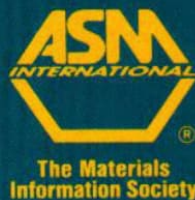


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Volume
16

Machining



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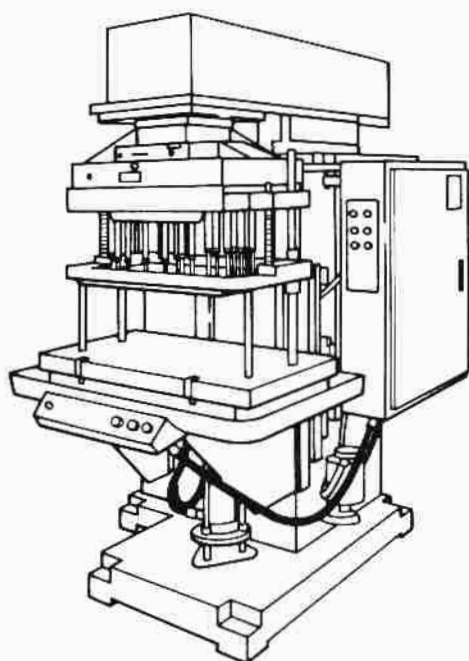


Fig. 7 Multiple-spindle drilling machine of the open-side type incorporating a way design

spindles are driven by a single powerhead and are fed simultaneously into the work (Fig. 7). The spindles are driven and can be adjusted over a limited area by means of sliding-bar guides. Because the areas that can be covered by adjacent spindles overlap, the machine can be set up to drill holes at any location within its overall capacity. For example, a typical machine having 20 spindles can drill holes at any location within a 760 mm (30 in.) diam circle. A special drill jig is made for each job to provide accurate guidance for each drill (Fig. 8). Although such machines are costly, they can be readily converted for use on different jobs where the quantity to be produced will justify the small setup cost and the cost of the jig.

Multiple-spindle drilling machines are available with a wide range of numbers of spindles in a single head, and two or more heads are frequently combined in a single machine for mass-production work. In some cases, such machines perform drilling operations simultaneously on two or more sides of a workpiece.

Applications. Multiple-spindle machines are primarily used for three general types of production operations:

- Multiple operations (drilling, reaming, chamfering, spotfacing, and so on) in a single hole. Machines used for these applications are often equipped with hand-positioned tables, shuttle tables, or rotary indexing tables
- One operation in multiple holes that are the same size or different sizes and are on the same or different planes. Machines

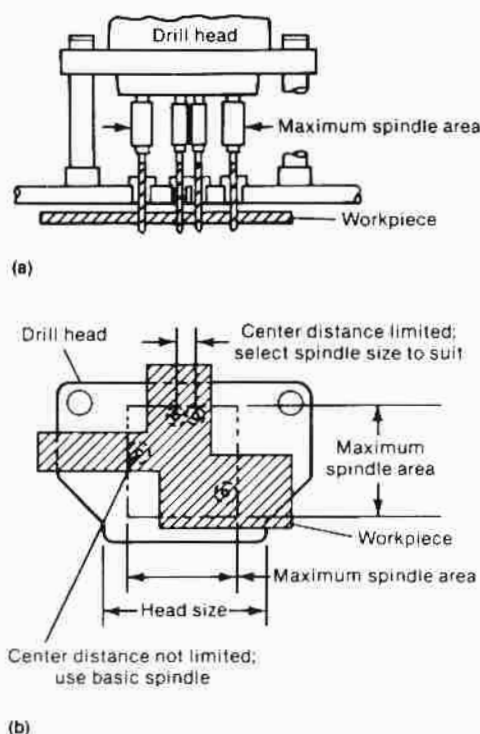


Fig. 8 Side view (a) and top view (b) of a multiple-spindle drill head showing the relative positions of the spindles, drill head, and workpiece and the dimensions that must be considered in choosing a drill head

used for these operations may require a rotary indexing table if hole center distances are close. Multiple-plane operations are often performed with multiple-position workholding fixtures.

- Multiple operations in multiple holes that generally require the machine to be equipped with a rotary indexing table or other type of table, especially when tapping is one of the operations to be performed

Multiple-spindle drill heads are designed for various applications and have geared or gearless (crank-type) drives. All tools on a head are fed into the workpiece together, but tool lengths are sometimes staggered so that cutting loads are applied progressively. There are three major types of geared drill heads, as follows.

Adjustable-arm, universal-joint drill heads are generally used for frequent change-over or limited production requirements. They provide maximum flexibility because the spindles can be adjusted to any desired location within the head housing. Spindles can be removed or added, up to the capacity of the head. The adjustable-arm spindles are rotated by universally jointed connecting rods that transmit power from a fixed-center, gear-driven, or crank-driven head. All spindles rotate at the same speed, which is normally limited to a maximum of 2000 rev/min primarily because of joint wear prob-

lems and the method of lubrication. Some standard machines come equipped with universal-joint heads having a high, neutral, and low-speed shifter range for each spindle. Special heads can be designed to incorporate this speed selector feature.

Slip-plate drill heads are often used for repetitive hole patterns and longer production runs. The same type of universal rods as those used on adjustable-arm heads drive slip spindles mounted in a slip plate that can be changed for different hole patterns. The capability of producing various hole patterns on fixed centers can make slip-plate heads more desirable than fixed-center heads; however, greater center distances are sometimes required between spindles, and the locational accuracy of the spindles is not as close. The spindles normally rotate at the same speed unless the head is of special design. These heads are generally used for drilling holes 1.6 to 57 mm ($\frac{1}{16}$ to $2\frac{1}{4}$ in.) or more in diameter in cast irons and steels.

Fixed-center drill heads are used for dedicated, high-production machines. The number of spindles can vary from 2 to 2000 or more, depending on the number of holes required in the workpieces or the ease with which the workpieces can be handled. Gearless heads are required for large numbers of spindles, and all spindles operate at the same speed for light-duty operations. These heads are stronger and more rigid than either the adjustable-arm or slip-plate head because the spindles are permanently fixed for required hole patterns.

Gearless, fixed-center, crank-driven drill heads are used when the need for close-center holes makes the use of gears and universal joints impractical or impossible. Some heads of this type are capable of drilling holes with center distances as close as 4.8 mm (0.19 in.) and diameters of 0.51 to 19.05 mm (0.020 to 0.750 in.). In one application, a gearless drill head having 1800 spindles was mounted on the ram of a punch press to drill acoustical tiles. A 38 kW (50 hp) electric drive motor was mounted on top of the press.

One design of a gearless drill head is illustrated in Fig. 9. The driver (A), in the drilling machine spindle rotates the drive crank (B) in the drill head. This crank moves the oscillator (C) in a short oscillating motion. The oscillating motion rotates the individual drill spindles (D) in the same direction and at the same speed as the drive crank (B).

Deep-Hole Drilling Machines

Several problems not encountered in ordinary drilling operations arise in the drilling of long holes in rifle barrels, long spindles, connecting rods, and certain oil-well drilling equipment. As the hole length increases, it becomes more and more difficult to support the work and the drill properly.

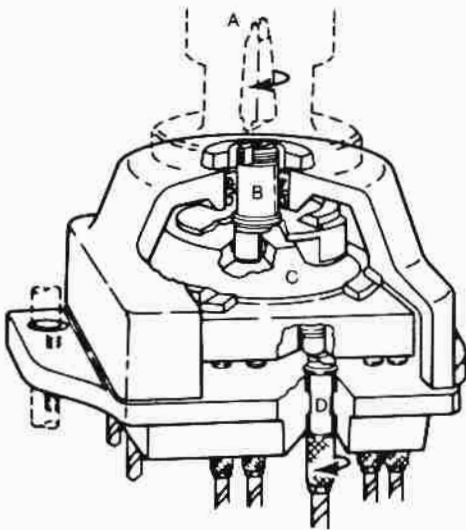


Fig. 9 Gearless drill head in which an oscillator (C) rotates the drill spindles (D).

The rapid removal of chips from the drilling operation becomes necessary to ensure the proper operation and accuracy of the drill. Rotational speeds (up to 20 000 rev/min) and feeds must be carefully determined because there is a greater possibility of deflection than when a drill of ordinary size is used.

To overcome these problems, deep-hole drilling machines have been developed (Fig. 10). These machines may be of either the horizontal or the vertical type, with either single-spindle or multiple-spindle construction. In addition, either the workpiece or the drill may revolve. Most machines are of horizontal construction, using a center-cut gun drill having a single cutting edge with a straight flute running throughout its length. Oil, under high pressure, is brought to the cutting edge through a hole in the drill. Normally, the drill is stationary and the work is rotated in a chuck with steady rests providing support along its length, but where it is difficult to rotate the work, the situation is reversed (Fig. 11). In gun drilling, the feed must be light to avoid deflecting the drill.

Because of its long stroke and ease of chip removal, a gun-drilling machine is also suitable for boring, trepanning, and chamfering. The revolving drill is fed into the workpiece resting on the platform. Equipment of this type requires an efficient cooling system to pump the coolant in large volume and high pressure for cooling the tool and flushing the chips. The system also filters the coolant and keeps it at a uniform temperature. Vertical deep-hole drilling machines are also available for work that is not relatively long.

Transfer Drilling Machines

Frequently designated as automated machines, transfer drilling machines complete

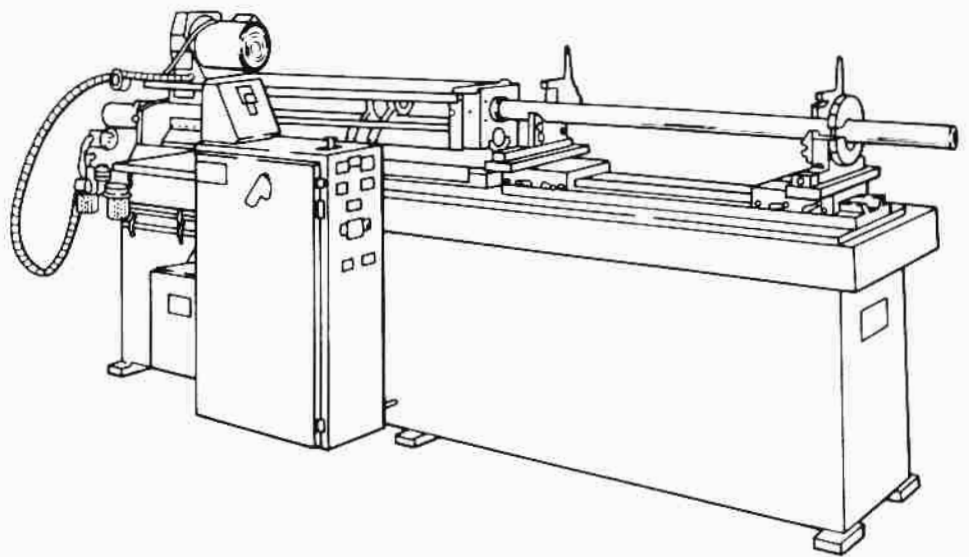
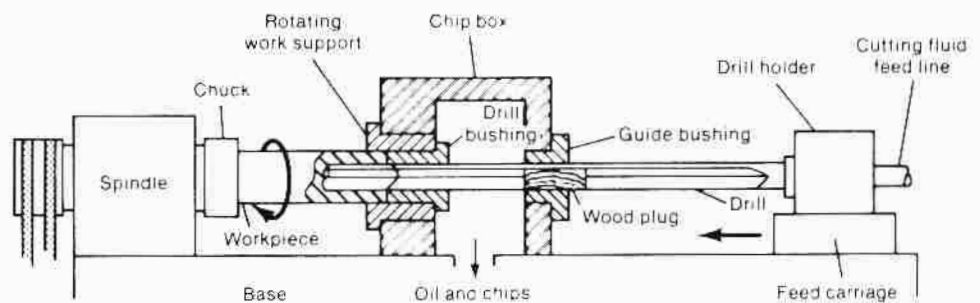


Fig. 10 Fixed-table, advancing-spindle machine designed for deep-hole drilling

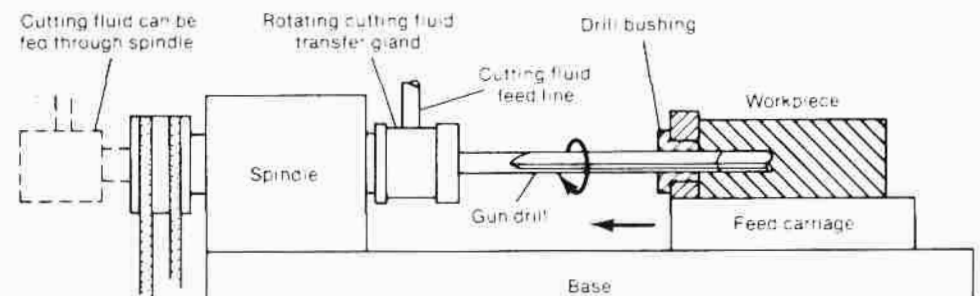
a series of machining operations at successive stations and transfer the work from one station to the next. They are, in effect, a production line of connected machines that are synchronized in their operation so that the workpiece, after being loaded at the first station, progresses automatically through the various stations to its completion. Automatic drilling machines are of the indexing table or the in-line transfer type, and

they are cost effective only for volume production.

Indexing Table Transfer Machines. Parts requiring only a few operations are adapted to indexing table machines, which are made with either vertical or horizontal units spaced around the periphery of an indexing table. A special vertical machine with a six-station indexing table can drill, ream, chamfer, and mill connecting rods at



(a)



(b)

Fig. 11 Two methods of gun drilling. (a) Workpiece rotates while the tool is held stationary. Cutting fluid is fed directly through the drill from the back end. (b) Tool rotates while the workpiece is held stationary. Cutting fluid is fed through a rotating oil gland from the fluid feed line or through the machine spindle.

Table 1 Typical drilling machine specifications

Type	Workpiece diameter, mm (in.)	Drill diameter, mm (in.)	Morse taper (No.)	Number of speeds	Power, kW (hp)	Weight, kg (lb)
Hand feed	395 (15½)	13 (½)	Chuck	12	0.4 (½)	100 (220)
Upright power feed	660 (26)	50 (2)	5	4	3.7 (5)	950 (2100)
Upright four-spindle gang type	660 (26)	—	2	8	1.5 (2)(d)	2200 (4800)
Multiple-spindle (12)(a)	305 × 510 (12 × 20)	—	—	—	5.6 (7½)(d)	—
Programmable multispindle(b)	610 × 1170 (24 × 46)	—	—	Infinitely variable	18.75 (25)(d)	—
Radial 330 mm (13 in.)(c)	1220 (48)	—	5	16	4.5 (6)(d)	2720 (6000)

(a) Diameter; (b) Work area; (c) Arm length; (d) Each spindle. Source: Ref 1

the rate of 450 per hour. All operations are performed simultaneously, and when all are complete, the table is automatically indexed to the next station.

In-Line Transfer Machines. The principal feature of in-line machines is that they are provided with suitable handling or transfer means between stations. The simplest and most economical method of handling parts is to move them on a rail or a conveyor between stations. When this is impossible because of the shape of the part, it is necessary to provide a holding fixture or pallet on which the work is clamped.

A typical application would be an eight-station automatic transfer machine performing a variety of operations on the center portions of axle housings. Palletized work holding fixtures secure the axles during all operations.

Transfer machines range from comparatively small units having only two or three stations to long straight-line machines with over 100 stations. Transfer machines are primarily used in the automobile industry, in which, because of full production schedules, it is possible to offset their high initial cost by savings in labor. Products processed by these machines include cylinder blocks, cylinder heads, refrigeration compressor bodies, and similar parts.

Special-Purpose Drilling Machines

Many drilling machines are built in a wide variety of designs and configurations for special-purpose applications. Special-purpose dedicated machines are often used when large quantities of parts require multiple operations. Dedicated units include shuttle-transfer, dial-index, and trunnion-index machines.

In shuttle-transfer machines, the workpiece is loaded in a fixture and indexed in a straight line to several machining stations between single or opposed machining heads. After the workpiece is machined, it is indexed to stations down the line for further machining until it reaches the unloading station. These machines are designed for the medium-to-low production of heavy or oddly shaped parts and offer more

flexibility in terms of fixture changes than transfer machines.

Dial-index machines maximize floor-space use by mounting fixtures on a horizontal-index table and moving the workpiece (held by the fixture) to the machining station, where it is surrounded by an array of radial, horizontal, and vertical machining units. Multiple-spindle heads are extensively used in dial-index machines.

Trunnion-index machines provide simultaneous machining operations at each station, along with the production of a completed part each time the trunnion (vertical table) is indexed. Five of the six sides of a rectangular workpiece can be machined in this unit in one cycle. Loading and unloading of the workpiece are done at a single station. Interchangeable heads and fixtures for similar parts allow some degree of flexibility in the production of parts.

Various factors influence the selection of a machine for a specific application. Some of these factors are the size and shape of the workpiece; the diameter and length of the hole to be drilled; the relationship of drilling to the other machining operations; the quantity of pieces to be drilled per hour, per day, or over a longer period; and cost.

Drilling Machine Selection

The sizes of drilling machines are designated in several ways. The most common designation for a vertical drill press is the diameter in millimeters (inches) of the largest disk or workpiece in which a hole can be drilled at the center on the drill press. Other designations are the diameter of the largest drill the press is designed to drive in cast iron or steel and the Morse taper size in the spindle hole. The size of a radial drill press is given in meters (feet) and designates the radius of the largest disk in which a center hole can be drilled with the head at its outermost position on the arm. Some drilling machine manufacturers also specify the diameter of the column in millimeters (inches) (Table 1).

Machine Selection for Economy of Production. In selecting a machine, the following options should be considered for their suitability to the specific job:

- **Machine type:** Manual control, numerical control; single spindle or multiple spindle
- **Machine calibrations:** Speed and feed range, manual or automatic machine positioning, and automatic preselect
- **Tooling:** Complex or simple fixturing; high-speed steel or carbide tools

Once these have been decided on, a machine is selected for greatest economy on the basis of size of production lot. Small lots (<100 pieces) seldom justify large expenditures for jigs and fixtures, but numerically controlled machines are being increasingly used for low production quantities. Large production quantities may require more expensive tooling, and single-purpose machine tools often provide the greatest economy.

Control Systems. Drilling machines are available for manual, semiautomatic, and automatic operation. Numerical control (NC) and computer numerical control (CNC) are used on many drilling machines, and these types of control are particularly suitable for producing patterns of holes in various workpieces. Numerical control or computer numerical control is usually standard on circuit board, tube sheet, and other special-purpose drilling machines. Programmable controllers are also used on some drilling machines and drill heads.

Tape-controlled radial, turret, or horizontal drilling machines simplify tooling because a means of holding and positioning the work is the only additional requirement. Tape control also minimizes the possibility of operator error and ensures repeatability of operation. The main disadvantages are the cost and complexity of the equipment and the time and skill required for preparing the tape.

The simplest type of numerically controlled machine has a two-position indexing table that automatically places the workpiece under a single vertical drill spindle. The movement of the drill spindle can also be numerically controlled, and this procedure, in conjunction with an automatic tool changer, can produce a completed part. The operator's principal function is to load and unload the workpiece.

The NC/CNC requirements for drilling machines vary, depending on the application. Simple two-axis (x and y) positioning systems are used only for table movement on some machines, with the drilling depth (z-axis) controlled manually, electrically, electromechanically, or mechanically. Many drilling machines are equipped with more complex systems that can control table positioning, drilling depths, spindle speeds, feed rates, and other functions. Some systems compensate for varying tool lengths.

One manufacturer offers a continuous monitoring control system for its NC machining centers and special drilling ma-

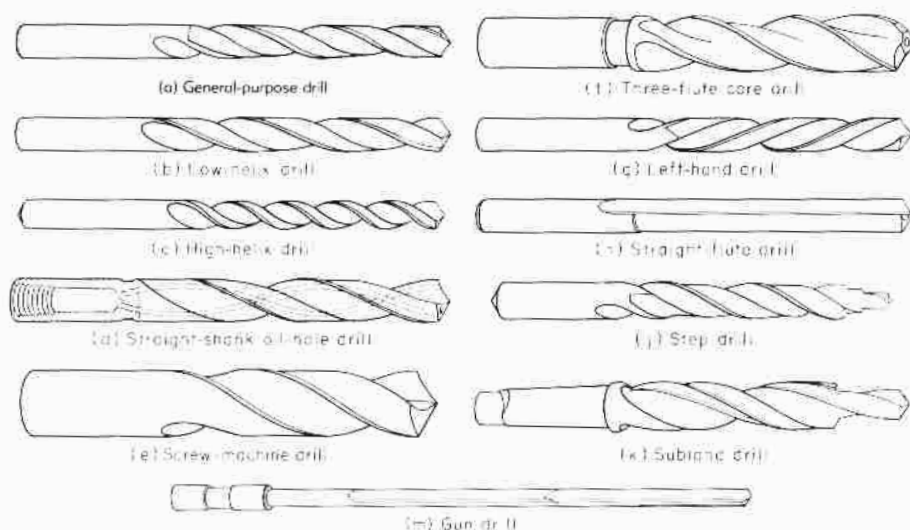


Fig. 12 Commonly used types of drills. Applications are described in text.

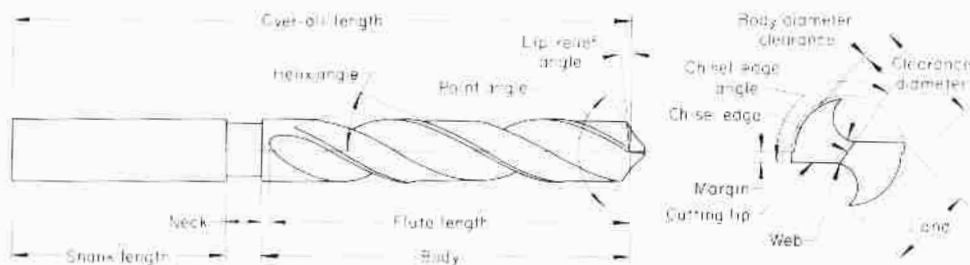


Fig. 13 Design features of a typical straight-shank twist drill

Table 2 Lip relief angles for twist drills

Drill diameter		Lip relief angle, degrees		
mm	in.	Cast iron or annealed steel	Hard or tough work metal	Soft or free-cutting metal
0.343-0.991	0.0135-0.0390	24	20	26
1.02-2.44	0.0400-0.0960	21	18	24
2.49-3.05	0.0980-0.1200	18	16	22
3.26-6.35	0.1285-1/4	16	14	20
6.53-8.7	0.2570-11/32	14	12	18
8.83-12.7	0.3480-1/2	12	10	16
13.1-19.1	3/4-3/4	10	8	14
19.4 and larger	1 and larger	8	7	12

chines. This system automatically lowers the feed rate when torque on the drill reaches a preset limit or when motor power exceeds the rated amount. Advantages include faster hole production with the same tool life, reduced tool breakage, improved chip-breaking action, and protection of the motor from overloads.

This closed-loop control system continually derives torque at the drill from measured horsepower and spindle speed. The calculated cutting torque is compared to the breaking torque punched into the NC tape. Whenever the cutting torque exceeds one-half the preset limit, the feed rate is automatically reduced. The feed rate is also lowered whenever the horsepower required exceeds the rated motor capacity.

Retrofittable adaptive control for NC drilling machines and machining centers is

also available. This is a microprocessor-based system with the capability of combining soft-wired modules for drilling, milling, boring, and tapping in the same unit. The drilling unit uses torque as a feedback.

Common Types of Drills

Drills are available in a variety of types, and several of these types are illustrated in Fig. 12. Size ranges vary; some drills can be obtained as standard tools up to 90 mm (3 1/2 in.) in diameter, and as special-order tools in even larger sizes (spade drills are usually cost effective for sizes above 38 mm, or 1 1/2 in., and have reportedly been used in sizes up to 380 mm, or 15 in.). The type of shank (straight or taper), the proportionate dimensions of flutes and shanks, and the helix angle also vary widely.

Drills with helical flutes are called twist drills. The features of a typical twist drill are illustrated in Fig. 13.

Type of Shank. Taper-shank drills offer these advantages over straight-shank drills:

- Greater tool rigidity
- Closer control of concentricity
- Closer spacing in gang drilling (because screw chucks are not used)
- Drive without slip

For shallow holes, however, straight-shank drills should be considered because they cost less. One disadvantage of straight shanks, particularly in drilling deep holes, is that they sometimes pull out of the chuck on the return stroke of the spindle. When this happens, the operation must be stopped to replace the drill. This pullout is more likely in an operation in which the spindle retracts automatically at intervals to clear chips.

Drill Design. The included angle of the point on a conventional twist drill is 118°. The lip relief angle varies with drill diameter and the composition and condition of the work metal (Table 2).

Drill design for specific operations depends on the application in which the drill is used. Drill life can sometimes be greatly improved by the use of a design that varies from the standards of the drill manufacturer. Drill design and rigidity of setup usually receive more attention than selection of the drill material. This is because in most drilling, improvement of design and rigidity offers a greater potential for increasing drill life and reducing cost than does a change in drill material. Special means of clamping may be needed to ensure rigidity of setup.

Drill Materials. Most drills are made of common grades of high-speed tool steel (M1, M2, M10, and occasionally T1). At comparatively low cost, these grades provide strength, toughness, and high-temperature hardness suitable for most drilling applications. For excessively hard or abrasive metals, drills can be made of higher-alloy high-speed tool steels such as M3, M4, M6, M33, or T15; these steels, however, are used to make only a small percentage of the drills produced. Additional information on high-speed tool steels is available in the article "High-Speed Tool Steels" and "P/M High-Speed Tool Steels" in this Volume and the article "Selection of Materials for Cutting Tools" in Volume 3 of the 9th Edition of *Metals Handbook*.

Carbide-tip drills are used for special applications, notably, for drilling abrasive metals of low tensile strength (such as cast iron and castings of high-silicon aluminum alloys) or heat-resistant alloys. Special carbide-tip drills with longitudinal passages for conducting coolant to the drill tip are used on steel in gun drilling, for which close tolerances on hole straightness, diameter, and parallelism must be maintained. Another special application of carbide-tip drills is

the drilling of steel harder than 48 HRC. Solid-carbide drills (for example, spade drills) are used for extreme rigidity and drilling accuracy.

Heat Treatment. The hardening, quenching, and tempering of the high-speed tool steel are critical to the quality and performance of twist drills. A particular high-speed tool steel of the same analysis can be heat treated differently by different manufacturers to develop desired properties for the specific application of a certain style of drill.

Twist drills made from general-purpose high-speed tool steels such as M1 and M7 are usually heat treated to a hardness range of 64 to 66 HRC. Drills made of high-speed tool steels containing cobalt generally have a hardness range of 65 to 67 HRC, although a higher hardness is sometimes used for unusual applications.

Surface Treatments. Various surface treatments are applied to high-speed tool steel drills to increase the hardness of the outer layer of material or to reduce the friction between the drill and the workpiece or chips in the flute. These treatments are normally applied after the drills have been finish ground. The treatments that produce a thin hard layer in the outer layers include nitriding, cyaniding, and less frequently, carbonitriding and carburizing. These processes are carried out in either a liquid or gaseous media at elevated temperatures to accelerate the absorption of the element(s) into the outer layers. Because these layers are hard but brittle, they are kept thin to reduce the probability of chipping. Nitride layers range from 0.013 to 0.05 mm (0.0005 to 0.002 in.) in thickness, but carburized layers are several times thicker. Carburizing and carbonitriding usually require temperatures above the tempering range, while gas nitriding or cyaniding can be done at about 540 °C (1000 °F).

In addition to the hard surfaces produced in the outer layers of the drill material by the processes mentioned, there is some small usage of the processes for producing surfaces on the exterior of drills for the same purpose. These surfaces are applied by electroplating, chemical plating, chemical and physical vapor deposition, and flame or arc deposition. Included in such platings are hard chromium, nickel, tungsten, tungsten carbide, titanium nitride, titanium carbide, and numerous other wear-resistant compounds. Considerable care is required during the processing to ensure that the deposition is uniform, continuous, and tightly adherent and that the tempering temperature of the high-speed tool steels is not exceeded.

Surface treatments for reducing friction or improving lubrication include the limited penetration of oxygen or sulfur into tool surfaces in a controlled-atmosphere furnace at an elevated temperature, and vapor or

liquid processing. The most widely used surface treatment for drills consists of the development of a thin surface oxide, which has been found to act as a solid lubricant and to prevent welding of chips to the drill. Although various oxide films can be produced in air at temperatures above 205 °C (400 °F), oxide films most advantageous for improved performance are formed in a dry or superheated steam atmosphere at temperatures of 425 to 565 °C (800 to 1050 °F). Oxides created in salt baths are not as effective as those produced by steam. Tools having the dark gray to blue-black surface oxide layers produced in this way are often used for drilling ferrous materials.

Although surface treatments have been discussed as separate entities, they are often used in combination. The most widely used combination treatment for drills is a surface oxide over a nitride layer.

Selection of Drills

The type of drill selected for a given application depends on:

- Composition and hardness of the work metal
- Rigidity of the tooling setup
- Dimensions of the hole to be drilled
- Type of machine used to rotate the drill or the workpiece
- Whether the drill is used for originating or enlarging holes
- Tolerances on the hole to be drilled
- Whether related operations, such as countersinking or spotfacing, must be performed with drilling
- Cost

The material drilled affects drill selection mainly because the need for a drill of rugged design increases with the hardness and strength of the work material. The need for rigidity in the setup also increases with work metal hardness and strength.

Drilling into hard materials such as heat-treated alloy steels, hard steel castings, partly chilled cast iron, and 18-8 stainless steels with high-speed tool steels requires carefully sharpened tools, adequate and uniform feeds, moderate speeds, and coolants suited to the type of material being machined. In an emergency, it is possible to drill holes in materials that would otherwise be considered unmachinable with high-speed tool steels. This is done by making sure the tool cuts continuously once it is started because the material will work harden to the point at which it is unmachinable if the drill is allowed to idle and rub on the cut surface.

Armor plate presents some difficult problems because of its hardness and extreme toughness, but it can be satisfactorily drilled with high-speed tool steels if the work-hardening and flame-hardening properties of armor plate are compensated for. If the

material has been flame cut, the areas adjacent to the region to be drilled should be annealed. If the armor plate is of the laminar type (that is, one side of plate is harder than the other), drilling should proceed from the harder side to the softer side because it is virtually impossible to drill successfully from the soft side. Speeds as low as 4.6 m/min (15 sfm) may be required, along with a 135 to 140° included point angle on the drill cutting point.

Molded plastics (resins, phenolics, cellulose acetates, polystyrenes, acrylics, and so on) require quick ejection of chips. If not ejected quickly, the chips will stick and pack in the drill flutes and heat the comparatively low-temperature plastic composition. Overheating is detrimental to both the tool and the work. These materials are drilled at speeds of 30 to 90 m/min (100 to 300 sfm), with tools having 60 to 90° included angle points for small sizes and 90 to 120° included angle points for larger hole sizes. Detailed information on the machining of a variety of materials is available in the Section "Machining of Specific Metals and Alloys" in this Volume.

Rigidity of Setup. In setups that are not rigid, drills with short flutes and tapered shanks are usually required.

Hole Dimensions. The diameter, length, and length-to-diameter ratio of holes to be drilled also influence selection of the drill. For maximum rigidity and minimum chatter, the shortest possible drill should be used. In drilling blind holes several times greater in length than in diameter, it may be necessary to use oil-hole drills or other special types of drills.

The type of machine to be used to drive (or hold) the drill is more likely to determine the design of the drill shank than of the fluted portion. However, some drills are designed for use with specific machines (such as screw-machine drills and left-hand drills).

Use of Drill. Whether a drill will be used for originating or enlarging holes also governs its selection. Holes can be enlarged more efficiently by drills designed for this purpose (core drills).

Tolerances. Although drilling is generally a roughing operation, with accurate surfaces depending on subsequent operations such as reaming or boring, tolerances do influence drill selection. Tolerances on roundness, diameter, and straightness are often affected by the ability of the drill to remove chips.

Number of Operations. When other operations, such as countersinking or spotfacing, are to be done with drilling, the use of combination tools should be considered. Dual-purpose tools are available that can combine the following operations: drilling two different diameters, drilling and reaming, drilling and countersinking, drilling and spotfacing, and drilling and counterdrilling or counterboring.

Cost. Carbon tool steel drills have a low initial cost and are acceptable for occasional use, but they must be run slowly. High-speed tool steel drills are the most popular and have good strength. Drills tipped with cemented carbide are economical for high production, but are expensive and must be handled carefully to avoid breakage.

General Drill Classification

Twist drills are manufactured in a wide variety of types and in many different sizes. To produce a hole of a given diameter, twist drills are commercially available with variations in length, flute and shank configuration, point geometry, and web thickness. In some cases, a dozen or more drills may be available to produce the same size hole.

Drills are made in many different diameter sizes—fractional, number (wire gage), letter, and metric—ranging from 0.150 to 89 mm (0.0059 to 3½ in.):

- **Millimeter series:** 0.01 to 0.50 mm increments, according to size, in diameters from 0.015 mm
- **Numerical series:** No. 97 to No. 1 (0.15 to 5.79 mm, or 0.0059 to 0.228 in.)
- **Lettered series:** A to Z (5.95 to 10.49 mm, or 0.234 to 0.413 in.)
- **Fractional series:** ¼ to 4 in. (and larger) by 64ths

Many drill styles can be grouped into two categories: general-purpose and heavy-duty. General-purpose drills are the most widely used. Slight alterations of the original point angles sometimes improve performance for given speeds and feeds. Because of their heavier webs, heavy-duty drills are designed to provide greater torsional strength and rigidity than general-purpose drills. Heavy-duty drills can be used to drill steel forgings, hard castings, and high-hardness ferrous alloys.

Straight-shank twist drills are made in three series, based on their range of lengths: jobbers length (a medium-length range), taper length (a long-length range), and screw-machine length (a short-length range). Thus, a 6.4 mm (¼ in.) diam drill would have a 70 mm (2¾ in.) flute length and a 102 mm (4 in.) overall length in a jobbers length version. The flute length and the overall length of the same tool would be 95 mm (3¾ in.) and 156 mm (6⅞ in.) for the taper length version and 35 mm (1⅜ in.) and 64 mm (2½ in.) for the screw-machine length version. Heavy-duty drills are also available in screw-machine lengths with 135° split points.

Screw-machine length straight-shank twist drills are used in screw machines of all types when conditions require the use of short drills for maximum rigidity. Other applications for these short drills include portable and sheet metal drilling, body work, and the drilling of tougher, harder

steels such as stainless and high-manganese steels.

Tangs can be added to these tools when they are used with ASA drill drivers.

Taper-shank twist drills are used for general-purpose drilling in all types of machines for which an American National Standards Institute taper shank is required. These drills are available with standard diameters, flute lengths, and overall lengths, as well as corresponding taper-shank sizes. Some sizes of these drills are available with shorter and longer shanks than standard, which decreases and increases their overall lengths. The high-speed tool steel drill body and the alloy steel shank (when used) on these drills are usually joined by electrical butt or friction welding. In some cases, the drill body can also be press fitted (crimped) into the shank end on smaller sizes.

Specific Applications by Drill Type

Most drills, particularly those discussed in this section, are specially designed for specific applications. Altering the drill point or drill hardness can greatly increase the range of applications for which these tools can be used. In addition, carbide inserts or indexable-insert cutting edges can be added.

Conventional drills have helix angles of 25 to 33°. Low-helix drills have 15 to 20° helix angles and high-helix drills typically have 35 to 40° helix angles.

General-purpose drills are of conventional two-flute design. Because of their versatility, low cost, and availability in a wide range of sizes, these drills are used for the general-purpose drilling of cast iron, steel, and nonferrous metals. They are suited to high-production applications and can be operated under a variety of conditions. A typical general-purpose drill is illustrated in Fig. 12(a). These jobbers length drills are available only with a straight shank. Their short flutes and relatively short length-to-diameter ratio aid in maintaining rigidity during drilling.

Low-helix drills (Fig. 12b), also known as slow-spiral drills, have a comparatively thin web, which facilitates the penetration of brass, plastics, and other soft materials and provides maximum space for chips. Low-helix drills are designed to break chips into small pieces and are well-suited for applications in which a large volume of chips is generated. Straight-shank low-helix drills are more rigid than drills with a standard twist and therefore permit greater torque. Low-helix drills are also less likely than standard-helix drills to grab the edge of a hole and hang up or pull through at drill breakthrough. Although developed primarily for drilling brass, these drills are often used successfully for drilling shallow holes in steel and in aluminum and magnesium

alloys. Solid carbide or carbide-tip versions of low-helix drills are used to produce holes in cast iron.

High-helix drills (Fig. 12c), also known as fast-spiral drills, are made with wide flutes and narrow lands. They are particularly recommended for drilling relatively deep holes in nonferrous metals and other low tensile strength materials. However, carbon, alloy, and stainless steels have been successfully drilled with these drills. The wide flutes and high helix facilitate chip removal. The high helix also creates more land surface per linear inch of drill, thus increasing the bearing surface of the drill. It is advantageous to replace a standard-helix drill with a high-helix drill mainly because a high-helix drill can remove chips from deep holes more efficiently than most other drills—especially in applications requiring relatively high feed rates.

Oil-Hole Drills. An oil-hole (or coolant-feeding) drill has one or more continuous holes through its body and shank to permit the passage of a cutting fluid under high pressure. The cutting fluid enters the shank and upon emerging at the drill point, assists in ejecting chips and dirt, which may clog or gall the hole being drilled. These drills can be used in a fixed position, as in a turret lathe or other type of multiple-operation machine, or they can be used with power drive in special sockets.

Straight-shank oil-hole drills (Fig. 12d) are well suited to drilling deep holes in hard metals. They are particularly useful when horizontal or inverted drilling is required or when it is difficult to get cutting fluid to the work or to the cutting edges of the tool. An oil-hole drill provides the necessary fluid at the cutting edges, thus permitting a greater feed rate (and therefore a greater volume of chips).

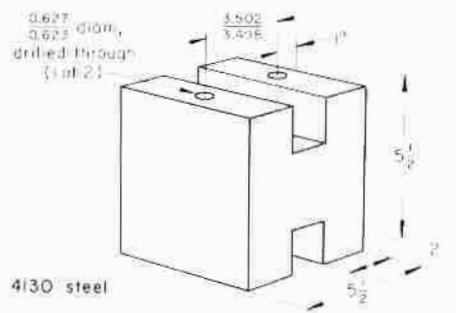
Taper-shank oil-hole drills have the following advantages over the straight-shank types:

- They allow closer concentricity
- Speed and feed can be higher
- The tool is more rigid

The following example describes an application for which a taper-shank oil-hole drill was selected in preference to a standard twist drill.

Example 1: Two Deep Holes. A taper-shank oil-hole drill was superior to a standard twist drill for drilling the two deep through holes (length-to-diameter ratio: nearly 9:1) in the 4130 steel guide block shown in Fig. 14. The oil-hole drill not only maintained the required straightness but also eliminated a subsequent reaming operation which is needed when using a standard twist drill.

Placed in a box-type drill jig, the guide block was drilled in a single-spindle drill press (19 mm, ¾ in., capacity; 430 mm, or



Speed, at 730 rev./min.	
m/min (sfm)	37 (120)
Feed, mm/rev (in./rev)	0.15 (0.006)
Cutting fluid	Soluble oil-water (1:20)
Setup time, min	30
Production rate, pieces (holes)/h.	25 (50)
Drill life per grind, pieces	125
Downtime for tool change, min	2
Workpiece hardness, HRC	20-27

Fig. 14 Guide block drilled with a taper-shank oil-hole drill under conditions listed in table. The oil-hole drill produced the deep through holes to the specified finish without subsequent reaming, which was required when a standard twist drill was used. Dimensions in figure given in inches.

17 in., swing). Speed, feed, and other operating data are given with Fig. 14.

Screw machine drills (Fig. 12e), sometimes called stub drills, are made with short flutes and short overall length for maximum rigidity without loss of cutting ability. They are designed primarily for use in multiple-operation machines and in portable equipment, and they are useful for drilling tough or hard materials. The short flute length (about half that of a standard-length twist drill) eliminates the excessive overhang of standard-length drills used without bushings. When an irregular, angled, or nonflat surface is drilled, excessive overhang causes walking or weaving of the drill, which results in oversize or tapered holes and in reduced tool life.

Core drills, which have three to six flutes, are used for enlarging cored, forged, or previously drilled holes. Core drills are sometimes considered as roughing cutters when used primarily for heavy stock removal in holes that are finally sized by boring or reaming.

Three-flute core drills (Fig. 12f) are normally used for holes up to 13 mm ($\frac{1}{2}$ in.) in diameter. These drills are designed to allow greater chip clearance for heavy cuts. Four-flute core drills are more commonly used for holes larger than 13 mm ($\frac{1}{2}$ in.) in diameter. They are designed to combine maximum flute space with maximum rigidity. Because of their greater number of cutting edges, core drills can be used at higher feed rates than other drills or boring tools without increasing chip load per cutting edge.

Operations such as counterboring and chamfering are often combined with core

drilling by step grinding the drill. Core drills normally have a relatively heavy web (up to 50% of the diameter) because they are not designed for center cutting. They are available with three or four flutes, straight or taper shanks, and in fractional sizes only. Straight-shank core drills are made with diameters from 6.4 to 32 mm ($\frac{1}{4}$ to $1\frac{1}{4}$ in.), flute lengths from 95 to 200 mm ($3\frac{3}{4}$ to $7\frac{7}{8}$ in.), and overall lengths from 156 to 318 mm ($6\frac{1}{8}$ to $12\frac{1}{2}$ in.). Taper-shank core drills are made with diameters from 6.4 to 64 mm ($\frac{1}{4}$ to $2\frac{1}{2}$ in.), flute lengths from 73 to 286 mm ($2\frac{7}{8}$ to $11\frac{1}{4}$ in.), and overall lengths from 156 to 476 mm ($6\frac{1}{8}$ to $18\frac{3}{4}$ in.).

Larger-diameter core drills usually embody a fluted cutter interchangeably mounted on the end of a fluted body. Such drills often incorporate pilots to ensure accuracy of hole alignment. Four-flute core drills are generally preferred unless the greater chip room of a three-flute tool is needed.

Left-hand drills (Fig. 12g) have the same flute length and overall length as general-purpose drills. The principal use for left-hand drills is in multiple-operation machines when the spindle is rotated in the reverse of normal direction. This often occurs when tapping follows drilling or when other machining operations are combined with drilling.

Straight-flute drills (Fig. 12h) are especially adapted for drilling brass and other soft materials and for drilling thin sheets of a wide variety of metals. Drills of this type do not run ahead or grab the work during drilling.

Single-fluted drills, also known as bobbin bits, are designed for drilling deep holes in wood. Because of their chip-clearing ability, they are used for the drilling of low-melting thermoset plastics, the chips of which will stick in the flutes of an ordinary drill. These drills are not recommended for use in materials of much higher tensile strength than wood, fiberboard, and soft plastics. Overall and flute lengths are the same as for general-purpose jobbers length drills.

Half-Round Drills. The cutting end of this drill is semicircular in cross section. Half-round drills are designed for use in brass and, in some cases, aluminum and die cast materials. They have found wide application in the screw-machine industry in the production of holes of exceptional straightness and high finish.

Double-margin drills are often used when holes must be straighter and to closer tolerances with respect to size than can normally be obtained with a single-margin drill. They have a second pair of margins at the trailing edges of the lands, about midway between the primary margins (Fig. 15), thus providing added bearing in bushings and holes with four guide surfaces. This construction also helps to eliminate the effects of errors in point grinding. Double margins are also used on some step drills for

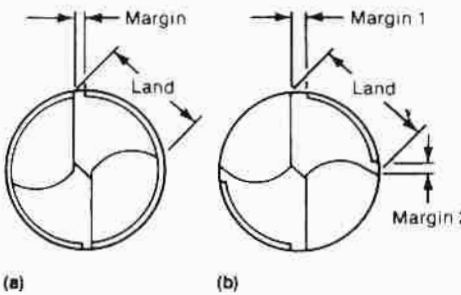


Fig. 15 Two types of margin configurations used on twist drills. (a) Conventional single margin. (b) Double margin

producing accurate holes when guide bushings cannot be used.

Crankshaft drills are designed for drilling holes in crankshafts, but are also used to produce holes deeper than five or six times the drill diameter in any tough or hard material. They have heavy webs, a higher-than-normal helix angle, a split or crankshaft point, and a surface treatment for increased abrasion resistance.

Automotive series drills are straight-shank twist drills of general-purpose construction. They have the same flute and overall lengths as regular jobbers length drills and are furnished with tang drive. They are also available in a long series with taper lengths and tang drive.

Cotter-pin drills are heavy-duty jobbers length drills designed for drilling cotter-pin holes in bolts, steering knuckles, pins, and similar parts, as well as cross holes in the heads of bolts. Heavy construction resists the high strains from such applications and makes them suitable for drilling some of the hard alloy steels, including the harder stainless steels. Such drills are generally surface treated.

Center Drills. These straight-shank twist drills are often used to center the ends of shaft-type workpieces. Their short flute and overall lengths, as well as their oversize shank diameters, provide good rigidity, thus reducing runout. Larger size center drills are sometimes used for starting operations when drilling is done on screw machines and other machine tools to increase the location accuracies of holes to be produced. When the design of the workpiece permits, the countersink portion of the center-drilled hole should be 0.08 to 0.15 mm (0.003 to 0.006 in.) larger in diameter than the finished hole size.

Rail Drills. These heavy-duty cobalt high-speed tool steel tools, originally designed for drilling high-manganese railroad rails, are used to drill a variety of hard, tough, high tensile strength and high-temperature resistant materials used by the aerospace industry. They are made with a low helix angle, heavy web, special web thinning for ease of penetration, and short flute and overall lengths, and they are surface treated.

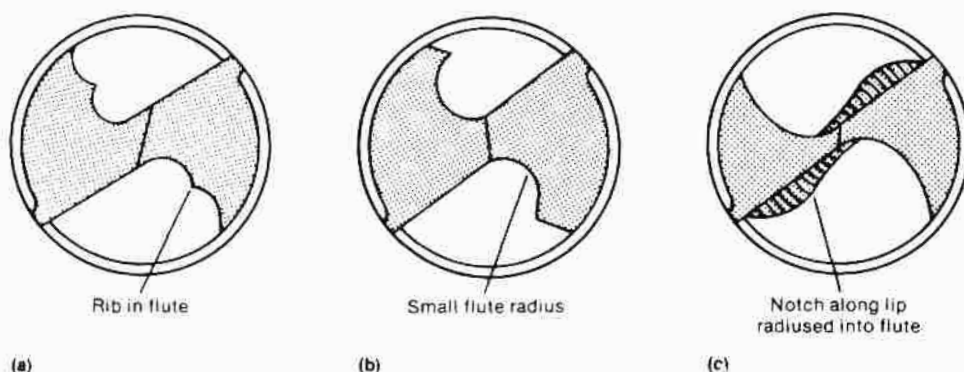


Fig. 16 Flute geometry of drills modified to provide chip-breaking action through the addition of a rib (a), a radius (b), or a notch (c) to the drill flute

Aircraft drills, which are extensively used by the aircraft and aerospace industries, are available as jobbers length drills and as extension drills. These tools have a flute construction conforming to National Aerospace Standard (NAS) 907 prepared by the Aerospace Industries Association, spring-tempered shanks to prevent permanent bending, and overall lengths of 152 to 305 mm (6 to 12 in.). They are available with either 118° or 135° split or offset drill points. These drills are principally used for drilling holes in inaccessible places that cannot be reached with regular-length drills; they are generally operated in portable drilling units.

Straight-shank, jobbers length aircraft drills conforming to NAS 907 are available in two types. Type A drills, with 118° split points, are used for drilling aluminum, low-carbon steels, magnesium, and other soft materials. Type B drills, with 135° split points, are of heavier design and are surface treated for drilling hard steels, stainless steels, titanium, and other hard materials.

Short-flute aircraft drills with 118° points are desirable for tough, portable applications in titanium, heat-treated steels, and aluminum. These drills are surface treated and have no body clearance. Type C drills, with 135° split points, are made in screw-machine lengths for use in machines or portable units to drill hard, tough sheet metals of the heat-resistant stainless and titanium alloy types.

Chip-breaker drills have flute modifications or other design features to curl and break the chips produced in most materials in which long, stringy chips are normally produced, thus minimizing clogging problems. Most of the various chip-breaker designs involve a flute configuration that forces long chips to curl and bend sufficiently so that small broken chips are produced.

Until recently, the flute of the drill was thought of only as a path for the chips to follow as they emerge from the hole. However, with industry becoming more safety conscious, stringy chips are now considered to be a significant hazard to the operator.

Many approaches are used to modify the flutes to provide a chip-breaking action.

Drill points modified to enhance the chip-breaking action are illustrated in Fig. 16. Such flute designs are built into the drills, and no additional notches or grooves are required when regrinding. For some applications, particularly with larger size twist drills, chip-curling grooves are ground in the rake faces of the cutting lips, or chip-splitting grooves are ground in either the clearance or rake faces. Chip-breaker drills sometimes require more torque than standard drills, and there is a minimum feed rate below which they do not operate effectively.

Chip-breaker drills cost about 10% more than conventional drills, but the added cost is easily offset by the longer tool life and the time saved from not having the problem of long chips. Tool life increases because of the efficient chip ejection and better penetration of the coolant to the drill tip.

Spotting and centering drills are straight-shank twist drills designed to produce accurate and true centers. They have short flute and overall lengths and no body clearance, which allows them to be chucked close to the cutting point for accurate hole starting or workpiece centering. A constant web thickness eliminates the need for thinning these drills when repointing.

Holes that are to be drilled and chamfered in workpieces having a hard or scaled surface can be produced more economically by spot drilling (to form the chamfer) prior to drilling. With this method, the spot drill cuts only a short time through stock that has a detrimental effect on tool life, while the hole drill cuts for a longer time through easier-to-machine material. Processing in this way allows the drills to be rapidly advanced closer to the workpiece, thus decreasing the feed stroke and allowing a decrease in the feed rate to increase tool life.

Step drills (Fig. 12j) have two or more diameters, produced by grinding various steps on the diameter of the drill. The steps usually consist of a square or angular cutting edge. Step drills are extensively used in

applications requiring multiple-diameter holes. They can be made by grinding steps on common drills; usually, some thinning of the web is required. The simplest form of a step drill is a combination drilling and countersinking tool.

Subland drills (Fig. 12k) are combination tools having separate lands or margins, which extend the full length of the flutes, for each of the two or more diameters. Subland drills perform two or more operations in one pass of the tool. The different diameters or lands can be ground to permit drilling and countersinking for flathead screws, or drilling and counterboring for socket-head screws. Extensive use is made of subland drills in high-production work.

Subland drills with as many as four diameters have been successfully used. For optimum results, however, the largest diameter should be no greater than twice the smallest diameter because of the variation in cutting speeds and feeds.

Because the lands or margins of subland drills are ground to the correct size along the full length of the flute, each cutting edge can be sharpened separately and repeatedly without affecting the others. When correctly sharpened and operated, subland drills can readily produce accurate holes.

Gun drills (Fig. 12m), which are used in horizontal deep-hole drilling machines (see the section "Deep-Hole Drilling Machines" in this article), have a single V-shaped flute; the single cutting face is sharpened offset to form two cutting angles. When drilling, these angles form two chips broken into short lengths for easier expulsion. The drill body is usually a steel tube through which a cutting fluid passes under pressure and in sufficient volume to cool and lubricate the cutting area and flush out chips. To counter the unbalanced cutting force of the single cutting edge, wear pads (usually carbide) are provided in the drill opposite the cutting face to keep the drill on center. Gun drills are used to drill soft as well as hard material.

For accurate holes, gun drills must be used in rigid equipment with a positive feed. With such equipment, gun drilling eliminates the need for subsequent rough and finish reaming. A properly started gun drill guided by a drill bushing will produce a hole that does not drift from the centerline more than 0.013 mm (0.0005 in.) in 50 mm (2 in.) of drill travel. A spotface or a precision center drill can be used for more accurate starting of a gun drill. Gun drills are increasing in use because they can frequently produce holes as accurate as reamed holes in one pass. Tolerances as small as ± 0.025 mm (± 0.001 in.) and surface finishes up to 0.50 to 0.75 μm (20 to 30 $\mu\text{in.}$) are not uncommon for some gun drilling applications. For maximum efficiency in gun drilling, the cutting fluid should provide a fluid film between wear pads and work material,

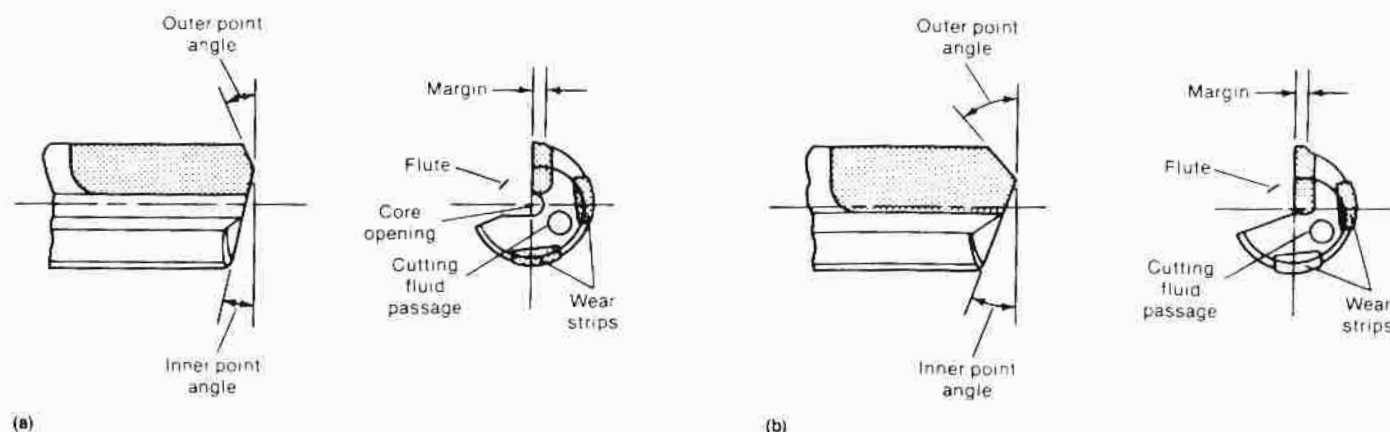


Fig. 17 Two types of straight-flute gun drills used in deep-hole drilling. (a) Trepanning drill. (b) Center-cut drill

prevent welding of chips to the cutting edge of the drill, cool the drill and the work, and dispose of chips by flushing out the hole.

Two types of straight-flute gun drills are used for deep-hole drilling. One type, known as a trepanning drill or a pin-cutting gun drill (Fig. 17a), has no dead center and leaves a solid core of metal. As the drill advances, the core acts as a continuous center guide at the point where the cutting is done. This prevents the drill from running to one side and the hole accuracy is easier to maintain. The other type, known as a center-cut gun drill (Fig. 17b), has been the conventional drill for many years. It is still used for much deep-hole drilling, such as the drilling of blind holes where a core-type drill cannot be used. Both trepanning and center-cut drills are generally carbide tipped (either solid carbide or a carbide insert).

Gun drills operate at much smaller feeds than conventional twist drills, but the cutting speeds are higher. Each type of drill has

only a single cutting edge with a straight flute running throughout its length. The chips are carried out of the hole along the flute of the drill as rapidly as they are formed. Greater accuracy and finish can be obtained in deep holes by the subsequent use of special reamers or broaching tools.

Gun drilling is especially well suited to producing long holes to close tolerances. In some applications, such as the drilling of deep blind holes, gun drilling may be the only practical method of drilling a hole to concentricity tolerances. Hole straightness, roundness, and size can be held within closer limits with a gun drill than with a twist drill, as demonstrated in the following example.

Example 2: Twist Drill Versus Gun Drill. A gun drill was compared with a standard twist drill for drilling 9.5 mm ($\frac{3}{8}$ in.) diam through holes 127 mm (5 in.) deep in gray iron and type 304 stainless steel specimens. The twist drill was used in a general-pur-

pose 1.5 kW (2 hp) vertical drill press; the gun drill, in a 3.8 kW (5 hp) modified boring machine with hydraulic feed. Processing details and results for each material drilled are given in Table 3. As these data show, the gun drill not only produced markedly better finish and dimensional accuracy than the twist drill but also drilled twice as many pieces per grind, under production conditions.

A **spade drill** is generally made up of a spade bit inserted in a holder (Fig. 18a) and fastened securely in a slot with a screw. This type of drill is most widely used for drilling holes 25 to 152 mm (1 to 6 in.) in diameter. (Solid spade drills, usually of carbide, are used for smaller holes.)

Spade drills (size range of 38 to 381 mm, or $1\frac{1}{2}$ to 15 in. in diameter) have risen rapidly in use in the last decade because of their efficiency in making holes and their low cost compared to twist drills. They are the only drills made as stock items in diameters over 89 mm (3.5 in.).

A dull blade can be replaced on the machine, as on indexable throwaway tools, without the necessity of refinding size, re-setting stops, breaking down setups, and increasing or decreasing the length of a drilling setup. Because of this feature, spade drills can be easily preset for use on automatic and NC machine tools. These inserted-blade tools, also available with indexable double-edge blades, are a type of flat end cutting drill used to produce large-diameter holes. Spade drilling is done with either the tool or the workpiece rotating.

Table 3 Gun drill versus standard twist drill for through holes in gray iron and stainless steel

Condition or result	Gray iron(a)		Type 304 stainless steel(a)	
	Gun drill(b)	Twist drill(c)	Gun drill(d)	Twist drill(e)
Operating conditions				
Speed, rev/min	2000	600	2000	500
Speed, m/min (sfm)	60 (200)	18 (60)	60 (200)	15 (50)
Feed, mm/rev (in./rev)	0.025 (0.001)	0.15 (0.006)	0.015 (0.0006)	0.13 (0.005)
Feed, mm/min (in./min)	50 (2)	91 (3.6)	30 (1.2)	64 (2.5)
Cutting fluid	Cutting oil(f)	Soluble oil(g)	Cutting oil(f)	Soluble oil(g)
Results				
Surface finish, μm ($\mu\text{in.}$)	0.25–0.38 (10–15)	2.50–3.75 (100–150)	0.25–0.38 (10–15)	2.50 (100)
Hole straightness, mm (in.)	0.025 (0.001)	0.64 (0.025)	0.025 (0.001)	0.76–0.89 (0.030–0.035)
Out-of-roundness, mm (in.)	0.005 (0.0002)	0.05 (0.002)	0.008 (0.0003)	0.05 (0.002)
Diametral tolerance, mm (in.)	0.013 (0.0005)	0.05 (0.002)	0.025 (0.001)	0.08 (0.003)
Drill life per grind, pieces	160	80	50	25

(a) Specimens of both materials were 22 mm ($\frac{7}{8}$ in.) in diameter and 125 mm (5 in.) long. Through holes drilled were 9.5 mm ($\frac{3}{8}$ in.) in diameter and 125 mm (5 in.) deep. (b) Carbide-tip center-cut drill, 9.5 mm ($\frac{3}{8}$ in.) diameter. (c) Taper-length twist drill 9.5 mm ($\frac{3}{8}$ in.) diameter. (d) Solid-carbide center-cut drill, 9.5 mm ($\frac{3}{8}$ in.) diameter. (e) Heavy-web jobbers drill, 9.5 mm ($\frac{3}{8}$ in.) diameter. (f) Chlorinated mineral oil. (g) Mixed 1 part to 15 parts water.



Fig. 18 Two types of spade drills. (a) Spade drill with interchangeable tip. (b) Special drill for hard steels