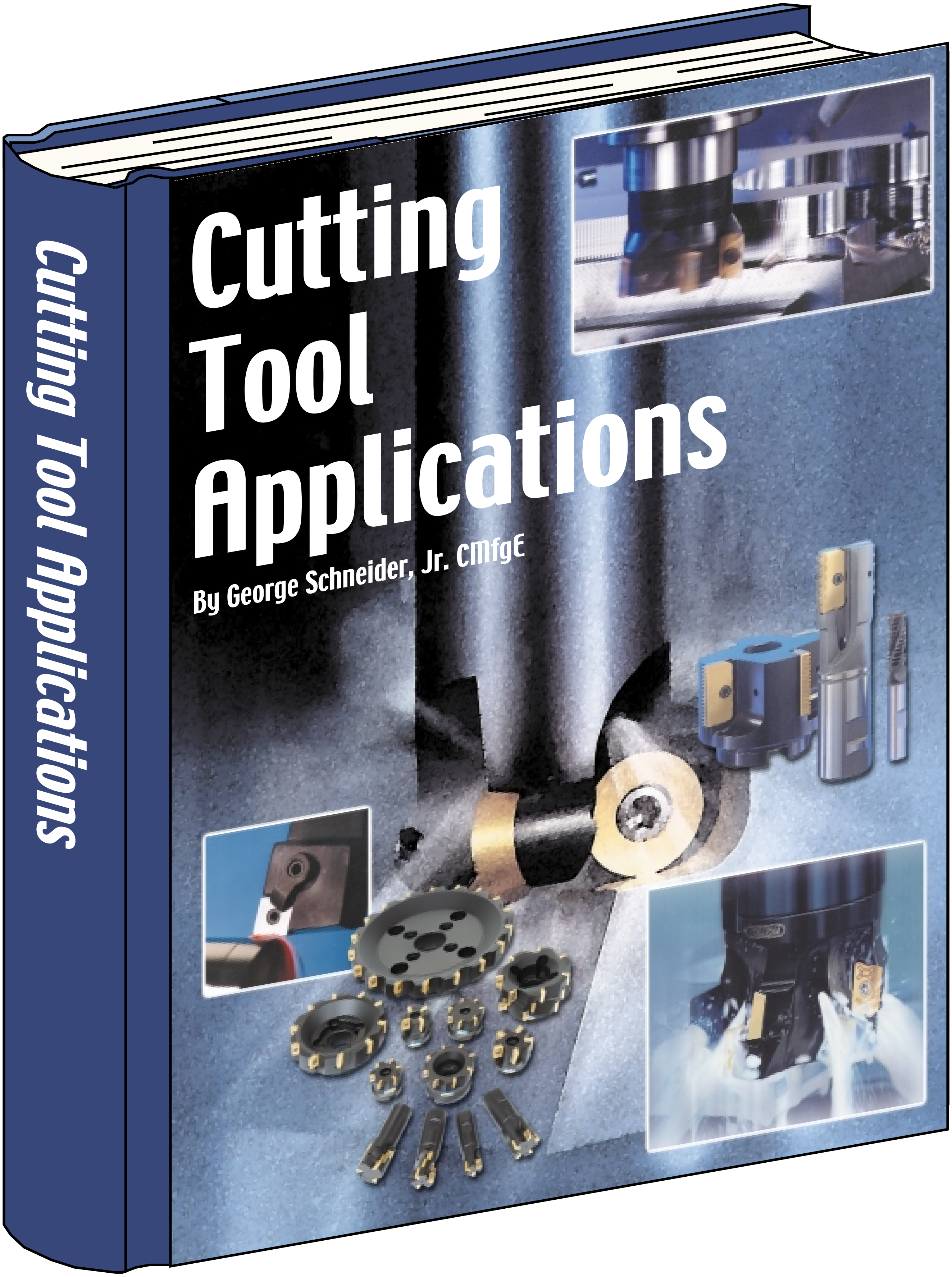
Cutting Tool Applications
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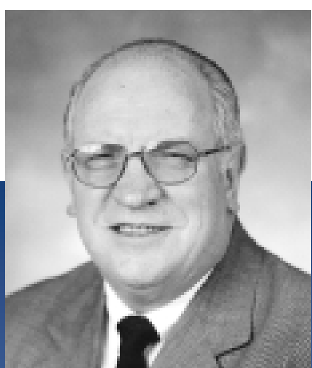
By George Schneider, Jr. CMfgE



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Chapter 9 Drilling Methods & Machines

9.1 Introduction

One of the most important and essential tools in any metalworking shop is the drilling machine or drill press. Although the drilling machine is used primarily for drilling holes, it is often used for reaming, boring, tapping, counterboring, countersinking, and spotfacing.

All drilling machines operate on the same basic principle. The spindle turns the cutting tool, which is advanced either by hand or automatically into a workpiece that is mounted on the table or held in a drill press vise. Successful operation of any drilling machine requires a good knowledge of the machine, proper set-up of the work, correct speed and feed, and proper use of cutting fluids applied to the cutting tool and work.

9.2 Types of Drill Presses

Many types and sizes of drilling machines are used in manufacturing. They range in size from a simple bench mounted sensitive drill press to the large multiple-spindle machines able to drive many drills at the same time.

Figure 9.1 shows a schematic diagram of a standard vertical drill press as well as a schematic diagram of a turret-drilling machine. Described below are these and other types of drill presses such as sensitive and radial drills.

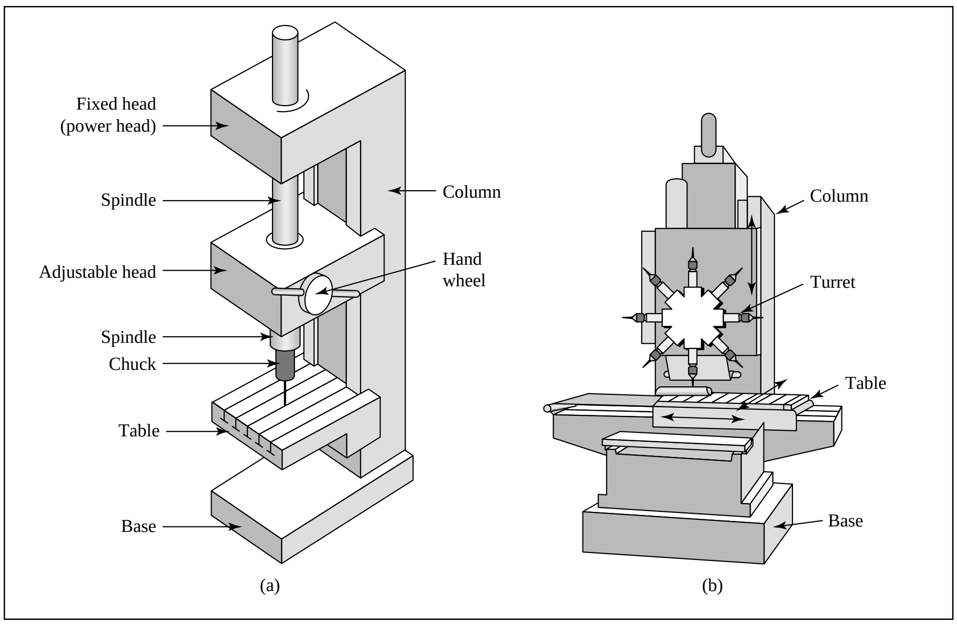

FIGURE 9.1: Schematic illustration of (a) vertical drill press, (b) CNC turret drilling machine.

9.2.1 Simple Drill Press

A simple drill press (Fig.9.2) may be floor mounted as shown, or have a shorter main post and be mounted on a bench. The motions of this machine are very simple. The table on a floor model can be raised or lowered and rotated around the machine column. The spindle rotates and can be raised and lowered, with a stroke of 4 to 8 inches. Stops can be set to limit and regulate the depth.

9.2.2 Sensitive Drill Press

The name 'sensitive' is used to indicate that the feed is hand operated and that the spindle and drilling head are counterbalanced so that the operator can 'feel' the pressure needed for efficient cutting. A table mounted sensitive drill press is shown in Figure 9.3.

The drill press has the same motions as the previous one plus a telescoping screw for raising and lowering the table and a sliding 'drill head'. These two features allow easier handling of parts of varying heights.

9.2.3 Radial Drill

For handling medium to very large size castings, weldments, or forgings, radial drills are ideal. The length of the arm along which the spindle housing rides specifies their size. This arm can be from 3 to 12 feet long. The column that holds the arm may be from 10 to 30 inches in diameter. A radial drill is shown in Figure 9.4.

For very large work, the arm may be rotated 180 degrees and work placed on the shop floor. Speeds and feeds are dialed in by the machine operator and are the same as for other drill presses. Drilling is either hand or power feed.

9.3 Drilling Machine Components

Rigid and accurate construction of drilling machines is important to obtain proper results with the various cutting tools used. The sensitive drilling machine construction features are discussed in this section because its features are common to most other drilling machines.

Base: The base is the main supporting member of the machine. It is heavy gray iron or ductile iron casting with slots to support and hold work that is too large for the table

Column: The round column may be

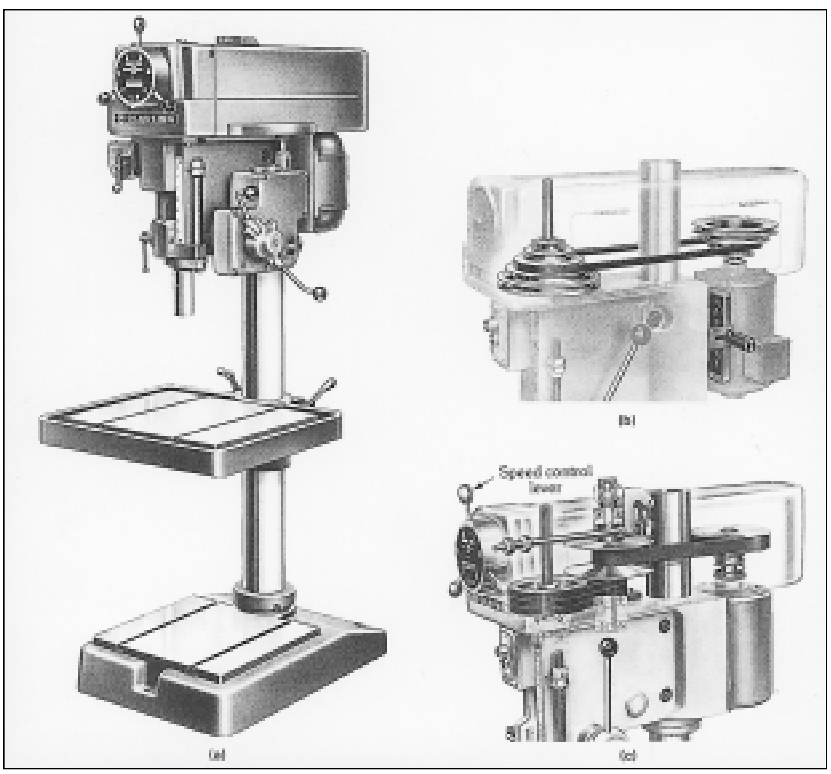

FIGURE 9.2: a) a sensitive drill press is used for drilling holes; b) speeds on a stepped V pulley drive are changed by hanging the position of the V belt; c) speeds on a variable-speed drive mechanism are changed by the handwheel on the head. (Courtesy Clausing Industries, Inc.)

FIGURE 9.3: A table mounted sensitive drill used for drilling small holes. (Courtesy Clausing Industries, Inc.)

made of gray cast iron or ductile iron for larger machines, or steel tubing for smaller bench drill presses. It supports the table and the head of the drilling machine. The outer surface is machined to function as a precision way of aligning the spindle with the table.

Table: The table can be adjusted up or down the column to the proper height. It can also be swiveled around the column to the desired working position. Most worktables have slots and holes for mounting vises and other work-holding accessories. Some tables are semi universal, meaning that they can be swiveled about the horizontal axis.

Head: The head houses the spindle, quill, pulleys, motor, and feed mechanism. The V-belt from the motor drives a pulley in the front part of the head, which in turn drives the spindle. The spindle turns the drill. Two head assemblies are shown in Figure 9.2 b and c. Speeds on a stepped V pulley drive are changed by changing the position of the V-belt (Fig. 9.2b) Speeds on a variable-speed drive mechanism are changed by a hand wheel on the head. (Fig. 9.2c) The spindle must be revolving when this is done.

Quill assembly: The spindle rotates within the Quill (Fig. 9.5) on bearings.

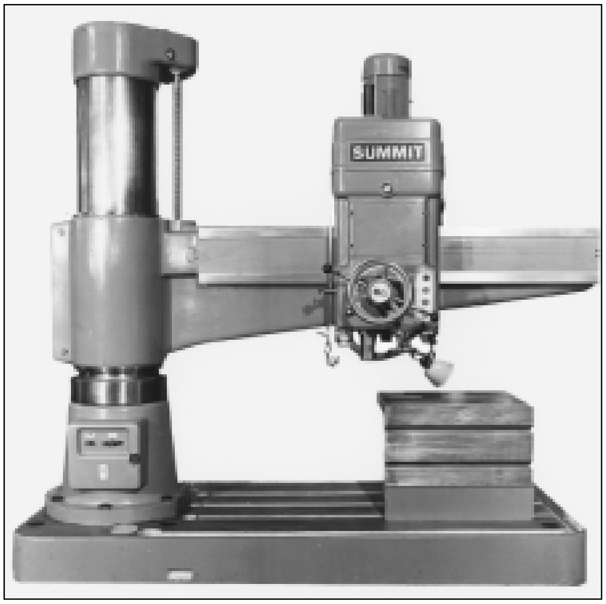

FIGURE 9.4: Radial drills are used to machine large castings, weldments or forgings. (Courtesy Summit Machine Tool Manufacturing Corp.)

The quill moves vertically by means of a rack and pinion. The quill assembly makes it possible to feed or withdraw the cutting tool from the work. Located on the lower end of the spindle is either a Morse tapered hole or a threaded stub where the drill chuck is mounted. For drilling larger holes, the drill chuck is removed and Morse tapered cutting tools are mounted.

Size Classification: The size (capacity) of a drilling machine is determined by all the following features:

• Twice the distance from the center of the spindle to the inner face of the column
• The maximum length of quill travel
• The size of the Morse taper in the spindle
• The horsepower of the motor.

9.4 Drilling Systems

Drilling systems are usually automated and computer controlled. Speeds, feeds, and depth of cut are often pre-set. Such systems combine drilling operations with reaming, tapping, countersinking, etc. Figure 9.6 shows a 3-axis CNC drilling machine.

9.4.1 Multi Spindle Drilling

This type of drilling can be done on drill presses by using special attachments. The spindle locations are adjustable, and the number of spindles may be from two to eight. Drills, reamers, countersinks, etc., can be used in the spindles. The RPM and feed rate of all spindles in one drill head are the same, and the horsepower needed is the sum of the power for all cutting tools used. In this type of machine, a large number of holes may be drilled at one time. Several different diameters of drills may be used at the same time.

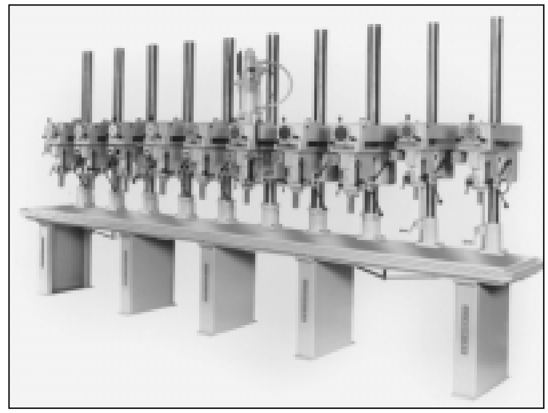

FIGURE 9.7: Gang drilling machines permit economical ways to perform several different operations. (Courtesy Clausing Industries, Inc.)

9.4.2 Gang Drilling

An economical way to perform several different operations on one piece is by gang drilling as shown in Figure 9.7. This might include drilling two or more sizes of holes, reaming, tapping, and countersinking. The work is held in a vise or special fixture and is easily moved along the steel table from one spindle to the next.

The drill presses usually run continuously so the operator merely lowers each spindle to its preset stop to perform the required machining operation.

9.4.3 Turret Drill

Turret drills (Fig. 9.1b) with either six or eight spindles enable the operator to use a wide variety of cutters and yet move the workpiece only a few inches, according to the hole spacing. The turret can be rotated (indexed) in either direction, and then lowered, by hand or automatically, to make the cut.

Some turret drills have automatic, hydraulically controlled spindles. Speeds, feeds, and depths of cut can be preset for fast production. Figure 9.1b shows an automatic machine. These machines are also made with the entire operation computer controlled, (CNC turret

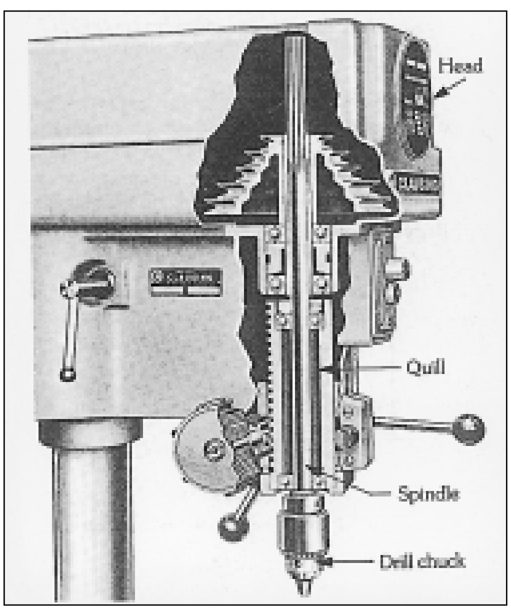

FIGURE 9.5: The spindle rotates within the quill. The quill moves vertically by means of a rack and pinion. (Courtesy: Clausing Industries, Inc.)

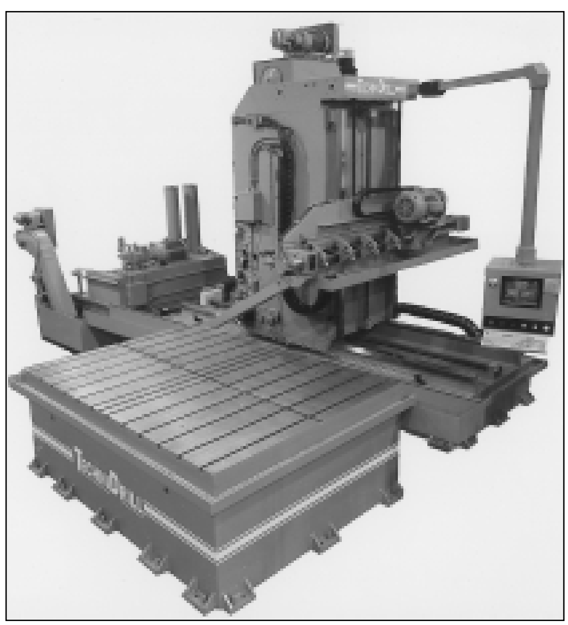

FIGURE 9.6: Shown is a 3-axis CNC drilling Machine (Courtesy: TechniDrill Systems, Inc.)

drill), so that the operator merely has to load and unload the parts. A numerically controlled turret drill is shown in Figure 9.8.

9.5 Operation Set-up

In drilling operations the three most common work holding methods are:
• Vises
• Angle Plate
• Drill Jigs

Vises: Vises are widely used for holding work of regular size and shape, such as flat, square, and rectangular pieces. Parallels are generally used to support the work and protect the vise from being drilled. Figure 9.9 shows a typical vise. Vises should be clamped to the table of the drill press to prevent them from spinning during operation. Angular vises tilt the workpiece and provide a means of drilling a hole at an angle without tilting the table. An angular vise is shown in Figure 9.10.

Angle Plates: An angle plate supports work on its edge. Angle plates accurately align the work perpendicular to the table surface, and they generally have holes and slots to permit clamping to the table and holding of the workpiece.

Drill Jigs: A drill jig is a production tool used when a hole, or several holes, must be drilled in a large number of identical parts. Figure 9.11 shows a diagram of a typical drill jig. The drill jig has several functions. First, it is a work holding device, clamping the work firmly. Second, it locates work in the correct position for drilling. The third function of the drill jig is to guide the drill straight into the work. This is accomplished by use of drill bushings.

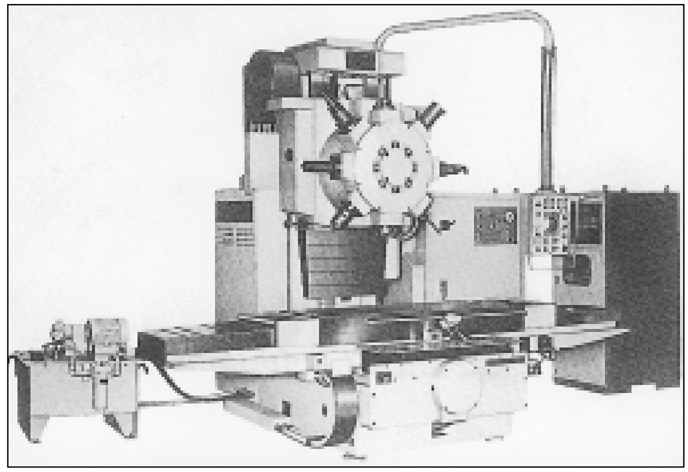

FIGURE 9.8: Numerically controlled turret drill automatically positions the worktable. (Courtesy: Kanematsu USA, Inc.)

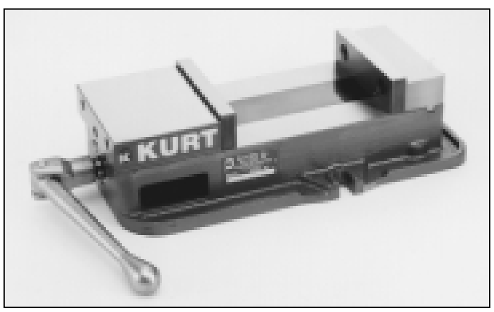

FIGURE 9.9: Vises should be clamped to the table of drill presses to prevent them from spinning. (Courtesy Kurt Manufacturing Co.)

9.5.1 Tool Holding Devices

Some cutting tools used in drilling can be held directly in the spindle hole of the machine. Others must be held with a drill chuck, collet, sleeve, socket, or one of the many tool-holding devices shown in Figure 9.12.

Drill Chucks: Cutting tools with straight shanks are generally held in a drill chuck. The most common drill chuck uses a key to lock the cutting tool. Drill chucks, both with key and keyless, are shown in Figures 9.13.

Sleeves: Cutting tools with tapered shanks are available in many different sizes. When a cutting tool that has a smaller taper than the spindle taper used, a sleeve must be fitted to the shank of the cutting tool.

Sockets: If the cutting tool has a tapered shank larger than the spindle taper, a socket is used to reduce it to the correct size. Figure 9.14 shows various size keyless drill chucks with one straight and two tapered shank mountings.

9.6 Deep-hole Drilling

The term 'deep holes' originally referred to hole depths of over 5 x the diameter. Today, deep-hole drilling is a collective name for methods for the

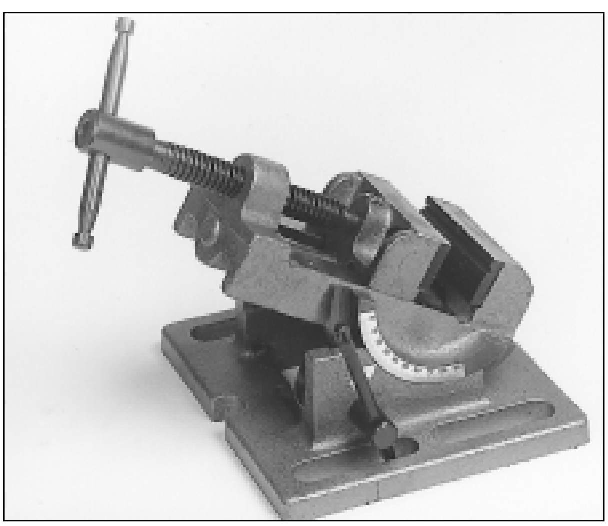

FIGURE 9.10: The angle vise tilts the workpiece and provides a means of drilling a hole at an angle. (Courtesy: Palmgren Steel Products, Inc.)

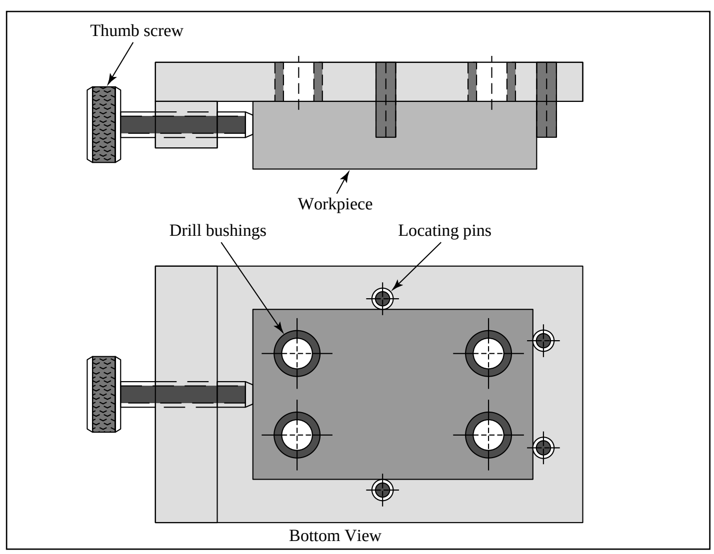

FIGURE 9.11: Drill jigs locate and clamp workpieces, and guide the drill through a drill bushing.

FIGURE 9.12: Various tool-holding devices such as chucks, collets, sleeves, and sockets are shown. (Courtesy Lyndex Corp.)

machining of both short and deep holes.

Deep-hole drilling is the preferred method for drilling hole depths of more than 10 x the diameter, but because of the method's high metal-removal capacity and precision, it is also competitive for small holes down to 2 x the diameter.

During drilling, it is important that the chips be broken and that they can be transported away without jamming and affecting the drilled surface. In deep-hole drilling, cutting fluid supply and chip transport have been provided for by the development of three different systems that permit trouble-free machining of hole depths of more than 100 x the diameter. The three systems are called: the Gun Drilling System, the Ejector System (two-tube system) and the Single Tube System (STS).

FIGURE 9.13: Key and keyless chucks are used to hold drills for holemaking operations. (Courtesy Bridgeport Machine, Inc.)

FIGURE 9.14: Various size drill chucks are shown. (Courtesy: Royal Products)

Some of the tools used in deep-hole drilling are shown in Figure 9.15. Hyper Tool manufactured the gun drills, and Sandvik manufactured the indexable tools.

9.6.1 Gun Drilling Systems

The gun drill system uses the oldest principle for cutting fluid supply. The cutting fluid is supplied through a duct inside the drill and delivers coolant to the cutting edge, after which it removes the chips through a V-shaped chip flute along the outside of the drill. Due to the V-groove, the cross section of the tube occupies 3/4 of its circumference. Figure 9.16 shows a gun drilling system and its component parts.

Gun Drills

Gun drills belong to the pressurized coolant family of hole making tools.

FIGURE 9.15: Deep-hole drilling tools; the gun drills were manufactured by Hyper Tool and the indexable tools were manufactured by Sandvik. (Courtesy TechniDrill Systems, Inc.)

They are outstanding for fast, precision machining regardless of hole depth. As a rule, a gun drill can hold hole straightness within 0.001 inch per inch (IPI) of penetration, even when the tool is reasonably dull. For most jobs a gun drill can be used to cut from 500 to 1000 inches in alloy steel before re-sharpening is necessary. In aluminum, it might be 15,000 inches, while in cast iron it is usually around 2000 inches. Figure 9.17a shows a gun drilling tool and Figure 9.17b shows the gun drilling process.

Depending on the tool's diameter, a gun drill is seldom run at feed rates exceeding 0.003 inches per revolution (IPR). This is extremely light compared to twist drill feeds, which typically range from 0.005 IPR to 0.010 IPR. But gun drilling does use a relatively high

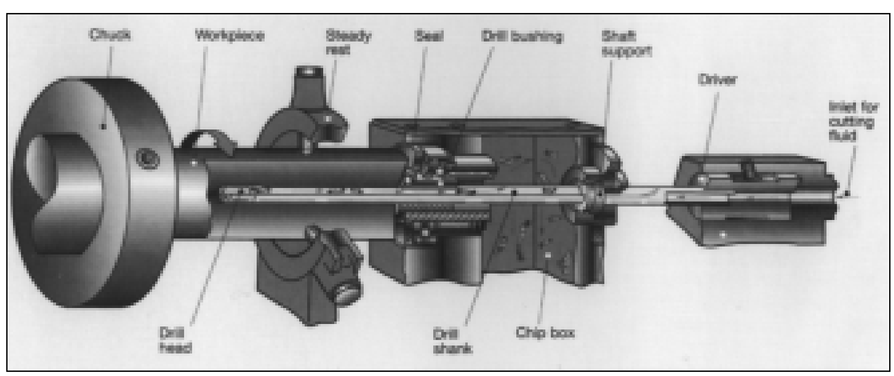

FIGURE 9.16: Schematic diagram of a gun drilling system with major components. (Courtesy Sandvik Coromant Co.)

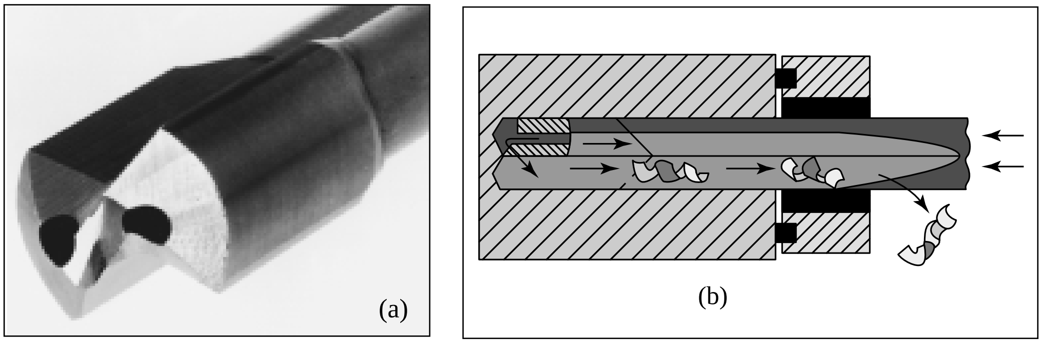

FIGURE 9.17: (a) Gun drilling head. (b) A drawing of a gun drilling process. (Courtesy Star Cutter Co.)

speed compared to high speed steel (HSS) twist drilling. This accounts for the high metal-removal rates associated with the process. In aluminum, speeds may be 600 surface feet per minute (SFPM), in steels from 400 SFPM to 450 SFPM.

Speeds and feeds for gun drilling are based on the workpiece material and shop floor conditions. Published charts only provide starting points. On-the-floor experimentation is critical to determine the right combination for maximum tool life.

Gun Drill Body

The body of a gun drill is typically constructed from 4120 aircraft quality steel tubing that is heat treated to between 35 to 40 Rc. A 4140 steel driver is brazed to one end of the tube and a carbide tool tip is brazed to the other end. Figure 9.18 shows five different tool tip geometries with various coolant hole placements.

There are two body styles for multiple flute tools; milled and crimped. The former is a thick wall tubular shaft with the flutes milled into the body. The latter is a thin wall tubular shaft that has the flutes swaged into it. The number of flutes depends on the material being cut. When drilling in a material that breaks easily into small chips, such as cast iron, a two flute tool is the choice. On the other hand, for a material such as D2 tool steel, a single flute design is preferred. In this case, chips tend to be stringy and a single flute tool will minimize the chance of jamming as they are removed from the hole.

Figure 9.19 shows both a crimp style gun drill body with two flutes produced by swaging and a conventional milled style gun drill. The coolant holes in the crimped body have an irregular shape that permits carrying a much larger volume of coolant than comparable holes in a conventional equivalent diameter tool body. Also, the flutes that are formed are much deeper than milled tools because allowance does not have to be made for wall thickness between flute and coolant hole. These deeper flutes improve the chip removal efficiency of the tool.

Gun Drill Tip

A conventional gun drill has a hole in its carbide tip underneath the cutting edge. Pressurized cutting fluid is pumped through the tool's body and out the hole (see Figure 9.18). The fluid serves a three-fold purpose: it lubricates and cools the cutting edge; it forces the chips back along the flute in the tool body; and it helps to stiffen the shank of the tool.

A new design has one hole in the top of the tool tip that effectively directs fluid at the cutting edge. The other hole that is in the conventional location helps to provide the chip ejection function. Total flow of cutting fluid is doubled with this two-hole arrangement. More importantly, the design produces chips about half the size of a conventional gun drill of the same diameter using the same speed and feed rate, so that packing of chips along the tool's shank is avoided in most materials.

The most common tool tip material is C2 carbide, which is one of the harder grades and is generally associated with cast iron applications. Because excessive tool wear is a major problem when cutting steel, a hard grade such as C2 is recommended, even though C5 carbide is labeled as the steel machining grade in most text books. C5 carbide is a shock resistant grade, not a wear-resistant grade, so that it is not as suitable for a gun drill tool tip. C3 carbide is harder than C2, and is used for certain applications; however, greater care must be taken when re-sharpening this material because it is easier to heat check the cutting edge.

Recently, coatings such as titanium nitride are being applied to gun drill tips to extend tool life. Physical Vapor Deposition (PVD) is the only practical process for depositing coatings on precision tools such as gun drills, but the results have not been encouraging. Unlike coating high-speed steel tools, PVD coating of a carbide gun drill tip does not seem to form a good metallurgical bond. The coating wipes off during the metal cutting process. Using Chemical Vapor Deposition (CVD) will form a metallurgical bond between the coating and carbide substrate, but the high heat required by the process distorts the tool. Hopefully these problems will be resolved in the near future.

FIGURE 9.18: Shown are five different tool tip geometries with various coolant hole placements (Courtesy: Star Cutter Co.)

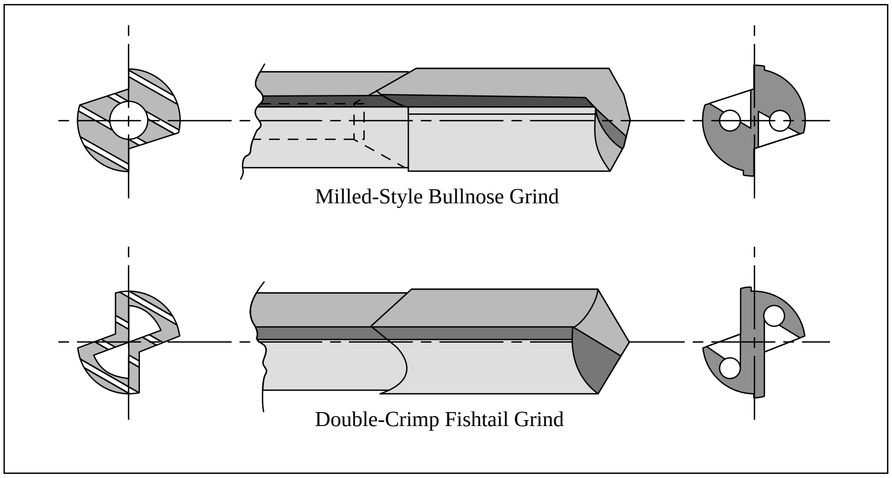

FIGURE 9.19: There are two body styles of multifluted gun drills: milled style and double-crimp style.

9.6.2 The Ejector System

The Ejector System consists of drill head, outer tube, inner tube, connector, collet and sealing sleeve. The drill head is screwed to the drill tube by means of a four-start square thread. The inner tube is longer than the outer tube. The drill tube and the inner tube are attached to the connector by means of a collet and a sealing sleeve. The collet and sealing sleeve must be changed for different diameter ranges. Figure 9.20 shows the Ejector System and its components.

9.6.3 The Single Tube System (STS)

The Single Tube System is based on external cutting fluid supply and internal chip transport. As a rule, the drill head is screwed onto the drill tube. The cutting fluid is supplied via the space between the drill tube and the drilled hole. The cutting fluid is then removed along with the chips through the drill tube. The velocity of the cutting fluid is so high that chip transport takes place through the tube without disturbances. Since chip evacuation is internal, no chip flute is required in the shank, so tip cross-section can be made completely round, which provides much higher rigidity than the gun drill system. Figure 9.21 shows the Single Tube System and its components.

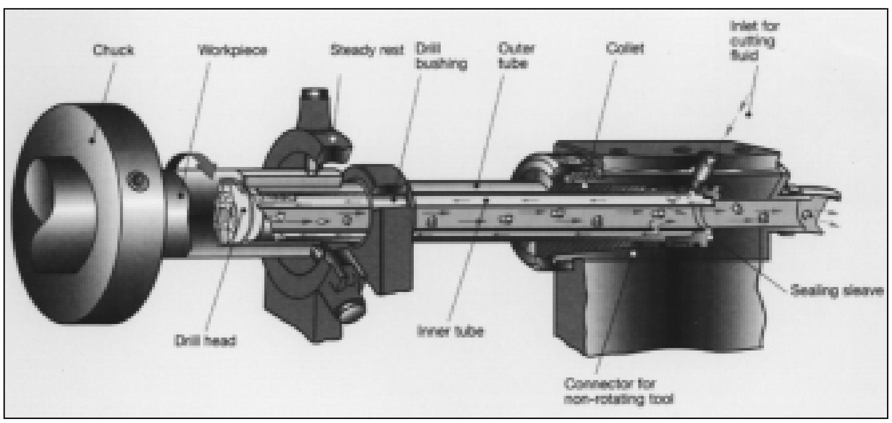

FIGURE 9.20: The ejector system and its major components. (Courtesy Sandvik Coromant Co.)

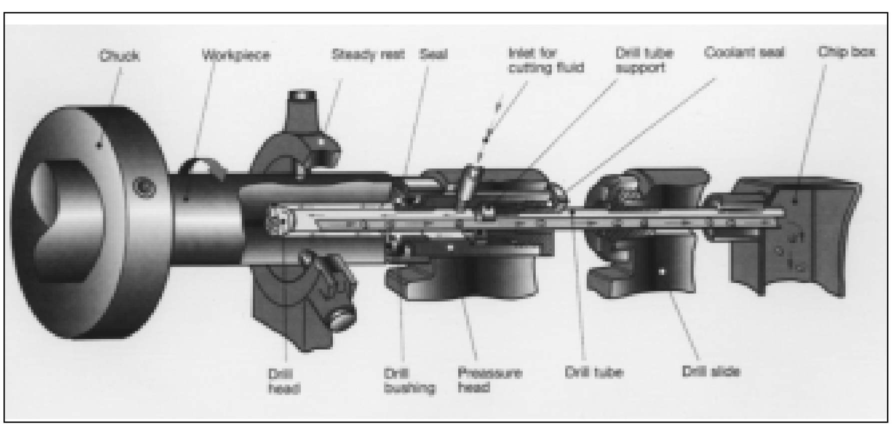

FIGURE 9.21: The single-tube system (STS) and its major components. (Courtesy Sandvik Coromant Co.)

9.6.4 Comparison of STS and Ejector Systems

Both the Single Tube System and the Ejector System have wide ranges of application, but there are times when one system is preferable to the other.

STS is preferable in materials with poor chip formation properties such as stainless steel, low carbon steel, and materials with an uneven structure, when chip breaking problems exist. STS is also more advantageous for long production runs, uniform and extremely long workpieces and for hole diameters greater than 7.875 inches.

The Ejector System requires no seal between the workpiece and the drill bushing. The system can therefore be adapted easily to existing machines and is preferable in NC lathes, turning centers, universal machines and machining centers. Since the cutting fluid is supplied between the outer and inner tubes, no space is required between the drill tube and the hole wall as in the case of STS drilling. The Ejector System is therefore often used for machining in workpieces where sealing problems can arise. The Ejector System can be used to advantage when it is possible to use a predrilled hole instead of a drill bushing for guidance, for example in machining centers.

9.6.5 Operational Requirements

Machining with high cutting speeds and high demands on surface finishes and tolerances requires a machine tool that is both very rigid and very powerful. It is possible to use conventional machines with sufficient power and rigidity.

Machine Requirements: The high

FIGURE 9.22: The length of a deep-hole drilling machine depends on the diameter and the length of the workpiece. (Courtesy Sandvik Coromant Co.)

feed speeds that characterize deep hole drilling impose high demands on available power. In order to achieve good precision, the machine must be rigid and the spindle bearings free of play. Good chip breaking often requires high feed and the feed must be constant, otherwise the chip breaking may vary, leading to chip jamming. The best possible chip breaking can be obtained with infinitely adjustable feed.

It is important that the machine be equipped with safety devices to protect the machine, the tool and the workpiece. The purpose of the safety device is to stop the machine automatically in the event of overloading. The machine spindle should not be able to start until the pressure of the cutting fluid has reached a preset minimum. The temperature and quantity of the cutting fluid should also reach a correct level before the machine starts.

Best are overload protections that are connected to the feed pressure. It is extremely important that the overload limits be set no more than 10 - 13 percent above the actual drill pressure for each drill diameter and feed. The feed will then be able to stop before the drill is damaged.

Machine Types: The design of deep hole drilling machines varies. The lengths of the machines are adapted to the special diameter ranges and lengths of the workpiece. A special very long machine is shown in Figure 9.22

Deep hole drilling machines are often designed to permit a choice between a rotating workpiece, a rotating tool or both rotating workpiece and rotating tool. In the machining of asymmetric workpieces, the machine works with a rotating drill and a non-rotating workpiece, since the workpiece cannot rotate at sufficient speed. In the machining of long, slender workpieces, a non-rotating drill is fed into a rotating workpiece. When the hole must meet high straightness requirements, both the drill and the workpiece rotate. The direction of rotation of the drill is then opposite to that of the workpiece.

The Single Tube System is difficult to adapt to standard machines, while Ejector drilling and, in some cases, gun drilling, can be done relatively simply in conventional machines. The largest extra costs are then for the cutting fluid system, chip removal arrangement, filter tank and pump. Figure 9.23 shows a special gun-drilling machine to drill six camshafts simultaneously. This machine includes auto loading and unloading of parts.

Chip Breaking: Of primary importance in drilling operations is transporting the chips away from the cutting edges of the drill. Excessively long and large chips can get stuck in the chip ducts. A suitable chip is as long as it is wide. However, the chips should not be broken harder than necessary, since chip breaking is power consuming and the heat that is generated increases wear on the cutting edges. Chips with a length 3 - 4 times their width can be acceptable, provided that they can pass through the chip duct and drill tube without difficulties. Chip formation is affected by the work material, chip breaker geometry, cutting speed, feed and choice of cutting fluid.

Coolant System: The purposes of the coolant in a drilling system are:

- Support and lubrication of the pads
- Improvement of the tool life
- Dissipation of heat
- Flushing of chips

The coolant system has to provide an adequate supply of clean coolant to the tool at the correct pressure and temperature.

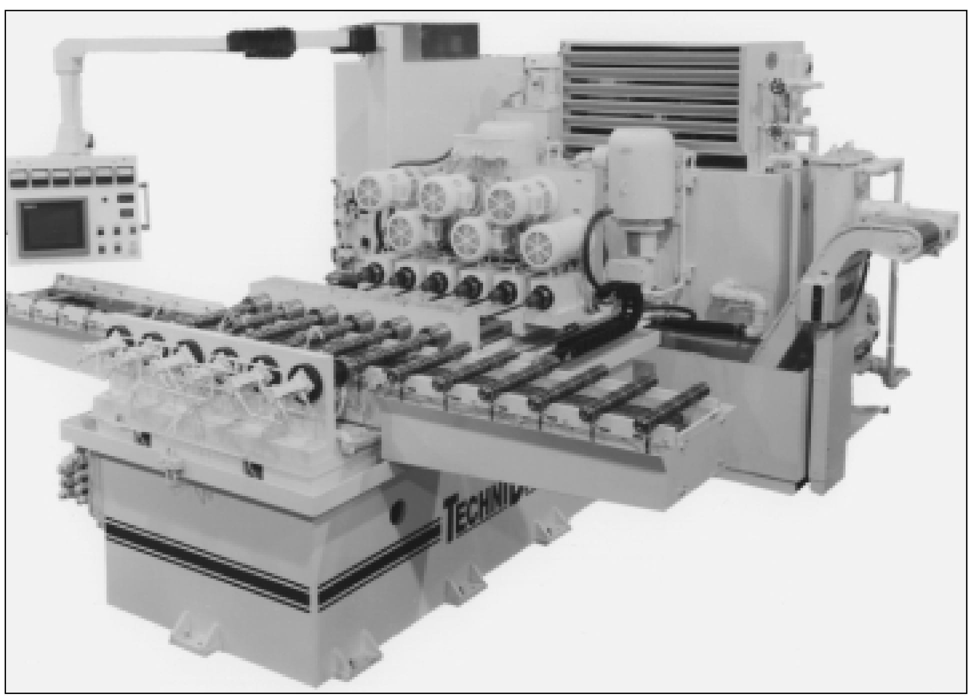

FIGURE 9.23: Special gun drilling machine is shown drilling six camshafts simultaneously. This machine includes automatic loading and unloading of parts. (Courtesy TechniDrill Systems, Inc.)