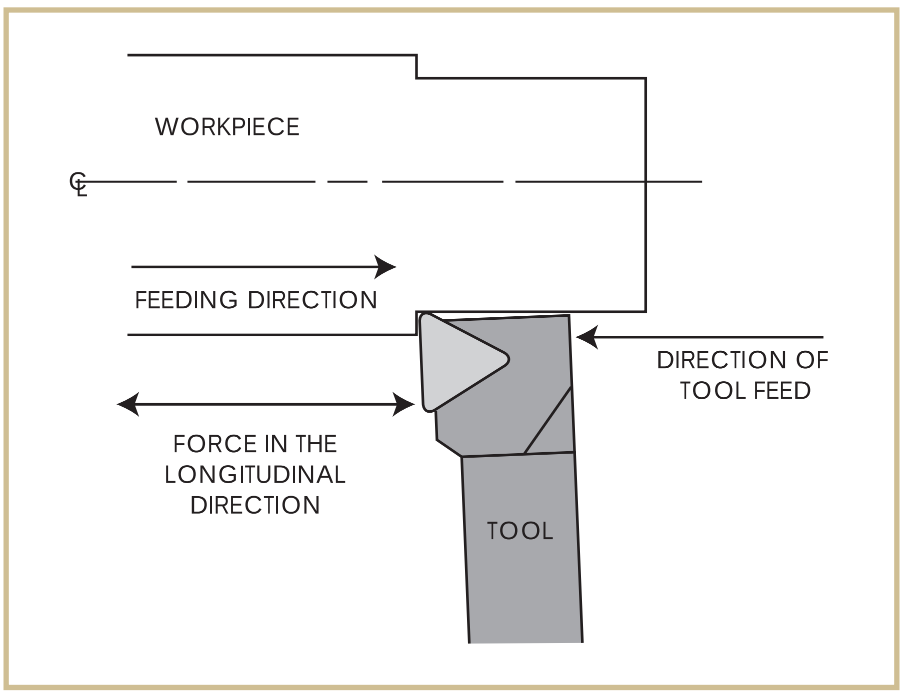
When metal is cut during the turning process, forces at the tip of the cutting tool shear the metal from the work piece, forming chips. The cutting angles determines the direction of these forces. If the lead cutting edge angle is 0 degrees, that is, the leading edge of the cutting tool is perpendicular to the rotation axis, then the force on the tool and the work piece is

*FIGURE 28—The rake angle is also affected by the position of the cutting edge relative to the axis of rotation of the work piece. In turning operations the insert's cutting point must be aligned with the work piece's center of rotation.*




mostly in a direction parallel to the rotation axis, with almost no force in the radial direction. Figure 29 shows that the force on the tool and the work piece acts in the longitudinal direction.

*FIGURE 29—As the cutting tool is fed into the work piece, forces are generated on the work piece and toolholder that are in a combination of radial and longitudinal directions.*




However, if the leading edge cutting angle is changed to a positive value, part of the force is then applied in the radial direction, as shown in Figure 30. This situation may lead to chatter, poor finishes, and dimensional inaccuracy because

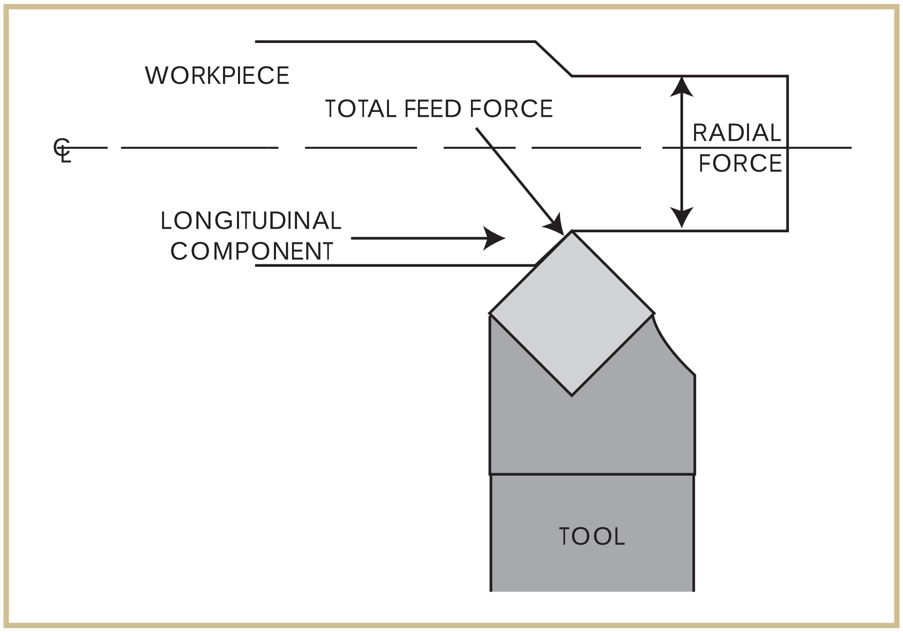



***FIGURE 30—Large positive leading edge cutting angles generate large radial forces on the tool-holder that can lead to chatter, poor finishes, and breakage.***

the work piece usually bends slightly in the radial direction. When larger lead angles are necessary, the work piece may need to be supported in a tailstock. Another consideration is that larger lead angles require larger inserts for the same depth of cut.

Round inserts and inserts with large nose radii always generate radial cutting forces, and aren't recommended where chatter may be a problem or where high precision is required and work pieces have geometries such that they are likely to bend.

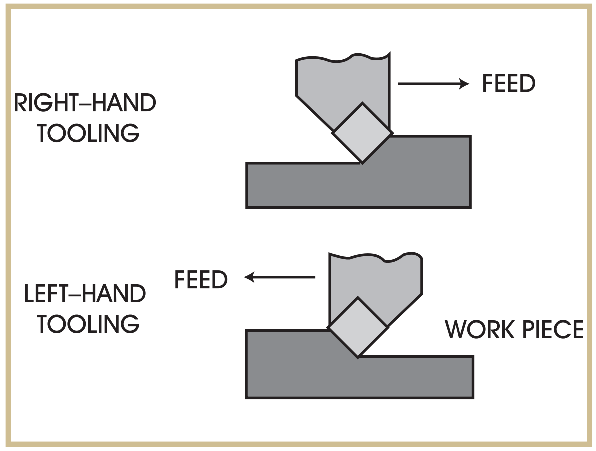
## Shank Size

Toolholder shanks are available in a number of common sizes, with variations from different manufacturers. The rigidity of the toolholder is determined by its geometry, and manufacturers will often recommend the maximum overhang and method of clamping the toolholder into the lathe to minimize vibration and deflection.

## Hand of Tool

The side of the toolholder where the cutting edge is located determines the *hand* of the tool. Depending on which way the work piece is rotating, different hands are needed for proper cutting angles. Figure 31 shows examples of right-and left-hand tooling. Right-hand tooling means that the insert is on the right side of the tool when viewed from the front of the tool and the insert is on the top of the tool.

***FIGURE 31—Toolholders are classified as right-handed or left-handed by the position of the cutting point when viewed from the front of the tool.*** **(Courtesy of Sandvik Coromant Company)**




## Qualified Surface and Length

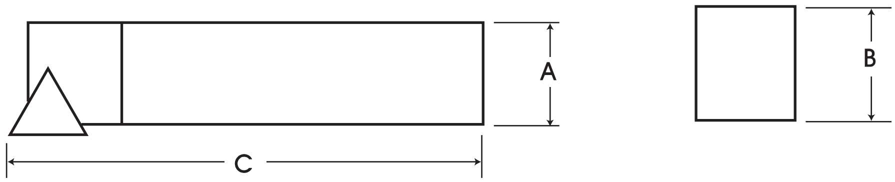
When toolholders are replaced during machining operations, special toolholders may be used that reduce the amount of machine setup due to differences in locations of the cutting edges. These toolholders have the dimensions from some of the end surfaces of the shank to the cutting edge of the insert controlled to within plus or minus 0.003 inches (plus or minus 0.08 mm). These toolholders are available in back-and end-qualified, front-and end-qualified, or back-, front-, and end-qualified versions. Figure 32 shows the locations of these surfaces as well as the ANSI letter designation for the toolholder identification system.

## Tooling Selection Guide

Table 2 lists some suggestions for making correct choices when selecting toolholders and inserts for turning operations.

# Toolholders for Drilling and Milling Operations

As we mentioned before, milling machines and drilling machines remove material from the work piece by bringing a rotating cutting tool into contact with a work piece. Drilling




| BASIC SHANK SIZE | SHANK DIMENSIONS FOR INDEXABLE TOOLHOLDERS | | | | | |
|---|---|---|---|---|---|---|
| | A | | B | | C* | |
| | IN. | mm | IN. | mm | IN. | mm |
| 1/2 x 1/2 x 4 1/2 | .500 | 12.70 | .500 | 12.70 | 4.500 | 114.30 |
| 5/8 x 5/8 x 4 1/2 | .625 | 15.87 | .625 | 15.87 | 4.500 | 114.30 |
| 5/8 x 1 1/4 x 6 | .625 | 15.87 | 1.250 | 31.75 | 6.000 | 152.40 |
| 3/4 x 3/4 x 4 1/2 | .750 | 19.05 | .750 | 19.05 | 4.500 | 114.30 |
| 3/4 x 1 x 6 | .750 | 19.05 | 1.000 | 25.40 | 6.000 | 152.40 |
| 3/4 x 1 1/4 x 6 | .750 | 19.05 | 1.250 | 31.75 | 6.000 | 152.40 |
| 1 x 1 x 6 | 1.000 | 25.40 | 1.000 | 25.40 | 6.000 | 152.40 |
| 1 x 1 1/4 x 6 | 1.000 | 25.40 | 1.250 | 31.75 | 6.000 | 152.40 |
| 1 x 1 1/2 x 6 | 1.000 | 25.40 | 1.500 | 38.10 | 6.000 | 152.40 |
| 1 1/4 x 1 1/4 x 7 | 1.250 | 31.75 | 1.250 | 31.75 | 7.000 | 177.80 |
| 1 1/4 x 1 1/2 x 8 | 1.250 | 31.75 | 1.500 | 38.10 | 8.000 | 203.20 |
| 1 3/8 x 2 1/16 x 6 3/8 | 1.375 | 34.92 | 2.062 | 52.37 | 6.380 | 162.05 |
| 1 1/2 x 1 3/4 x 9 1/2 | 1.500 | 38.10 | 1.500 | 38.10 | 7.000 | 177.80 |
| 2 x 2 x 8 | 1.750 | 44.45 | 1.750 | 44.45 | 9.500 | 241.30 |
| | 2.000 | 50.80 | 2.000 | 50.80 | 8.000 | 203.20 |

* HOLDER LENGTH; MAY VARY BY MANUFACTURER. ACTUAL SHANK LENGTH DEPENDS ON HOLDER STYLE.

***FIGURE 32—Qualified toolholders have the dimensions from various surfaces to the cutting point controlled to specified precisions to ensure accuracy when replacing cutting tools.* (*Machinery's Handbook,* 25th Edition, page 731, Table, Standard Shank Sizes for Indexable Insert Holders)**

and milling machines use very similar operations, and use cutting tools such as drills, reamers, taps, end mills, and various milling cutters that are mounted in rotary toolholders that mate to the spindle. Milling machines can be either vertical or horizontal types.

## Collets

Drills and other straight-shanked cutting tools are usually held in place by a collet. As you learned earlier in this study unit, the two principal types of collets are spring collets and solid collets. Figure 33 shows examples of spring and solid collets. Spring collets are keyed into the spindle to give the driving force, but they depend on friction to hold the cutting tool in place. Solid collets are connected to and driven by the

| Table 2 | |
|---|---|
| **SUGGESTIONS FOR TOOLING SELECTION** | |
| **Suggestion** | **Benefits** |
| Select standard sizes and products, if possible. | • Price and availability<br>• Known, proven design |
| Select the strongest insert shape the work piece will allow. | • Higher productivity<br>• Lower cost |
| Select the largest end or side cutting edge angle possible. | • Better heat dissipation<br>• Thinner chips<br>• Lower insert wear |
| Use negative rake geometry, if possible. | • Greater strength<br>• Better heat dissipation<br>• Cutting edge is protected |
| Select the smallest insert for the specific operating conditions. | • Lower cost |
| Select the largest nose radius possible. | • Better heat dissipation<br>• Thinner chips<br>• Greater strength<br>• Better finish |
| Select the highest feed rate possible. | • Greater productivity<br>• Negligible effect on insert wear |
| Select the greatest depth-of-cut possible. | • Greater productivity<br>• Negligible effect on insert wear |
| Use the shortest overhang possible. | • Greater strength<br>• Less chatter, better finish |

spindle through drive keys, but the cutting tools are held in place by setscrews that push against a flat on the shank of the cutting tool.

Manufacturers offer a wide variety of toolholders for milling machines. Solid and collet-style toolholders can be configured for almost any style of cutting tool available to milling

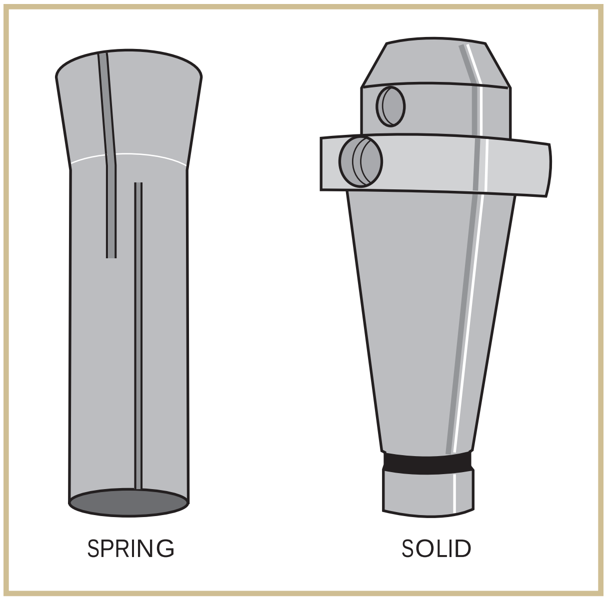


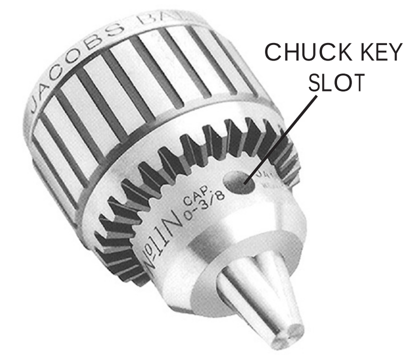

***FIGURE 33—Collets for milling machines are available in spring or solid types.***

machines. The length of the toolholder can be extended with adapters placed on the nose of the toolholder. You may hear about different styles of collets for milling machines, such as *BT* or *CAT-V*, or others. These designations refer to dimensional standards of the flanges used to grip them in machines with automatic tool changers. In manual operations, different collet styles may be interchangeable, but they can't be interchanged when used in automatic machines. You should check with the machine manufacturer's manuals before interchanging any collet styles.

Drilling operations are one of the most common processes for both milling machines and drilling machines. The most commonly used drills are the type called *twist drills*, which are available in standard fractional, numerical, or letter sizes. Common twist drills are available with straight or tapered shanks, which determine how they're mounted into the toolholder. Straight-shank drills are usually mounted in the collet, which has jaws that clamp the sides of the drill to align it and hold it in place. The collets are available in both fixed sizes and variable size configurations.

Adjustable collets are also available with internal jaws that are tightened on the drill shank using a key that acts as a gear to turn a locking mechanism within the collet. Figure 34 shows an illustration of an *adjustable collet*, which is also know as a chuck. An adjustable collet uses a special geared

***FIGURE 34—Adjustable collets or drill chucks are available for general-purpose use in a lathe or drill press. They aren't used for precision applications due to the chance of poor concentricity of the cutting tools when placed in the collet.*** **(Courtesy of DoAll Company, Des Plaines, IL)**




key to loosen and tighten the drill in the collet. Adjustable collets are used to quickly change drills of various sizes, but aren't used for precision work because they don't have the accuracy or concentricity of a fixed collet. Keyless chucks are used on light-duty and hand-held tools.

Fixed-size collets are available in several styles, with each style having a range of drill size capacities. Figure 35 shows several of the many varieties of collets for lathes, mills, and other machine tools. Fixed collets typically have three or more *jaws*, or fingers, that are tapered on the outside, and mate to a taper on the toolholder in the lathe or milling machine. The back of the collet has threads so that a threaded ring in the lathe or mill can be attached and used to pull the collet tightly into the mating taper, which causes the jaws to clamp tightly onto the cutting tool. This type of collet very accurately centers the drill into the toolholder and holds it firmly while the drill cuts the material. The disadvantage to fixed collets is that a set of many different sizes must be purchased to cover all of the anticipated shank sizes of the cutting tools and/or work pieces.

Both the fixed collets and the adjustable collets are usually mounted in the lathe, drill press, or milling machine before inserting the cutting tool.

## Tapered Toolholders

Machine tool spindles, and many lathe tailstocks, toolholders, and turrets, have tapered holes into which the cutting tools or toolholders are mounted. These tapers center the

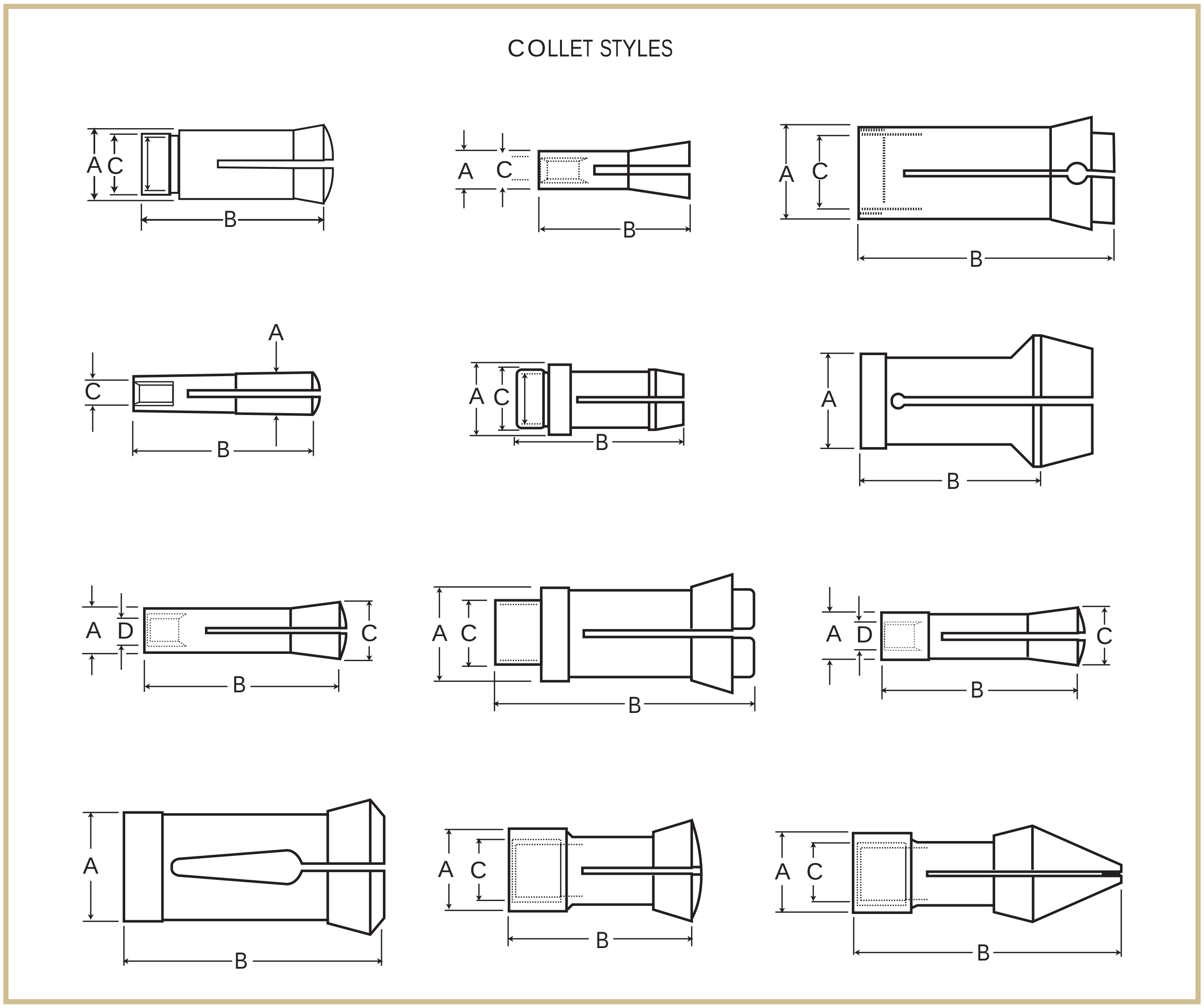
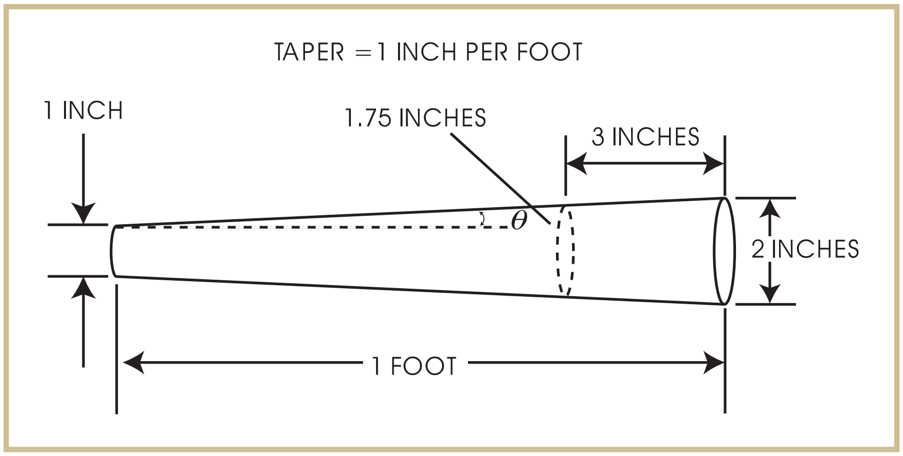



***FIGURE 35—Collets are available in several styles depending on the type of machine tool being used. Collets are purchased in sets to cover the desired range of sizes.* (*Machinery's Handbook,* 25th Edition, page 966, Collets for Lathes, Mills, Grinders, and Fixtures)**

toolholder or cutting tool and provide the force to keep the cutting tool from turning while under the machining load. The term *taper* refers to the amount the diameter of the tool or toolholder changes per linear foot (or inch) of tool length, as shown in Figure 36. For example, a taper specified for 1 inch per foot would have a diameter change of 0.250 inches for a tool that was 3 inches long. If the tool diameter is 1.250 inches at the start of the taper, the end of the tapered section would have a diameter of 1.000 inch. You could easily determine the angle of the taper using geometry, but toolholders and tools are usually specified only by the taper per linear foot or inch, or else with a number that refers to a standard size for a tool.

*FIGURE 36—Taper is defined as a change in diameter with a linear change in distance from the end of the tool. Toolholders with a taper have a generally conical shape.*




Tapers are classified as either *self-holding* or *self-releasing*, depending on the sharpness of the taper. The self-holding tapers have a very small angle, usually only two or three degrees. When a force is applied that pulls the toolholder or tapered drill into the spindle, a very large frictional force is generated on the sides of the tool that prevents it from turning while cutting. Sometimes just the force of jamming the drill into the spindle is enough to hold it firmly in place.

Self-releasing tapers have relatively large included angles, on the order of 16 degrees or more, so that the holding force on the taper is much less. For example, a milling machine may have a taper on the toolholder of 3½ inches per foot. These toolholders may be removed much more easily, but require some method of locking the tool in place to prevent it from turning. Tapered shank drills have a flat tang on the back that's fitted into a slot at the back of the toolholder. The drill is removed from the toolholder by driving a tapered key into a slot behind the tang of the drill.

## Types of Tapers

There are several standard taper systems you'll need to be familiar with when selecting toolholders. These include the Morse taper, the Brown and Sharpe taper, the Jarno taper, the American National Standard Machine Tapers, and occasionally, the British Standard taper. These systems use a numbering system to identify each taper size and corresponding geometry.

Most lathe spindles use Morse tapers, while milling machines tend to use American Standard tapers. Drilling machines and the shanks of twist drills use the Morse taper. The Morse taper is slightly different for each number, but is approximately ⅝ inch per foot. Table 3 shows a listing of the Morse taper numbers and the corresponding dimensions of the shanks. Morse tapers are the most commonly used tapers on machine tools.

**Table 3**

**MORSE STANDARD TAPER SHANKS**

| Taper Number | Shank Length (inches) | Shank Depth (inches) |
|---|---|---|
| 0 | 2 11/32 | 2 7/32 |
| 1 | 2 9/16 | 2 7/16 |
| 2 | 3 1/8 | 2 15/16 |
| 3 | 3 7/8 | 3 11/16 |
| 4 | 4 7/8 | 4 5/8 |
| 5 | 6 1/8 | 5 7/8 |
| 6 | 8 9/16 | 8 1/4 |
| 7 | 11 5/8 | 11 1/4 |

The Brown and Sharpe taper is approximately ½ inch per foot, but also varies for each number. Brown and Sharpe tapers are used on many arbors and collets of machine tools, especially milling machines and grinding machines.

A few machines use a Jarno taper, which has a taper of 0.600 inch per foot for all taper sizes. The diameter at the large end is the taper number times ⅛ inch, while the diameter at the small end is the taper number times ⅒ inch. The length of the taper is the taper number times ½ inch. For example, a number 6 Jarno taper is 6 × ⅛ inch, or ¾ inch at the large end, and 6 × ⅒ inch, or 0.600 inch at the small end. The length of the taper is 6 × ½ inch, or 3.0 inches. Jarno tapers are used on several machine types such as profiling machines and die-sinking machines.

The tapers discussed so far have been of the self-holding types. On machines where the tools must be changed quickly, perhaps even by the machine itself, self-releasing toolholders must be used. As you recall, self-releasing types use much steeper tapers. Figure 37 shows the dimensions of the American National Standard for spindle noses on milling machines. You'll note that the sizes all have the same 3½ inches per foot linear taper, and that the difference between the taper numbers reflects the different diameters at the large end, or *gage line*. ANSI B5.18–1972, R1991, governs this geometry. Toolholders that hold the actual cutting tools are mated to this spindle in various ways, depending on the manufacturer and design of the spindle. Machines that use these types of tapers must have some way to firmly hold the

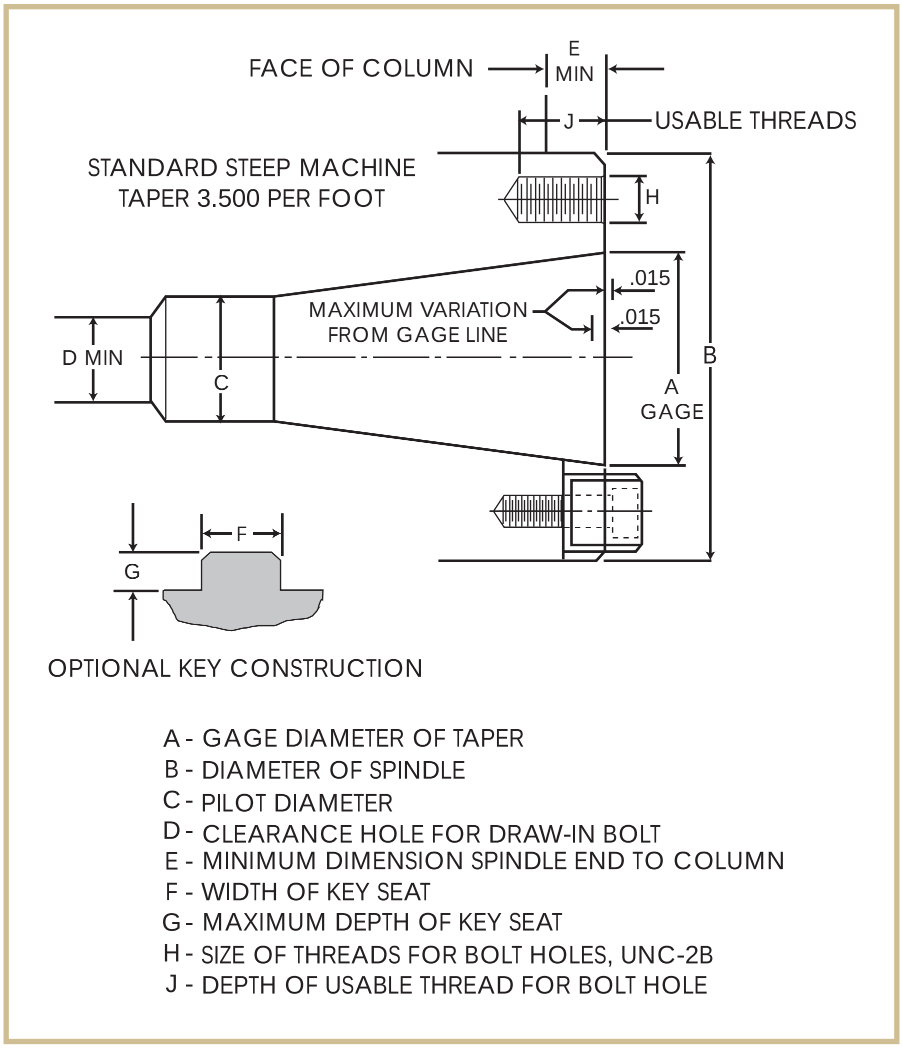



***FIGURE 37—Shown here are the essential dimensions of ANSI spindle noses.*** **(Copyright © ANSI 1997-2000, ANSI B5.18-1972, R1991. Source: Machinery's Handbook, 25th Edition, page 918, Table 1, Essential Dimensions of American National Standard Spindle Noses for Milling Machines)**

tool in the toolholder and a way to prevent the tool from rotating while cutting.

For a complete listing of the various taper types and the corresponding dimensions, you should refer to the *Machinery's Handbook* or manufacturers' catalogs.

Now, take a few moments to review what you've learned by completing *Self-Check 2*.

# Self-Check 2

1. *True or False?* A 60 degree triangular insert is stronger that a square insert.
2. *True or False?* Inserts with large positive leading edge cutting angles can be used effectively on long, hard, thin work pieces.
3. A ________ on the end of a toolholder is used to accurately locate the insert.
4. A lathe machine feed of 0.025 inches per revolution and a depth-of-cut of $\frac{1}{8}$ inch should have a minimum nose radius of ________.
5. The ________ rake angle produces the best surface finish.
6. Two types of collets for milling machines are ________ collets and ________ collets.
7. The milling machine taper of $3\frac{1}{2}$ inches per foot is called a ________ taper.

**Check your answers with those on page 71.**

# TOOLHOLDERS FOR CNC APPLICATIONS

Toolholders for CNC machines are much more critical than for standard machine tools. CNC machines are able to produce parts with accuracies of plus or minus 0.00035 inches with spindle speeds of over 30,000 RPM. Feed rates can be as high as 400 inches per minute and tool changes can take place in as little as 2–4 seconds! These high-production capabilities place great demands on toolholder design. Figure 38 shows several examples of toolholders for a CNC milling machine. With a *quick-change toolholder system*, different types of cutting tools, such as drills, end mills, fly cutters, or grinding tools, are available to do many different machining operations on a work piece. The CNC program controls the sequence, the tool path, and the tool change for the entire machining program.

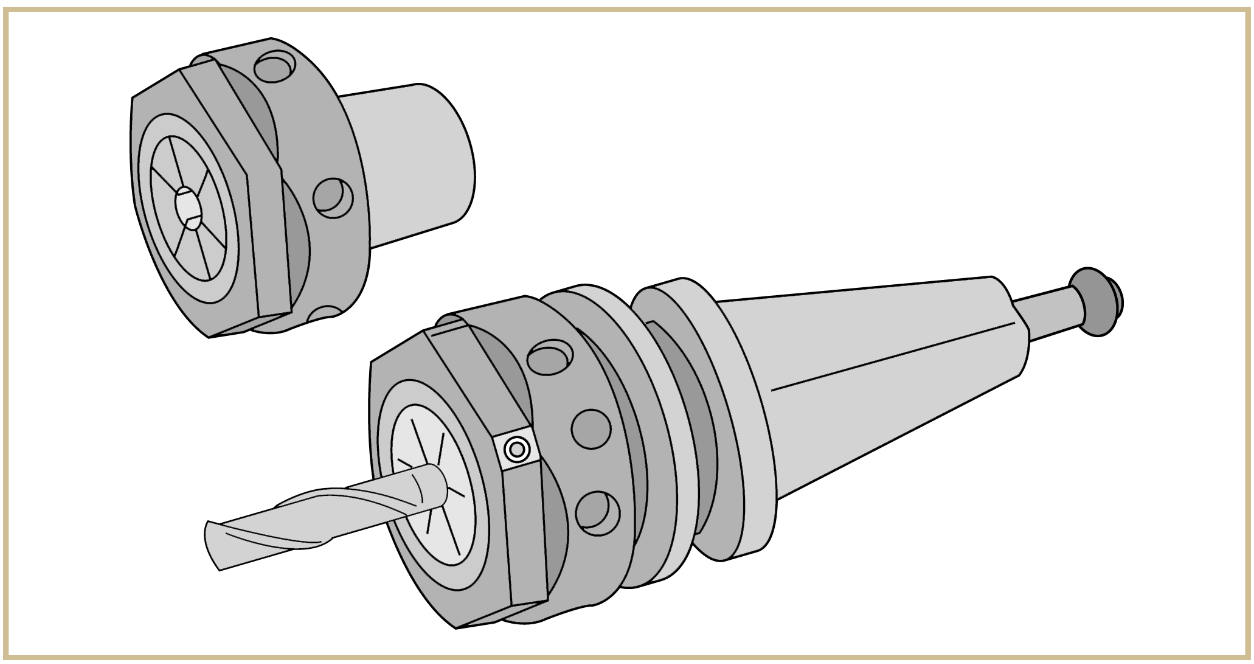
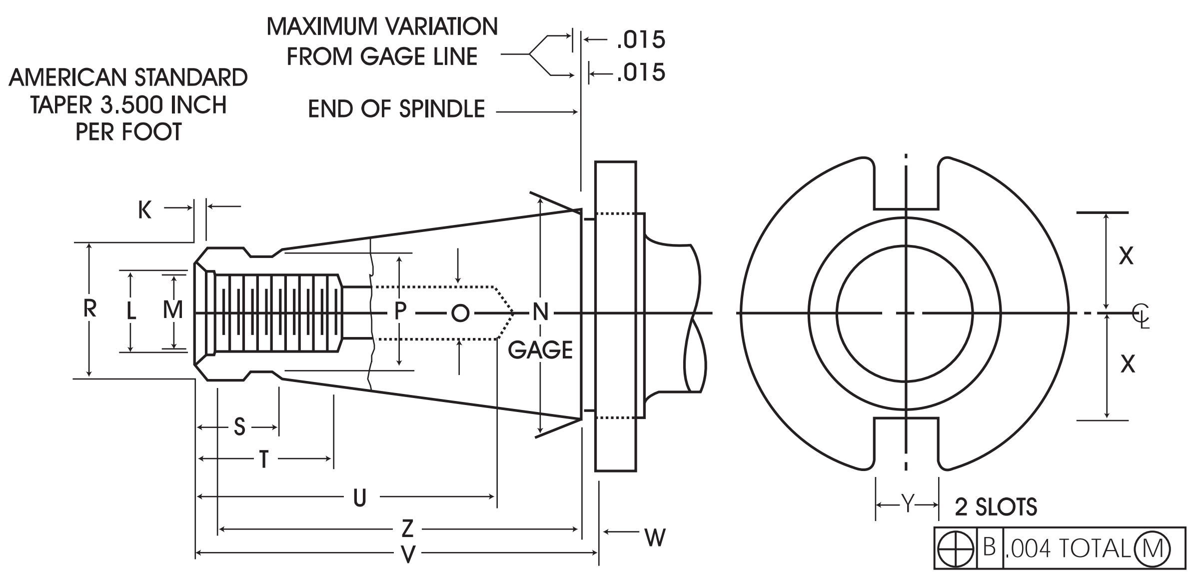


***FIGURE 38—The spindles of milling machines have standard dimensions to ensure compatibility with different manufacturers' products. These tapers are a self-releasing type so that tools can be rapidly changed by automatic toolholder changes.***

Because they must be changed quickly, toolholders for CNC machines are always of the self-releasing type. The tapers are steep and held in place in the spindle with a drawbar that attaches to the back of the toolholder. The drawbar pulls the toolholder back into the spindle where the mating taper centers it and provides a frictional load to resist machining forces. The American National Standards Institute specifies standard steep machine tapers in the specification ANSI B5.10–1981, R1987. There are 12 sizes, 5 through 60, with 30, 40, 45, 50, and 60 being the preferred sizes for milling machines. Each different number specifies a gage diameter size for the dimension at the large end of the taper, and each number has the same taper of 3.5 inches per foot. Figure 39 shows the configuration of the shank for milling machine spindles that conform to ANSI B5.18–1972, R1991.




N- GAGE DIAMETER OF TAPER
O- TAP DRILL SIZE FOR DRAW-IN-THREAD
P- DIAMETER OF NECK
M- SIZE OF THREAD FOR DRAW-IN-BOLT UNC-2B
R- PILOT DIAMETER
S- LENGTH OF PILOT
T- MINIMUM LENGTH OF USABLE THREAD
U- MINIMUM DEPTH OF CLEARANCE HOLE
V- DISTANCE FROM REAR OF FLANGE TO END OF ARBOR
W- CLEARANCE OF FLANGE FROM GAGE DIAMETER
X- TOOL SHANK CENTERLINE TO DRIVING SLOT
Y- WIDTH OF DRIVING SLOT
Z- DISTANCE FROM GAGE LINE TO BOTTOM OF C-BORE
K- DEPTH OF 60° CENTER
L- DIAMETER OF C–BORE

***FIGURE 39—Toolholders have standard dimensions to ensure proper fit within spindles of machine tools.*** **(Copyright © ANSI 1997-2000, ANSI B5.18-1972, R1991. Source: *Machinery's Handbook,* 25th Edition, page 920, Table 2, Essential Dimensions of American National Standard Tool Shanks for Milling Machines)**

The toolholder is a critical link between the machine spindle and the cutting tool in achieving the concentricity, balance, and rigidity that assures high-quality machining. Table 4 shows the ANSI requirements for gage diameter for spindles and tool shanks.

**Table 4**

**GAGE DIAMETERS FOR SPINDLES AND TOOL SHANKS FOR AMERICAN NATIONAL STANDARD TAPERS**

| Size Number | Gage Diameter of Taper, inches (N) | Distance from Gage Line to Bottom of C'Bore (Z) |
|---|---|---|
| 30 | 1250 | 2.50 |
| 40 | 1750 | 3.50 |
| 45 | 2250 | 4.06 |
| 50 | 2750 | 4.06 |
| 60 | 4250 | 7.81 |

## Indexing and Accuracy

The ANSI standard B212.3–1986, Precision Holders for Indexable Inserts, covers the dimensional specification, styles, and alphanumeric designators for toolholders and inserts that are used in precision CNC machining. When a program is written to machine a part, the path of the tool is defined as the path of the center of the tool tip. Because the tips of the inserts are radiused, the machined surfaces that result are a function of the nose radius and the lead angles of the cutting edges. The tool programmer must compensate for different radii by calculating the differences in the dimensions between the actual tool tip and a reference point formed by the intersection of the major and minor cutting edges of insert. The ANSI Standard B212.3–1986 gives these dimensions for different toolholder styles and inserts. Manufacturers' catalogs also list important dimensions of inserts, including compensation dimensions for tool radii.

Every cutting tool used on a part must maintain accuracy with respect to surfaces already machined. When the toolholder is changed to perform another machining operation, the CNC program must know exactly where to begin a cutting operation. For this reason, qualified toolholders, as we've already described, are used. Distances from the cutting edges and tips to various surfaces of the toolholder are controlled to within a few thousandths of an inch to ensure repeatability as cutting tools are changed or indexed.

Even with qualified toolholders, when the insert itself is indexed to expose a new cutting edge, the machinist must be careful to set the insert clamping mechanism the same way each time. A popular method of locking inserts into toolholders is the *unthreaded cam pin*, which uses an unthreaded pin with an offset cam to lock the insert to the toolholder. Cam pins tighten the insert with either clockwise or counterclockwise turns. Figure 40 shows the effect of the change in position of the cutting edge and point when the cam pin is turned in the opposite direction from the first installation. A general guideline would be to always tighten the cam lock in the same direction, although this may not always be possible. Regardless of the locking mechanism, you should be aware of the possible effects if the assembly were adjusted differently each time.

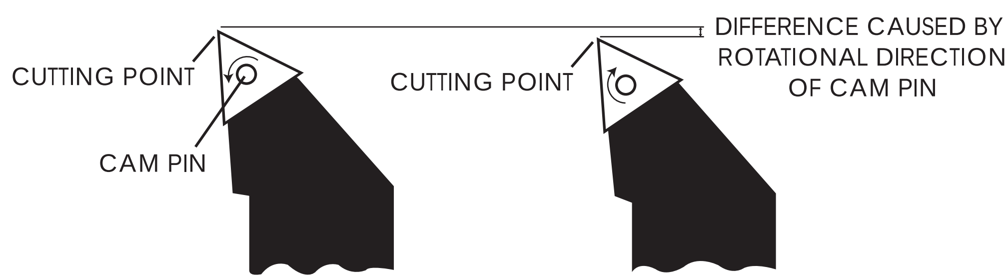



***FIGURE 40—Inaccuracies in the position of the cutting point can result from some methods of insert clamping.***

## Milling Machine Cutters

Milling machines, especially CNC milling machines, can produce a wide variety of different surface contours. There are two general types of milling machines: horizontal and vertical. Within these broad categories, many other types of cuts can be performed. Some of the different types of milling cutters are face milling cutters, square shoulder cutters, slot cutters, pocket and contour cutters, helical cutters, radii and chamfer cutters, and plunge cutters. Each of these cutters is intended for different types of milling cuts. In a CNC machine with automatic tool changers, various tool types may be found in the same holding area, known as the *tool magazine*.

Figure 41 shows several types of specialized milling cutters. Notice that the general configuration is a specially shaped head with inserts attached at its outer radius. The head is then attached to a tapered tool-holder that's inserted into the milling machine spindle. Usually the inserts are all in the same plane. However, in helical cutters the inserts are spaced apart in planes along the axis of the cutter, so that one cutter may use dozens of inserts! Other specialized cutters may have more than one layer or location for inserts. You should refer to a manufacturer's catalog for all the available configurations.

***FIGURE 41—Milling machine cutters are available in many different configurations for different cutting applications. Many cutters require multiple inserts for each cutter.*** **(Courtesy of Carboloy Inc., www.carboloy.com)**

Inserts for milling machines have a different numbering configuration that's similar, but not the same as the insert identification standards for turning inserts. Figure 42 shows a chart for insert designations from ISO 1832–1991.

## Quick-Change Tooling Systems

Your employer's survival in the competitive manufacturing environment requires efficient use of time and resources in every facet of the manufacturing process. As technology advances, faster machining speeds and feed rates are being used, and extra efforts are made to reduce setup times. In

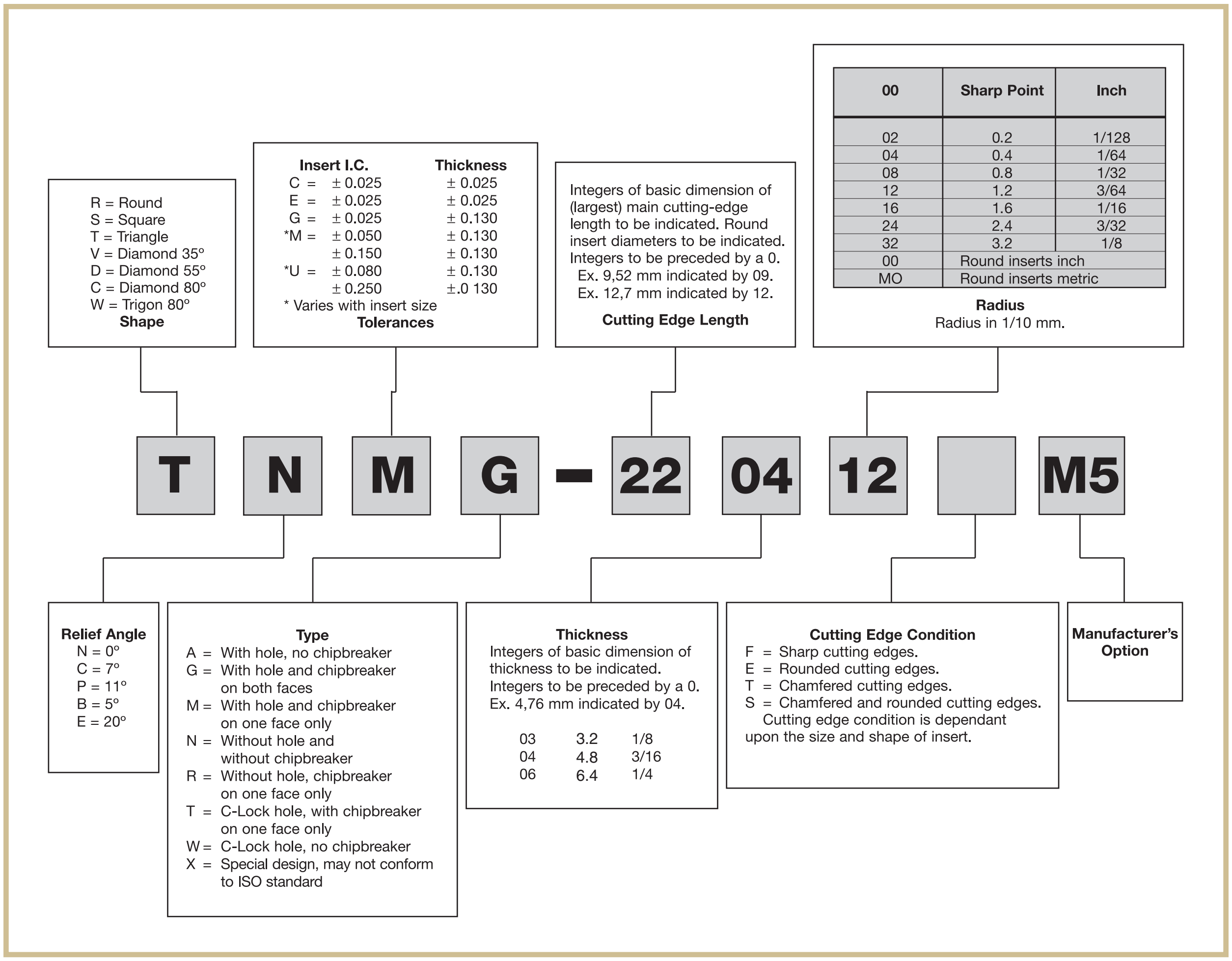



***FIGURE 42—Shown here is the code key for milling-machine insert designations.*** **(Courtesy of Carboloy Inc., www.carboloy.com)**

the manufacture of a machined part, especially with turning operations, many different operations are needed. A part may need to be drilled, reamed, machined on the outside diameter, chamfered on the sharp edges, and then cut off from the stock. All of these operations require a different tool and toolholder. It would take a machinist several minutes to complete each new tool setup, if it weren't for the development of quick-change toolholder systems.

On lathes, indexable turrets are mounted on the side or in the position of the tailstock. These turrets have multiple positions for mounting several different cutting tools. When one operation is complete, the operator unlocks the turret (after safely moving it out of the way of the work piece), rotates the turret to the next position, and then locks the turret in place.

This process allows the machining operation to proceed from start to finish without stopping to remove and replace different cutting tools in a single toolholder. Of course, the machinist must still set up every tool before the procedure starts. Figure 43 shows an example of a turret installed on a manual lathe. CNC machines also use turrets, but the machine program controls their position and movement.

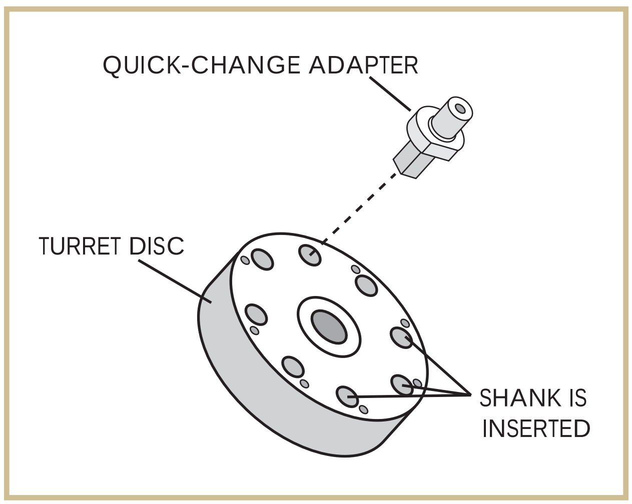
***FIGURE 43—This is an example of a conventional lathe with a turret that can hold multiple cutting tools. The operator manually rotates the turret after each cutting operation.***

The CNC program is able to quickly move the turret from one position to the next, move the tool to a reference point for calibration, and start the next machining operation. Figure 44 shows a CNC machine with an automatic tool changer.

A more modern quick-change tooling system is the VDI Quick-Change toolholder system, which is shown in Figure 45. This design allows individual toolholders to be quickly and


***FIGURE 44—Many machine cutters have toolholders loaded in a magazine to allow a tooling change controlled by a computer. Tool changes can take place in seconds without operator intervention.***

***FIGURE 45—The VDI system allows many different types of cutting tools to be mounted securely in a turret that can be computer controlled. The turret can even channel coolant towards the machining area.***




rigidly attached to a main turret disk. Individual toolholders have a round shank with a flat shank that's serrated. This shank is inserted into the turret and locked by tightening a single Allen screw. The screw tightens another block with mating serrations onto the toolholder shank, locking it in place. Some turrets can hold a dozen or more tools, such as mixtures of right-and left-hand toolholders, drills, reamers, boring bars, and taps. Coolant or cutting fluids can even be directed through the holder onto the work piece as it's being machined.

## Advanced Considerations for Toolholder Selection

Concentricity and balance of the toolholders and cutting tools have a significant effect on the quality of the machining operation. The *concentricity* of the cutting edges determines how nearly they each follow the same path as the tool rotates. *Balance* is a measure of how evenly the weight of the cutting tool and toolholder is distributed around the axis of the spindle. If the weight isn't distributed evenly, forces are generated that can deflect the cutting teeth from the desired path, resulting in poor surface finishes.

### Concentricity

Concentricity is the most crucial factor in the quality of a toolholder. The shank of the toolholder must fit into the corresponding taper of the spindle in exactly the same orientation, every time it's inserted.

If a tool's center line doesn't coincide with the spindle's axis of rotation, the cutting edges of the tool exhibit runout. This measured runout is an indication of the lack of concentricity. The amount a toolholder deviates from perfect concentricity is known as eccentricity. For example, if the center of a drill is 0.0005 inch off center from the axis of the toolholder, the outer edge of the drill will vary a total of 0.001 inch. This condition is described as an eccentricity of 0.0005 inch. This variation will, in turn, affect the hole's roundness, the depth of cut, and surface finish. Figure 46 shows an exaggerated example of a toolholder's eccentricity, as well as the runout that the eccentricity produces. Concentricity can also affect the balance of the toolholder assembly. If the locating diameters of the toolholder aren't concentric, the center of mass of the cutting tool won't align with the axis of rotation, and the balance of the assembly will be less than ideal.

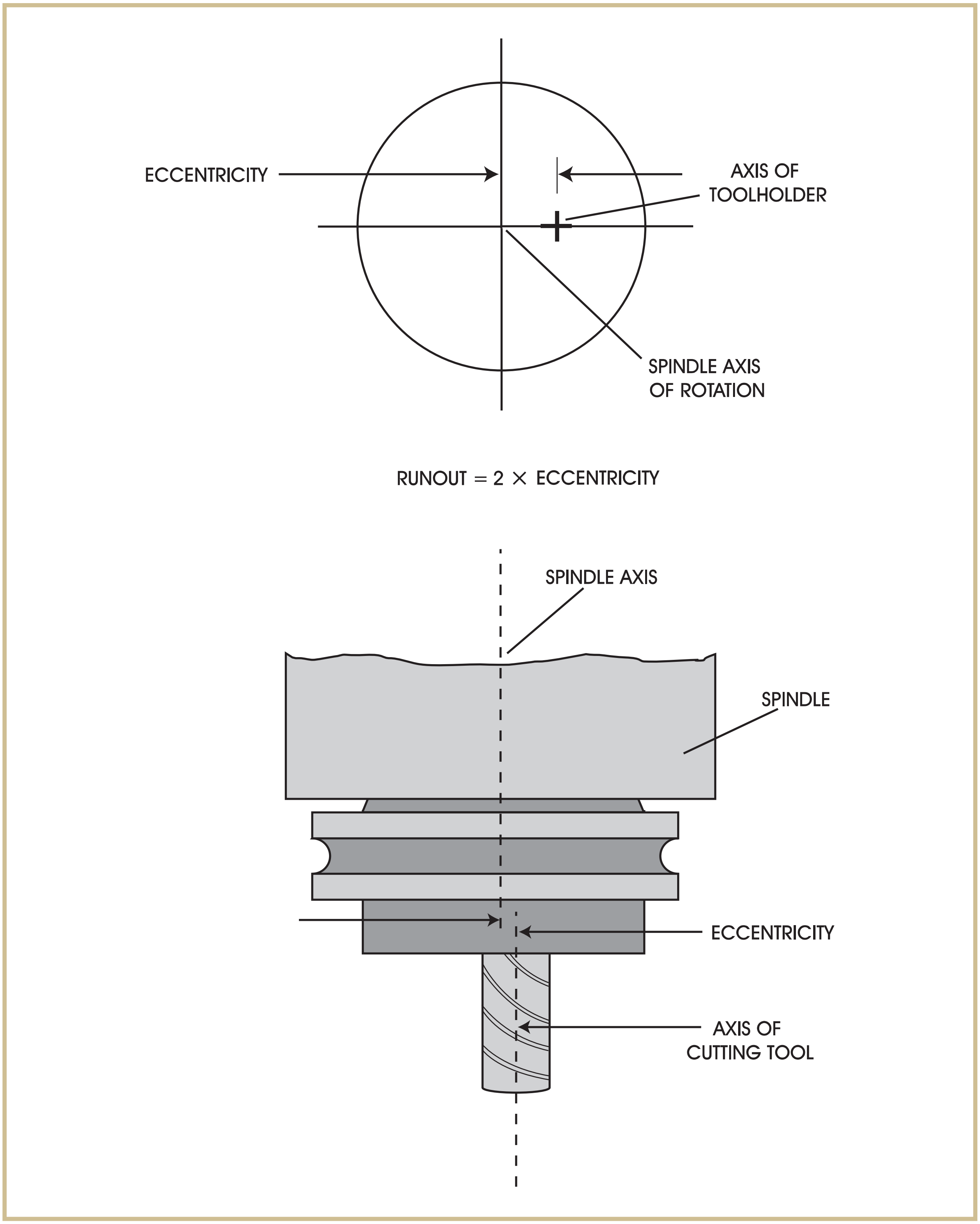



***FIGURE 46—Concentricity is one of the most important considerations for toolholder selection. Excessive eccentricity can result in poor finishes, chatter, and tool breakage.***

Modern machining centers often turn at high speeds, and, as a result, the depth of cut is low. Cutting loads are lighter and variation of the load due to runout in the cutting tool, therefore, becomes more significant. Tool wear can also be affected by concentricity. Tools must offer high wear and heat resistance, but this is often achieved at the expense of tool toughness. Carbide tools selected for high hardness fracture much more easily than high-speed steel cutting tools. For these high-speed tools, uneven loads due to tool runout can result in unacceptable tool life.

In machines using collets, one method of achieving an acceptable concentricity involves an indicator and a mallet. The machinist measures the runout with a dial indicator, by mounting the indicator so that its plunger is in contact with a smooth surface on the milling machine's cutter, then turning the spindle by hand to observe the maximum change in postion or measured by the dial. In this manner the machinist finds the point of maximum runout, which coincides with the rotational position where the dial indicator reads a maximum change, and then taps on the collet at this spot. He or she repeats this process until the runout is acceptable. The disadvantage to this method is that it takes time and skill to adjust concentricity this way, and this isn't an acceptable method for multiple operations in a modern machining center.

When high-precision concentricities are needed, and standard tool-holders aren't producing acceptable results, shrink fit systems and hydraulic toolholders (which will be discussed shortly) allow the machinist to achieve high clamping forces and high concentricity in the same setup.

## Balance

As we noted above, balance is a measure of how the mass of a cutting tool and toolholder is distributed around the axis of the spindle. As any mass is rotated, forces are generated that tend to push the mass outward. If you've ridden the centrifuge at a carnival, you've experienced this *centrifugal force* that keeps you pinned in place against the wall of the ride. In a cutting tool and toolholder system that's perfectly symmetrical, all of the forces resulting from the spinning of the mass around the axis are equal and evenly directed away from the axis of rotation. Forces generated on one side of the tool are canceled by the forces in the opposite direction, and there's no net unbalance force.

Technically, balance is a measure of how far the center of the rotating mass is from the axis of rotation, and the units are usually gm-mm, or gram millimeters. Figure 47 shows instances when the center of mass of a toolholder is or isn't aligned with the axis of rotation. For each tiny chunk of metal in a toolholder, there must be a corresponding chunk of metal on the opposite side of the toolholder, or else there will be an unbalance. Also, if the product of a chunk of mass times its distance from the axis is the same as another chunk's product times distance from the axis, the effect on

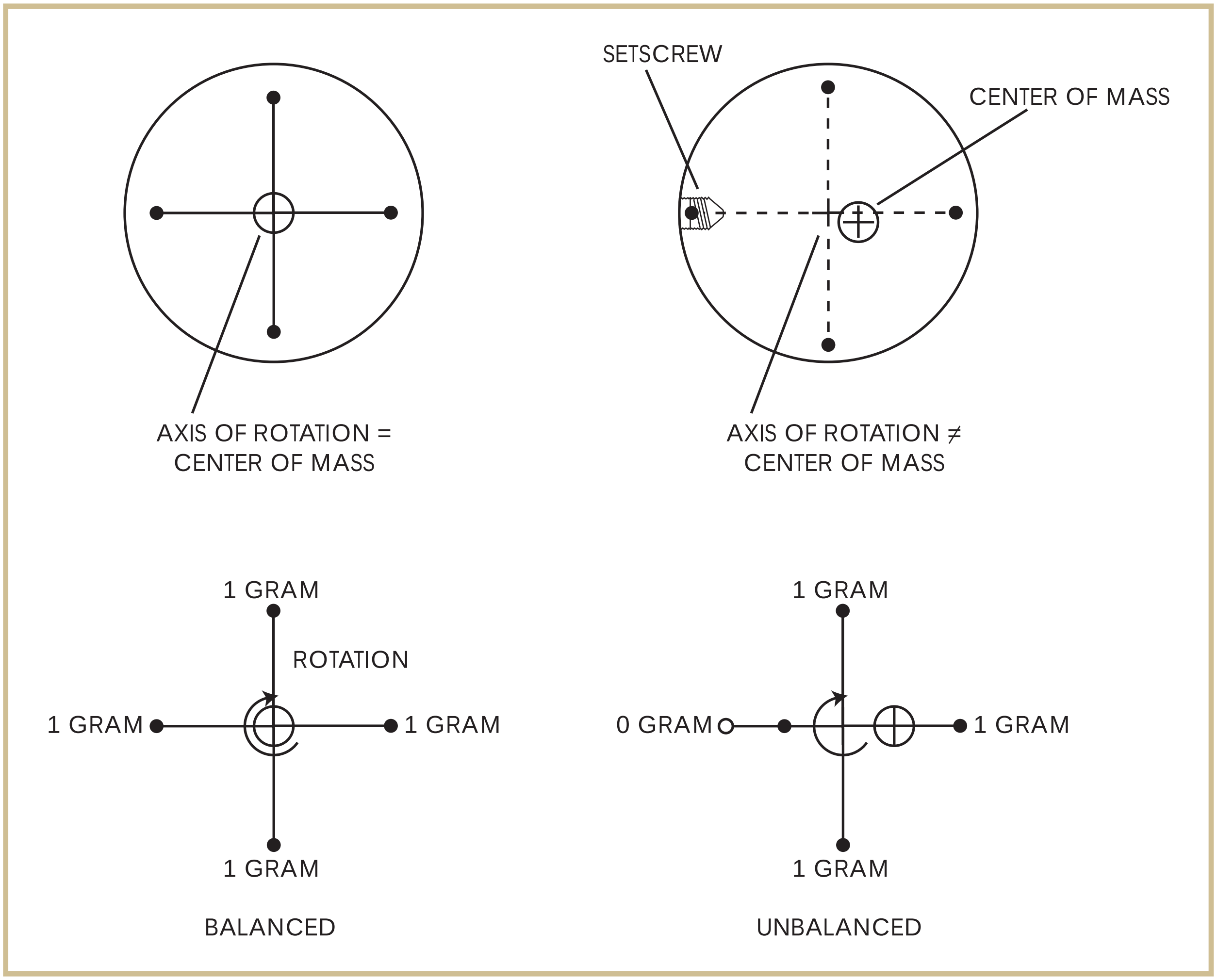



***FIGURE 47—Asymmetries such as setscrew holes and voids within the material affect the balance of a tool-holder. These asymmetries separate the center of mass and the axis of rotation, resulting in unbalance.***

the rotating part is the same (assuming they're in the same horizontal plane). For example, a mass of 1 gram that's 6 mm from the axis has the same effect as a mass of 2 grams that's 3 mm from the axis. The product of the mass times the distance from the axis is 6 gm-mm for both masses.

The unbalance also tells how much mass to add or remove in order to restore balance. If a toolholder has a measured unbalance of 40 gm-mm, the toolholder can be balanced by removing a mass of 2.0 gm at a distance of 20 mm from the axis, because 2.0 gm × 20 mm = 40 gm-mm.

The force that results from an unbalance can be calculated using the following equation:

$$force\ (\mathrm{lb.}) = \frac{unbalanced\ (gm\text{-}mm) \times (speed\ in\ RPM)^2}{405{,}000{,}000}$$

Notice that the force generated depends on the square of the speed. Doubling the RPM results in four times the centrifugal force being generated.

For example, the unbalance force in pounds for a toolholder assembly with a measured unbalance of 30 gm-mm that's turning at a spindle speed of 15000 RPM is

$$force\ (\mathrm{lb.}) = \frac{(30\ gm\text{-}mm) \times (15{,}000)^2}{405{,}000{,}000} = 16.7\ \mathrm{lb.}$$

This number can be compared to the tool loading resulting directly from feed rate and depth of cut to determine if it's a significant factor. Remember, tool unbalance affects surface finish and tool life. The ANSI Standard S.19–1975, *Balance Quality of Rigid Rotating Bodies*, defines what's acceptable for various groups of rotating equipment based on maximum service speed. For machine tools, the standard is G2.5. You will find that many manufacturers advertise toolholder balances that are considerably better than G2.5, such as G1.5 or even G1.0. These are more expensive but often necessary for high-speed machining.

Allowable unbalance can be calculated from the following relation:

$$U = \frac{G \times 9549 \times W}{RPM},$$

where

*U* is the amount of unbalance allowed (in gm-mm)

*9549* is a constant to adjust the units involved

*W* is the weight of the toolholder assembly (in kilograms)

*G* is the standard for the balance quality of rotating machinery, and 2.5 mm/sec is the constant assigned for machine tool spindle drives (often referred to as the *class* of the allowable unbalance)

*RPM* is the rotating speed of the assembly

For example, the allowed unbalance at 1000 and 12,000 RPM of a toolholder assembly that weighs 2.8 kg for a class G 2.5 is

For 1000 RPM:

$$U = \frac{2.5\,\frac{mm}{\text{sec}} \times 9549 \times 2.8\text{ kg}}{1000\ RPM} = 66.8\text{ gm-mm}$$

For 12,000 RPM:

$$U = \frac{2.5\,\frac{mm}{\text{sec}} \times 9549 \times 2.8\text{ kg}}{12{,}000\ RPM} = 5.6\text{ gm-mm}$$

Unbalance naturally results from features on the toolholder and cutting tool that are necessary for the proper function of the assembly. These features may include location slots, clamping components, setscrews, and holes. Other contributions to unbalance come from material flaws, such as voids or porosities in the base material or any parts of the tool that weren't machined and, therefore, may not have all of the material distributed symmetrically around the rotational axis. The natural unbalance of production toolholders is often in the range of 250 gm-mm. The force generated by this unbalance can lead to premature bearing failures, work piece chatter, decreased accuracy, and surface finish quality.

Toolholder and cutting tool assemblies can be balanced on specialty machines that determine the imbalance and can indicate the amount and location of material to be removed from the assembly. Of course, once a toolholder and cutting tool have been balanced, they must remain assembled to each other, or balance is lost. One company, Balancing

Dynamics Corporation of Ann Arbor, Michigan, makes a balancing system that attaches counterweighted rotor assemblies to the machine's spindle. An electronic controller measures the spindle vibration and moves the counterweights to compensate. Balancing takes less than three seconds, and the complete assembly of toolholder, cutting tool, spindle, and attachments is balanced as a unit. This type of system is relatively expensive, and the costs must be evaluated against the benefits of the desired quality to justify such a system.

## Hydraulic Toolholders

Hydraulic toolholders are one method used to solve balance and concentricity problems in high speed machining (HSM). Figure 48 shows a simplified cutaway of a hydraulic toolholder. Hydraulic toolholders have an inner chamber filled with hydraulic fluid. The solid outer portion of the toolholder

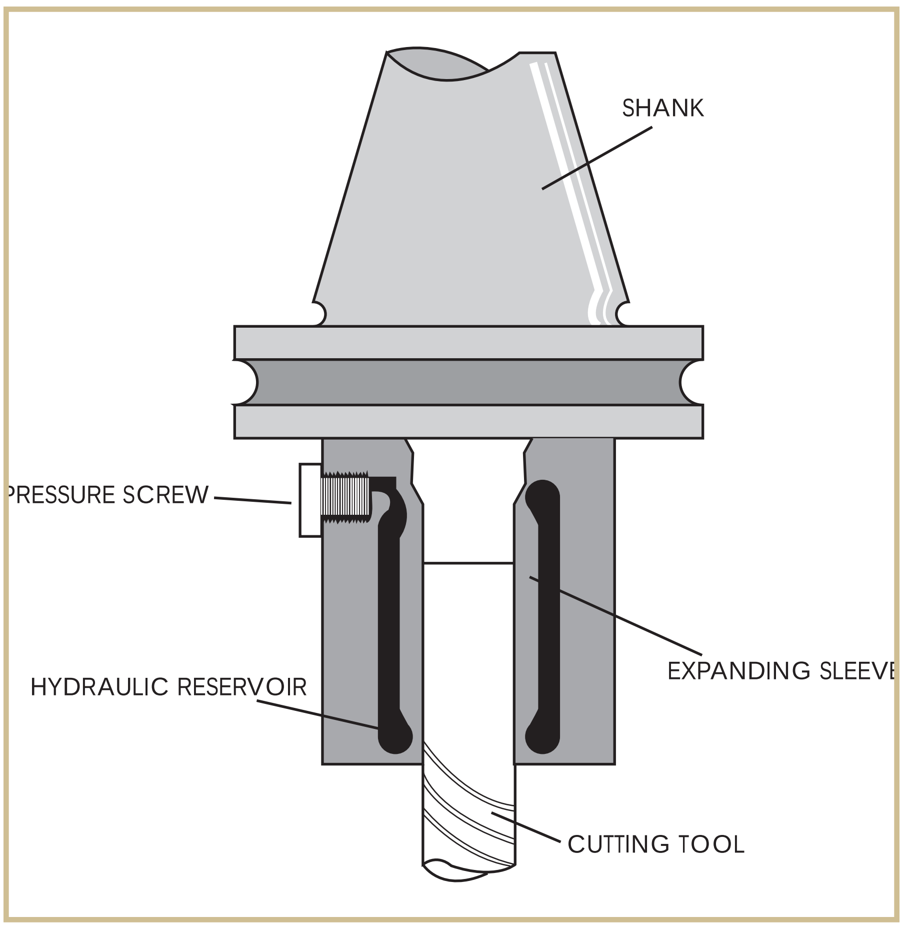



***FIGURE 48—Hydraulic toolholders provide high clamping forces, good concentricity, and few unbalances. Clamping forces are generated by a piston acting on a hydraulic reservoir within the end of the toolholder that forces an expanding sleeve to grip the cutting tool.***

is tapered in the same way as conventional toolholders, but the inside portion that contacts and grips the tools is thin and flexible. As the hydraulic pressure increases, the inner walls expand to grip the cutting tool. A threaded screw usually functions as a piston to control hydraulic pressure. Greater pressure develops in the chamber as the screw is turned. As the screw is turned in, the volume of the fluid is decreased and the pressure rises.

The advantages of hydraulic toolholders include better balance at high speeds and high clamping forces. The hydraulic oil acts as a damper for vibrations and cutting load variations and has better centering capabilities than standard toolholders. Also, cutting tools may be removed and replaced without significant loss of balance. Hydraulic toolholders typically use a clearance of 0.005 inches for a 1-inch diameter tool, plus an additional 0.002 inches for every additional inch of cutting tool diameter. When replacing cutting tools, tool concentricity can be repeated to within 0.00005 inches.

## Shrink Fit Systems

Another way to achieve the high clamping forces and good balance demanded by high speed machining systems is a *shrink fit toolholder*. These toolholders take advantage of the thermal expansion of steel when it's heated, and the high clamping forces that are generated when a metal contracts upon cooling. At room temperature, the bore of the toolholder is undersized (smaller in diameter than the cutting tool). For a half-inch cutting tool, the inside diameter of the toolholder is 0.4985 inch, so there's 0.0015 inch of interference. This generates over 10,000 pounds of clamping force. Shrink fit systems can deliver high rigidity along with high concentricity and balance, which won't change under machining loads.

To install a tool using a shrink fit system, the toolholder is heated in a special induction heater until the inside diameter of the toolholder just fits over the cutting tool. The operator removes the assembly from the heater and places it on an aluminum cooling block. The assembly is then permitted to cool. The whole process of heating and cooling takes less than a minute and can be repeated thousands of times without damage to the toolholder.

Individual hydraulic toolholders are more expensive than shrink fit systems, but the costs of the induction heater must be considered when evaluating overall costs. As the number of high speed machining jobs increases, the costs of the expensive heater can be spread over more time, and thus can become more attractive than the cost of a large number of hydraulic toolholders. At spindle speeds exceeding 10,000 RPM, the shrink fit system offers the highest level of concentricity and balance.

## The HSK and Other High Speed Machining Systems

High speed machining offers several challenges in addition to concentricity and balance issues. At very high spindle speeds, centrifugal forces on the spindle cause the inside diameter of the spindle to increase slightly. This allows the V-taper toolholder to be pulled farther into the spindle by the tension in the drawbar, changing its position in the Z-axis, as shown in Figure 49. This change affects the accuracy of the machining and can cause the toolholder to become stuck in the spindle when it's time to be removed.

The most prevalent spindle system for machine tools is the solid V-taper, as we've already discussed. Because of the pressure for higher and higher machining speed, toolholder positioning and balance become critical issues, and several other systems are being used to solve these problems. Of these, the *HSK system* is the more popular (HSK is an acronym for a German phrase meaning *hollow shank taper*). The basic feature of the HSK system is a short, hollow shank with a taper. Figure 50 shows a cross section of an HSK toolholder. Where standard V-tapers are about 4 inches long, the HSK taper is only 1.259 inches long.

Centrifugal force at high speeds causes the tool holding system to rotate in a large diameter, which is called *bell mouthing*. The HSK system attempts to solve the bell mouthing of the spindle at high rotation speeds by using a toolholder designed with a short taper, hollow shank, and an additional locating surface on the face of the spindle. The drawbar that attaches the toolholder to the spindle connects

***FIGURE 49—High centrifugal forces in the rotating spindle actually cause the inside diameter of the spindle to increase slightly. This change can cause the toolholder to be drawn farther into the spindle, causing a change in the Z-axis position and also making removal of the tool difficult when the spindle is stopped.***

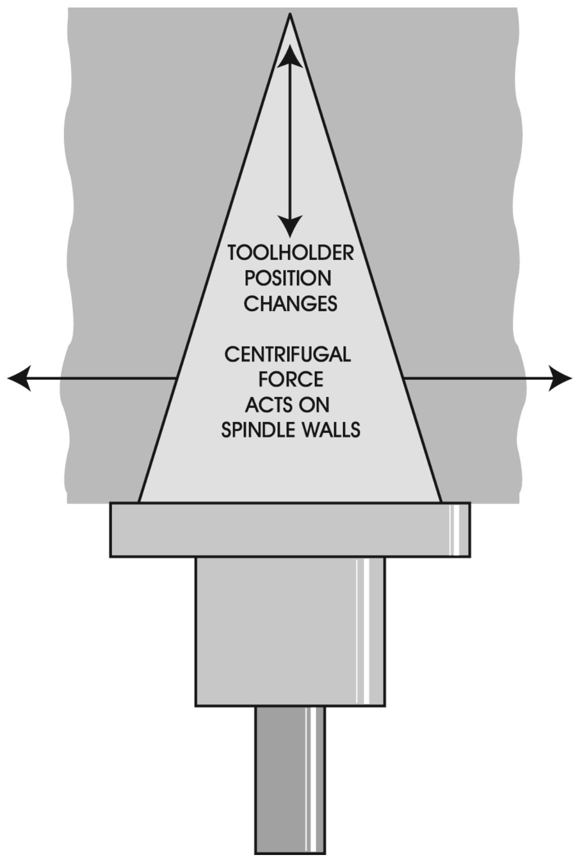
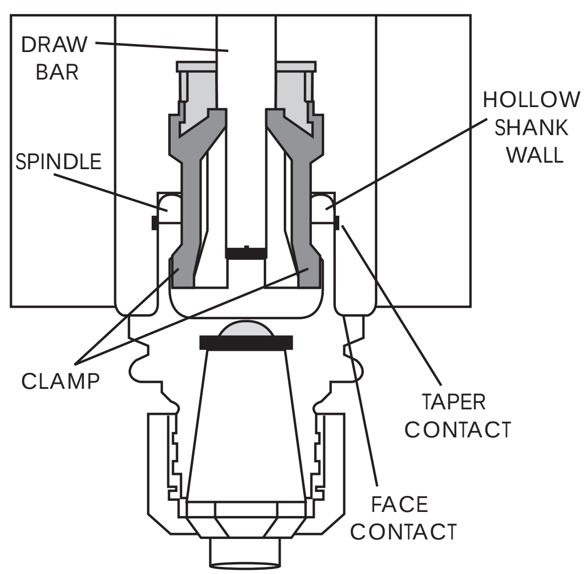



***FIGURE 50—The HSK system, which uses a hollow shank and taper, is a type of spindle system for machine tools.***



to a clamp that pushes on the toolholder from the inside. As the ID of the spindle grows due to centrifugal forces, these same forces cause the walls of the hollow shank HSK toolholder to grow, allowing it to maintain a constant grip on the spindle. Also, the drawbar expands the clamp on the inside of the toolholder, causing additional forces to keep the toolholder in place.

Another important factor in the stability of the HSK design is the second locating face on the front of the spindle and back of the toolholder. This keeps the toolholder from rising into the rotating spindle at high rotation speeds. These features ensure the rigidity of the toolholder/spindle assembly at high speeds, and make this system less prone to chatter.

Disadvantages of the HSK system include a relatively long distance from the front spindle bearings to the face of the spindle and lower cross-sectional area to remove the heat generated from high speed machining. Researchers estimate that 20% of the heat generated from machining is removed through the toolholder (75% through the chips, 5% through the work piece), and a high-resistance thermal path may lead to dimensional instabilities under some conditions. New spindle/toolholder systems are being developed to overcome these disadvantages, and may become more prominent as high speed machining evolves. These include the *NC5* system and the *Big Plus* system, both developed in Japan. Both systems use short, solid tapers with dual contacting surfaces to ensure stability at high speeds, taking very different approaches for their designs.

## Safety with Toolholders and Cutting Tools

The often-heard safety adage about the old and the bold can be applied especially to the machining industry: there are old machinists, and there are bold machinists, but there are no old, bold machinists. Materials and technology have advanced significantly in the last few decades, such that machining processes can be very safe and also very dangerous. They're safe if machine operators follow all of the recommended guidelines for operation and setup of the machine and proper handling of all materials. You should become familiar with the following safety guidelines before you attempt to operate a machine tool in the shop, and never take any shortcuts when it comes to operating the machine safely. Always refer to the operating instructions of the machine to learn about required safety precautions, features, and principles of operation.

## Flying Particles

Machining, by definition, is removing metal particles from a work piece at high speeds. Therefore, there are always moving particles around any type of machining operation. Also, modern cutting tools are high strength but have almost no ductility. As a result, a cutting tool failure can result in very hard particles traveling at very high velocities. To avoid injuries from flying particles, always wear safety glasses or goggles with side shields while you're anywhere in the shop, even if you aren't operating a machine. Always keep doors and machine guides in place on metal-cutting machines, and never circumvent interlocks on the machine.

The chart in the previous section about inserts contains recommended thickness for various feeds and depths-of-cut. An insert that isn't thick enough is prone to sudden failure, which can result in flying pieces of carbide. If you have any doubts as to the ability of an insert to withstand the anticipated cutting loads, use either a thicker insert or reduce the feeds or speeds appropriately.

### Chip Control

Guards and shields are placed on machines to direct chips away from the operator, and should never be removed. Sometimes long, thin, or stringy chips are present and represent serious threats to the operator. They may wind back on the work piece, resulting in broken tools and ruined work pieces, or may fly off in unpredictable directions. Always stop the machine to remove these chips, and always handle them with a mechanical device such as tongs or hooks. Never handle chips with your hands, even if you're wearing gloves, as the chips are extremely sharp. Never remove chips from a machine by blowing them with an air hose.

## Cutting Fluids and Hazardous Materials

When machining practices call for use of a cutting fluid, make sure you understand any dangers involved in using the fluid. All materials used in a machine shop must have an *MSDS*, or *Material Safety Data Sheet*, and this sheet must be posted near the place of use. The MSDS contains a listing of all known safety hazards, and safe practices for handling the material. The sheet advises you about any *carcinogenic* (cancer-causing) properties of the material and also advises you of any possible known reactions from skin contact or breathing the material. If you don't know the precautions for using any particular cutting fluid, ask your supervisor or plant safety officer for a copy of the MSDS to review.

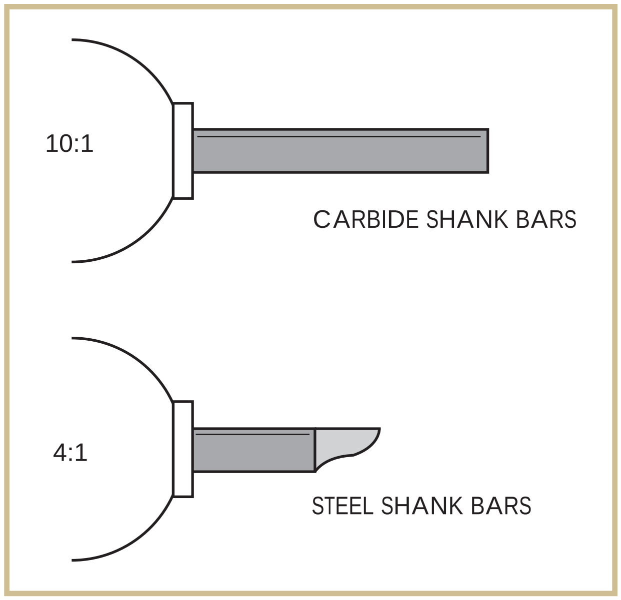
Some types of cutting fluids may present a fire hazard, since they can be ignited by hot chips. Some materials, such as magnesium, aluminum, titanium, or uranium, that produce fine chips or dust during the machining process (such as grinding) may be an explosion hazard. Finally, even some of the dust from the machining of certain materials may be a hazard when breathed. Some people have severe allergic reactions to some of the materials found in cemented carbides or to some metals such as beryllium copper. The best way to avoid injury is to be aware of the materials you're machining or using by reviewing the MSDS sheets, which are required by law to be available to anyone using or exposed to potentially hazardous materials.

## Tool Overhang and Mechanical Setups

When setting up a machine tool for turning, facing or milling processes, you should keep tool overhangs as short as possible. Excessive overhang, whether it's on a long milling machine tool, a boring bar, or a lathe tool-holder, tends to result in bending of the tool, which can result in broken tools, poor finishes, and chatter. An acceptable overhang for a toolholder, in terms of ratio of length to diameter, is no more than 4:1 with a steel shank, and no more than 10:1 with a carbide shank, as shown in Figure 51.

Toolholders often fail catastrophically when subjected to excessive bending, and chatter can loosen clamps or other

*FIGURE 51—Tool overhand should be minimized to avoid machining problems and to ensure operator safety.*




holders. At best, you may have a ruined part; at worst, you may have a serious injury to yourself or damage to the machine tool from flying parts.

Another consideration arises on parts with unusual geometries, such as long, slender parts. Be sure the workpiece itself is adequately supported to withstand the cutting forces without bending or working loose from its holder. On workpieces with high length-to-diameter ratios, use cutting tools with small nose radii and flat leading cutting edge angles.

## Additional Sources of Information

The information you've been learning in this unit is by no means complete. There are many other valuable sources of information that you can use to find out more about toolholders and other cutting tools. A valuable resource is the *Machinery's Handbook*, which is currently in its 25th edition. This handbook has many additional references to machining information and practices and should be in every machinist's and mechanic's library.

Other very valuable resources are manufacturers' catalogs. For example, Carboloy® publishes catalogs and technical guides for turning and drilling that have information about standard products, and technical information concerning cutting tools and toolholders. These catalogs and technical guides contain information you'll refer to many times to answer machining questions.

Another source of up-to-date information on advances in machining techniques and products are trade magazines published for people in the manufacturing industries. Excellent technical information is available in magazines such as *Machine Design*, *Modern Machine Shop*, and others. You can often find examples of these in a technical library, and subscriptions are often free for those employed in industries related to manufacturing. Even the advertisements in these magazines have valuable information about new products, techniques, and services!

And finally, in the last few years, the Internet has grown to the point where access to search engines and directories can easily point you to information from manufacturers all over the world. These manufacturers have web pages that describe their products and prices, along with technical information to help you make intelligent selections. The trade magazines mentioned previously also have web pages in which you can find useful articles about many manufacturing issues. Try accessing the web pages for *Machine Design* at www.machine design.com, and the web page for *Modern Machine Shop* at **www.mmsonline.com.** You'll find lots of articles about toolholders and tool selection at these websites.

Now, take a few moments to review what you've learned by completing *Self-Check 3*.

# Self-Check 3

1. The gage diameter of a #40 ANSI taper is ________.
2. Multiple-lathe toolholders can be mounted on a ________ to allow for rapid indexing.
3. When highly precise concentricities are demanded, ________ or ________ toolholders may be necessary.
4. Nonsymmetrical toolholders turning at high speeds produce large ________ forces.
5. The ANSI standard balance class for machine tool drives is G ________.
6. The ________ toolholder uses a threaded screw that functions as a piston.
7. Acceptable overhang for a steel shank toolholder 1 inch in diameter is ________.

**Check your answers with those on page 71.**

Answers

## Self-Check Answers 1

1. collet
2. accuracy, repeatability, reliability
3. taper
4. cemented carbide
5. triangular, 11
6. superhard

## Self-Check Answers 2

1. False
2. False
3. pocket
4. $\frac{1}{32}$
5. positive
6. spring, solid
7. self-releasing

## Self-Check Answers 3

1. 1.750 inches
2. turret
3. shrink fit, hydraulic
4. centrifugal
5. 2.5
6. hydraulic
7. 4 inches