Metalworking Tools

Taliyah Boren

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Email: info@wtbooks.com

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Chapter 1

Machine Tool

Lathe is an example of a machine tool

A **machine tool** is a powered mechanical device, typically used to fabricate metal components of machines by machining, which is the selective removal of metal. The term *machine tool* is usually reserved for tools that used a power source other than human movement, but they can be powered by people if appropriately set up. Many historians of technology consider that the true machine tools were born when direct human involvement was removed from the shaping or stamping process of the different kinds of tools. The earliest lathe with direct mechanical control of the cutting tool was a screw-cutting lathe dating to about 1483. This lathe "produced screw threads out of wood and employed a true compound slide rest".

Overview

Machines that a modern perspective might call machine tools have existed for millennia (for example, lathes and bow drills existed in ancient Egypt), but it was not until the later Middle Ages and the Age of Enlightenment that the modern concept of a machine tool—a class of machines used as tools in the making of other machines—began to evolve. Clock makers of the middle ages and renaissance men such as Leonardo da Vinci helped expand humans' technological milieu toward the preconditions for industrial machine tools. During the 18th and 19th centuries, and even in many cases in the 20th, the builders of machine tools tended to be the same people who would then use them to produce the end products (manufactured goods). However, from these roots also evolved an industry of **machine tool builders** as we define them today, meaning people who specialize in building machine tools for sale to others. The first machine tools offered for sale (i.e., commercially available) were constructed by Matthew Murray in England around 1800. Others, such as Henry Maudslay, James Nasmyth, and Joseph Whitworth, soon followed the path of expanding their entrepreneurship from manufactured end products and millwright work into the realm of building machine tools for sale.

Machine tools can be powered from a variety of sources. Human and animal power are options, as is energy captured through the use of waterwheels. However, modern machine tools began to develop only after the development of the steam engine, which led to the Industrial Revolution. Today, most machine tools are powered by electricity.

Machine tools can be operated manually, or under automatic control. Early machines used flywheels to stabilize their motion and had complex systems of gears and levers to control the machine and the piece being worked on. Soon after World War II, the numerical control (NC) machine was developed. NC machines used a series of numbers punched on paper tape or punched cards to control their motion. In the 1960s, computers were added to give even more flexibility to the process. Such machines became known as computerized numerical control (CNC) machines. NC and CNC machines could precisely repeat sequences over and over, and could produce much more complex pieces than even the most skilled tool operators.

Before long, the machines could automatically change the specific cutting and shaping tools that were being used. For example, a drill machine might contain a magazine with a variety of drill bits for producing holes of various sizes. Previously, either machine operators would usually have to manually change the bit or move the work piece to another station to perform these different operations. The next logical step was to combine several different machine tools together, all under computer control. These are known as machining centers, and have dramatically changed the way parts are made.

From the simplest to the most complex, most machine tools are capable of at least partial self-replication, and produce machine parts as their primary function.

Chapter 2

Threading (Manufacturing)

Threading is the process of creating a screw thread. More screw threads are produced each year than any other machine element. There are many methods of generating threads, including subtractive methods (many kinds of thread cutting and grinding, as detailed below); deformative or transformative methods (rolling and forming; molding and casting); additive methods (such as 3D printing); or combinations thereof.

Overview of methods (comparison, selection, etc)

There are various methods for generating screw threads. The method chosen for any one application is chosen based on constraints—time; money; degree of precision needed (or not needed); what equipment is already available; what equipment purchases could be justified based on resulting unit price of the threaded part (which depends on how many parts are planned); etc.

In general, certain thread-generating processes tend to fall along certain portions of the spectrum from toolroom-made parts to mass-produced parts, although there can be considerable overlap. For example, thread lapping following thread grinding would fall only on the extreme toolroom end of the spectrum, while thread rolling is a large and diverse area of practice that is used for everything from microlathe leadscrews (somewhat pricey and very precise) to the cheapest deck screws (very affordable and with precision to spare).

Threads of metal fasteners are usually created on a thread rolling machine. They may also be cut with a lathe, tap or die. Rolled threads are stronger than cut threads, with increases of 10% to 20% in tensile strength and possibly more in fatigue resistance and wear resistance.

Subtractive methods

Thread cutting

Thread cutting, as compared to thread forming and rolling, is used when full thread depth is required, the quantity is small, the blank is not very accurate, threading up to a shoulder is required, threading a tapered thread, or the material is brittle.

Taps and dies

A common method of threading is cutting with taps and dies. Unlike drill bits, hand taps do not automatically remove the chips they create. A hand tap cannot cut its threads in a single rotation because it creates long chips which quickly jam the tap (an effect known as "crowding"), possibly breaking it. Therefore, in manual thread cutting, normal wrench usage is to cut the threads 1/2 to 2/3 of a turn (180 to 240 degree rotation), then reverse the tap for about 1/6 of a turn (60 degrees) until the chips are broken by the back edges of the cutters. It may be necessary to periodically remove the tap from the hole to clear the chips, especially when a blind hole is threaded.

For continuous tapping operations (i.e., power tapping) specialized spiral point or "gun" taps are used to eject the chips and prevent crowding.

Single-point threading

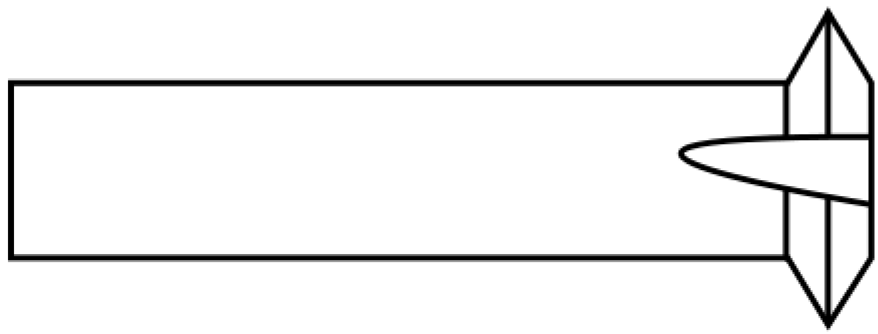
Single-point threading, also colloquially called **single-pointing** (or just **thread cutting** when the context is implicit), is an operation that uses a single-point tool to produce a thread form on a cylinder or cone. The tool moves linearly while the precise rotation of the workpiece determines the lead of the thread. The process can be done to create external or internal threads (male or female). In external thread cutting, the piece can either be held in a chuck or mounted between two centers. With internal thread cutting, the piece is held in a chuck. The tool moves across the piece linearly, taking chips off the workpiece with each pass. Usually 5 to 7 light cuts create the correct depth of the thread.

The coordination of various machine elements including leadscrew, slide rest, and change gears was the technological advance that allowed the invention of the screw-cutting lathe, which was the origin of single-point threading as we know it today.

Today engine lathes and CNC lathes are the commonly used machines for single-point threading. On CNC machines, the process is quick and easy (relative to manual control) due to the machine's ability to constantly track the relationship of the tool position and spindle position (called "spindle synchronization"). CNC software includes "canned cycles", that is, preprogrammed subroutines, that obviate the manual programming of a single-point threading cycle. Parameters are entered (e.g., thread size, tool offset, length of thread), and the machine does the rest.

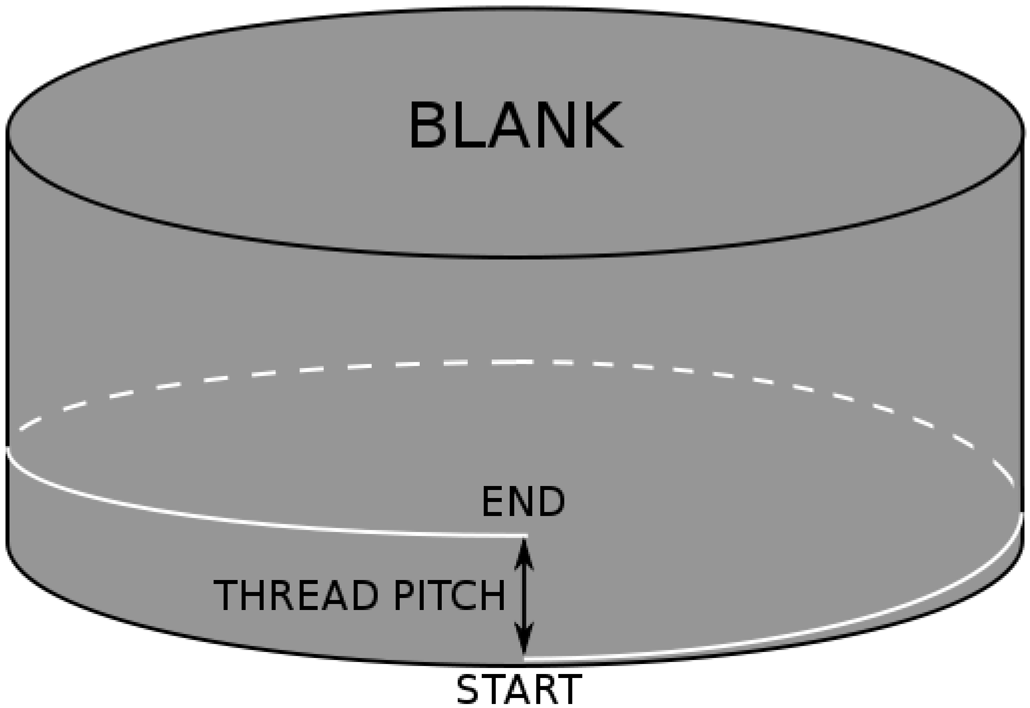
All threading could feasibly be done using a single-point tool, but because of the high speed and thus low unit cost of other methods (e.g., tapping, die threading, and thread rolling and forming), single-point threading is usually only used when other factors of the manufacturing process happen to favor it (e.g., if only a few threads need to be made, if an unusual or unique thread is required, or if there is a need for very high concentricity with other part features machined during the same setup).

Thread milling



A diagram of a solid single-form thread cutting tool

A solid multiple-form thread cutting tool



The path a multiple-form thread cutting tool travels to create an external thread.

Threads may be milled with a rotating milling cutter if the correct helical toolpath can be arranged. This has been *possible* mechanically since the early nineteenth century, but it was never a commonplace method of threading until the widespread dissemination of affordable, fast, precise CNC. Since that development, internal and external threads are often milled. Some advantages of thread milling, as compared to single-point cutting, are a better surface finish; improved concentricity in some cases; and that a left- or right-hand thread can be created with the same tool. Additionally, for large, awkward workpieces (such as a fire hydrant casting), it is simply easier to let the workpiece sit stationary on a table while all needed machining operations are performed on it with rotating tools, as opposed to rigging it up for rotation around the axis of each set of threads (that is, for the "arms" and "mouth" of the hydrant).

There are various types of thread milling, including several variants of *form-milling* and a combination of drilling and threading with one cutter, called *thrilling*.

Form-milling uses either a single- or multiple-form cutter. In one variant of form-milling, the single-form cutter is tilted to the helix angle of the thread and then fed radially into the blank. The blank is then slowly rotated as the cutter is precisely moved along the axis of the blank, which cuts the thread into the blank. This can be done in one pass, if the cutter is fed to the full thread depth, or in two passes, with the first not being to the full thread depth. This process is mainly used on threads larger than 1.5 in (38 mm). It is commonly used to cut large-lead or multiple-lead threads. A similar variant using a multiple-form cutter exists, in which the process completes the thread in one revolution around the blank. The cutter must be longer than the desired thread length. Using a multiple-form cutter is faster than using a single-form cutter but it is limited to threads with a helix angle less than 3°. It is also limited to blanks of a substantial diameter and no longer than 2 in (51 mm).

Another variant of form-milling involves holding the cutter's axis orthogonally (no canting to the thread's helix angle) and feeding the cutter in a toolpath that will generate the thread. The part is usually a stationary workpiece, such as a boss on a valve body (in external thread milling) or a hole in a plate or block (in internal thread milling). This type of thread milling uses essentially the same concept as contouring with an endmill or ball-nose mill, but the cutter and toolpath are arranged specifically to define the "contour" of a thread. The toolpath is achieved either using helical interpolation (which is circular interpolation in one plane [typically XY] with simultaneous linear interpolation along a third axis [typically Z]; the CNC control model must be one that supports using the third axis) or a simulation of it using extremely small increments of 3-axes linear interpolation (which is not practical to program manually but can be programmed easily with CAD/CAM software). The cutter geometry reflects the thread pitch but not its lead; the lead (thread helix angle) is determined by the toolpath. Tapered threads can be cut either with a tapered multiple-form cutter that completes the thread in one revolution using helical interpolation, or with a straight or tapered cutter (of single- or multiple-form) whose toolpath is one or more revolutions but cannot use helical interpolation and must use CAD/CAM software to generate a contour-like simulation of helical interpolation.

The tooling used for thread milling can be solid or indexable. For internal threads, solid cutters are generally limited to holes larger than 6 mm (0.24 in), and indexable internal thread cutting tools are limited to holes larger than 12 mm (0.47 in). The advantage is that when the insert wears out it is easily and more cost effectively replaced. The disadvantage is the cycle time is generally longer than solid tools. Note that solid multiple-form thread cutting tools look similar to taps, but they differ in that the cutting tool does not have a backtaper and there is not a lead-in chamfer. This lack of a lead-in chamfer allows the threads to be formed within one pitch length of the bottom of a blind hole.

Thrilling

Thrilling is the process of dr**illing** and **thr**eading internal threads using a specialized cutting tool on a CNC mill. The cutting tool tip is shaped like a drill, while the shank has a thread shaped form. The cutter first plunges to drill the hole. Then the thread is circularly interpolated just like the multiple-form cutter described above. The advantage is this process eliminates a tool, tool holder, and tool change. The disadvantage is that the process is limited to hole depth no greater than three times the diameter of the tool.

Thread grinding

Thread grinding is done on a grinding machine using specially dressed grinding wheels matching the shape of the threads. The process is usually used to produce accurate threads or threads in hard materials; a common application is ball screw mechanisms. There are three types: *center-type grinding with axial feed*, *center-type infeed thread grinding* and *centerless thread grinding*. Center-type grinding with an axial feed is the most common of the three. It is similar to cutting a thread on a lathe with a single-point cutting tool, except the cutting tool is replaced with a grinding wheel. Usually a single ribbed wheel is used, although multiple ribbed wheels are also available. To complete the thread multiple passes are commonly required. Center-type infeed thread grinding use a grinding wheel with multiple ribs that is longer than the length of the desired thread. First, the grinding wheel is fed into the blank to the full thread depth. Then the blank is slowly rotated through approximately 1.5 turns while axially advancing through one pitch per revolution. Finally, the centerless thread grinding process is used to make head-less set screws in a similar method as centerless grinding. The blanks are hopper-fed to the grinding wheels, where the thread is fully formed. Common centerless thread grinding production rates are 60 to 70 pieces per minute for a 0.5 in (13 mm) long set screw.

Thread lapping

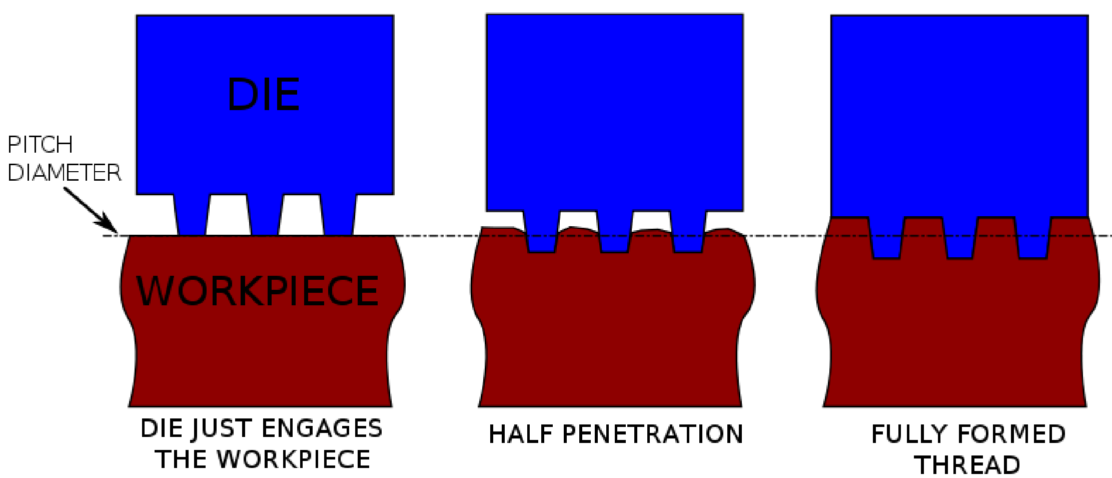
Rarely, thread cutting or grinding (usually the latter) will be followed by thread lapping in order to achieve the highest precision and surface finish achievable. This is a toolroom practice when the highest precision is required, rarely employed except for the leadscrews or ballscrews of high-end machine tools.

Threading with EDM

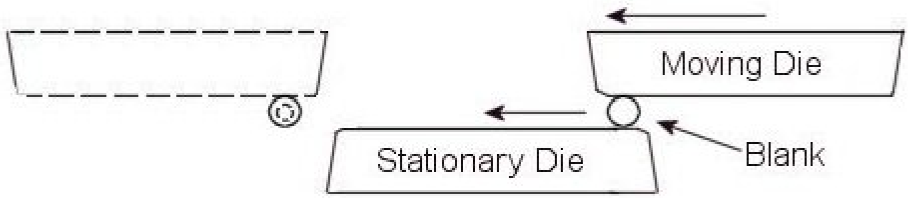
Internal threads can be electrical discharge machined (EDM) into hard materials using a sinker style machine.

Deformative or transformative methods

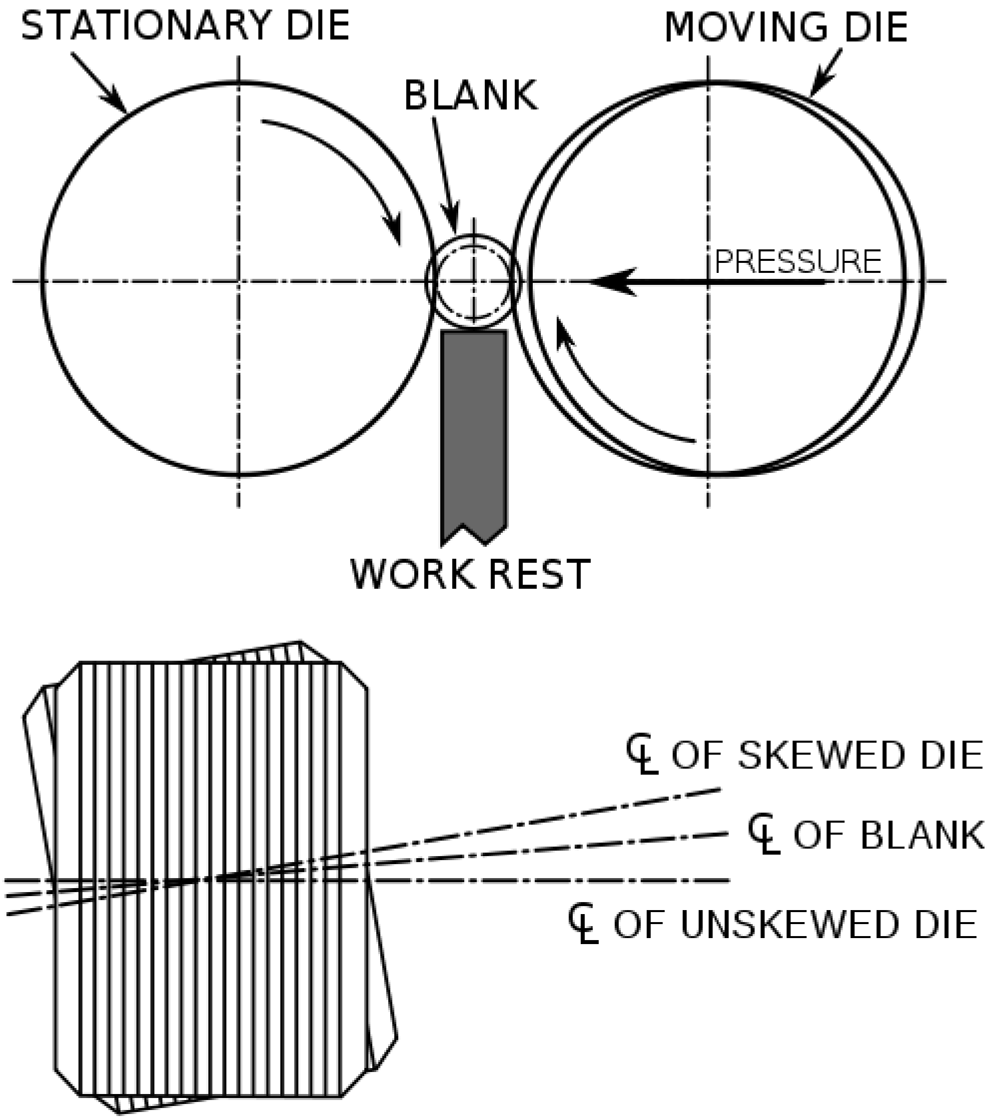
Thread forming and rolling



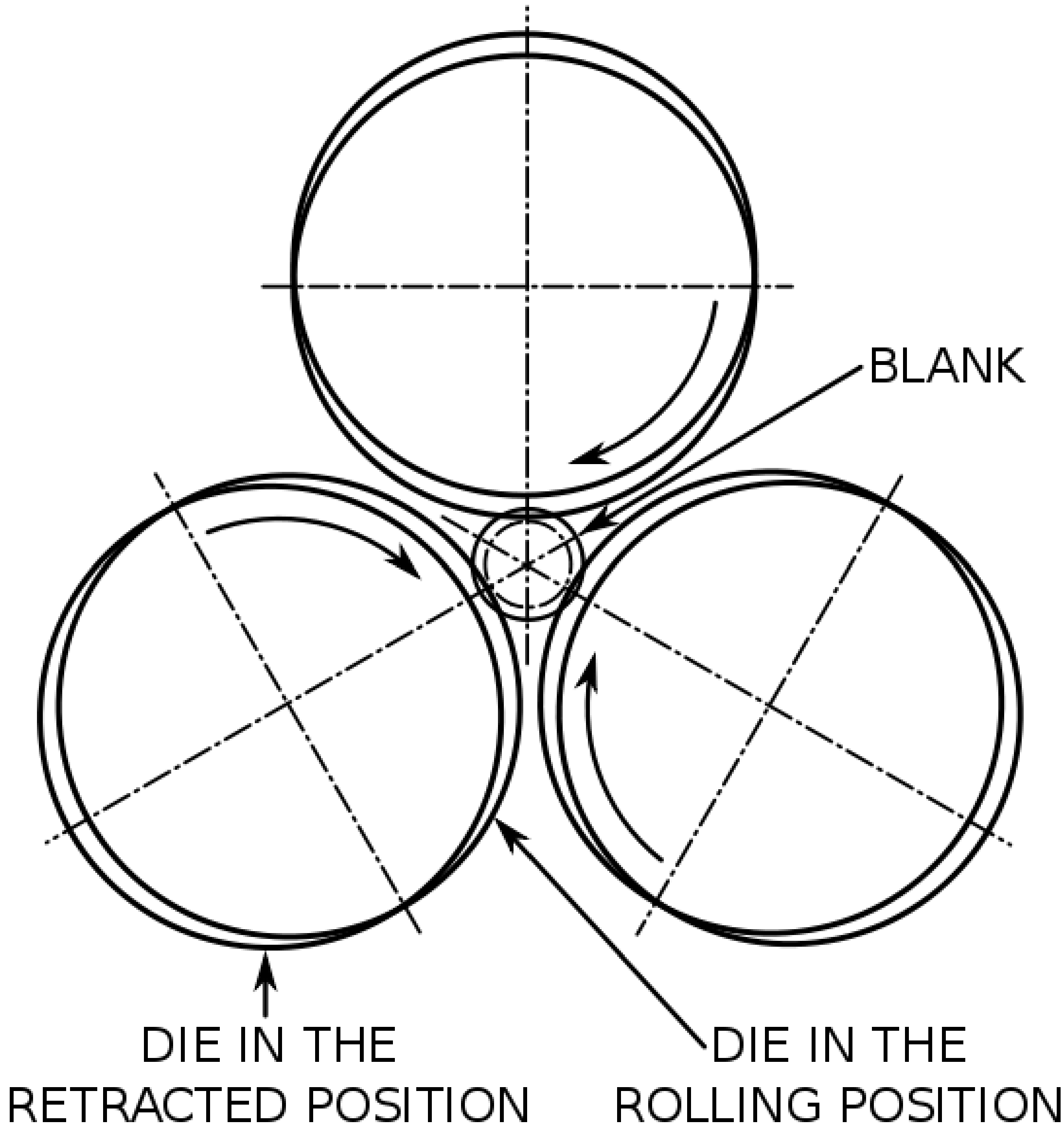
The thread forming and rolling concept



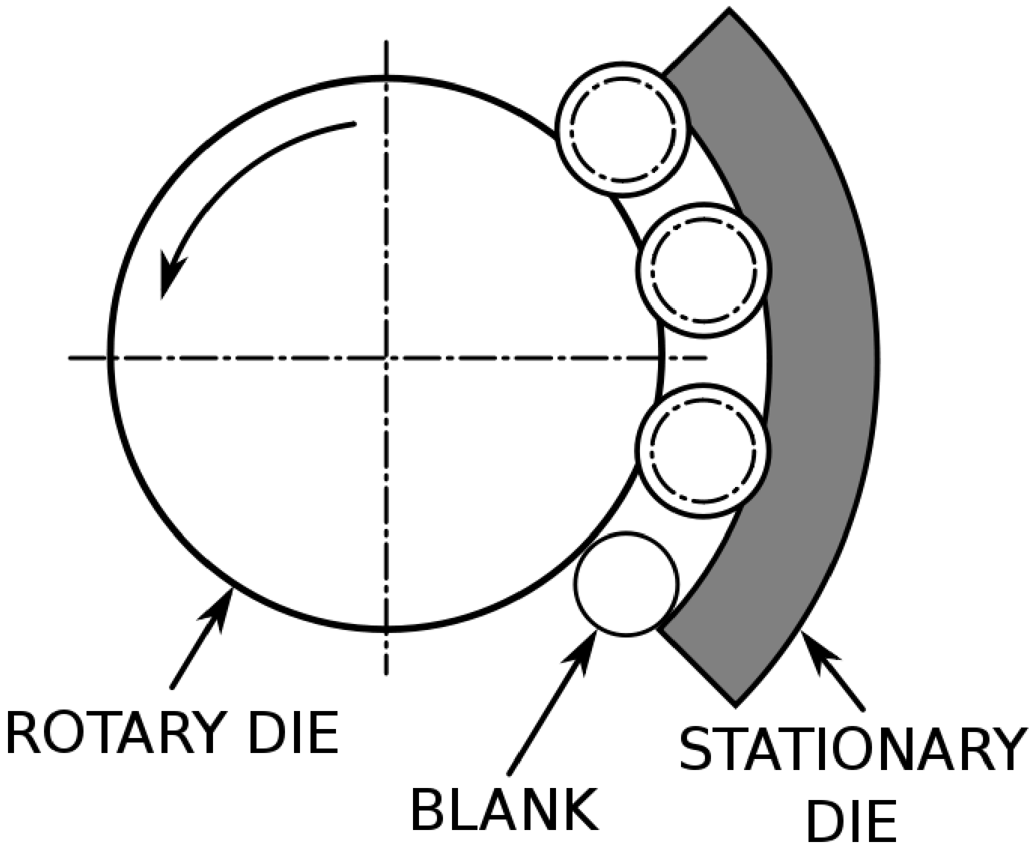
A schematic of the flat die process



A schematic of the two-die cylindrical process



A schematic of the three-die cylindrical process



A schematic of planetary thread rolling

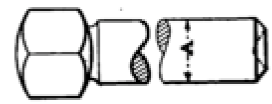
ROLLED THREADS

The rolled thread process dates back more than 50 years and was first patented in England. It was first used on comparatively rough work such as track bolts but has come to be used on such fine work as the sizing of taps and screws for micrometers.

The thread is forced up into the dies so that the finished screw is larger than the original wire by about the depth of one thread. In this way the size of the wire to use for any screw may be found by subtracting the depth of one thread from the outside diameter of the screw. This is $\frac{.866}{\text{threads per inch}}$. Exact allowance depends on material being rolled and other conditions.

The dies are usually flat plates of steel, having grooves of the same pitch and shape as the thread to be rolled. The dies can be easily laid out as follows:

Draw a horizontal line equal in length to the circumference of the *wire* or *blank*, and at its end draw a vertical line equal to the lead of the screw. The diagonal line made by joining these two points shows the angle of incline of the grooves. This can be done more easily if both the circumference and the pitch are laid out to *ten times* their actual dimensions.



DIMENSIONS OF BLANKS FOR U. S. S. ROLLED THREAD SCREWS
(REED & PRINCE MFG. CO.)

Size	T. P. I.	A	Size	T. P. I.	A
1/8	40	.1074 .1054	9/16	12	.5063 .5031
3/16	24	.1586 .1566	5/8	11	.5638 .5605
1/4	20	.2157 .2137	3/4	10	.6828 .6794
5/16	18	.2745 .2715	7/8	9	.8006 .7972
3/8	16	.3325 .3295	1	8	.9165 .9131
7/16	14	.3890 .3860	1 1/8	7	1.0298 1.0262
1/2	13	.4480 .4450	1 1/4	7	1.1548 1.1512

Page 23 of Colvin FH, Stanley FA (eds) (1914): American Machinists' Handbook, 2nd ed. New York and London: McGraw-Hill. Summarizes screw thread rolling practice as of 1914.

Thread forming and thread rolling are processes for forming screw threads, with the former referring to creating internal threads and the latter external threads. In both of these processes threads are formed into a blank by pressing a shaped die against the blank, in a process similar to knurling. These processes are used for large production runs because typical production rates are around one piece per second. Forming and rolling produce no swarf and less material is required because the blank size starts smaller than a blank required for cutting threads; there is typically a 15 to 20% material savings in the blank, by weight. A rolled thread can often be easily recognized because the thread has a larger diameter than the blank rod from which it has been made; however, necks and undercuts can be cut or rolled onto blanks with threads that are not rolled. Also, the end of the screw usually looks a bit different from the end of a cut-thread screw.

Materials are limited to ductile materials because the threads are cold formed, however this increases the thread's yield strength, surface finish, hardness, and wear resistance. Also, materials with good deformation characteristics are necessary for rolling; these materials include softer (more ductile) metals and exclude brittle materials, such as cast iron. Tolerances are typically ±0.001 in. (±0.025 mm), but tolerances as tight as ±0.0006 in (±0.015 mm) are achievable. Surface finishes range from 6 to 32 micro-inches.

There are four main types of thread rolling, named after the configuration of the dies: *flat dies*, *two-die cylindrical*, *three-die cylindrical*, and *planetary dies*. The flat die system has two flat dies, the bottom one is held stationary and the other slides. The blank is placed on one end of the stationary die and then the moving die slides over the blank, which causes the blank to roll between the two dies forming the threads. Before the moving die reaches the end of its stroke the blank rolls off the stationary die in a finished form. The two-die cylindrical process is used to produce threads up to 6 in (150 mm) in diameter and 20 in (510 mm) in length. There are two types of three-die processes; the first has the three dies move radially out from the center to let the blank enter the dies and then closes and rotates to roll the threads. This type of process is commonly employed on turret lathes and screw machines. The second type takes the form of a self-opening die head. This type is more common than the former, but is limited by not being able form the last 1.5 to 2 threads against shoulders. Planetary dies are use to mass produce threads up to 1 in (25 mm) in diameter.

Thread forming is performed using a *fluteless tap*, or *roll tap*, which closely resembles a cutting tap without the flutes. There are *lobes* periodically spaces around the tap that actually do the thread forming as the tap is advanced into a properly sized hole. Since the tap does not produce chips, there is no need to periodically back out the tap to clear away chips, which, in a cutting tap, can jam and break the tap. Thus thread forming is particularly suited to taping blind holes, which are tougher to tap with a cutting tap due to the chip build-up in the hole. Note that the tap drill size differs from that used for a cutting tap and that an accurate hole size is required because a slightly undersized hole can break the tap. Proper lubrication is essential because of the frictional forces involved, therefore a lubricating oil is used instead of cutting oil.

When considering the blank diameter tolerance, a change in blank diameter will affect the major diameter by an approximate ratio of 3 to 1. Production rates are usually three to five times faster than thread cutting.

Tool styles

Description	Application
Flat dies	Machine, tapping and wood screws
Cylindrical in-feed 2 dies	Large or balanced screws

Cylindrical in-feed 3 dies	Tube fitting, spark plugs
Planetary dies	High volumes screws, sheet metal screws, and drive screws

Production rates			
Thread diameter [in.]	**Flat dies [pieces/min]**	**Cylindrical [pieces/min]**	**Planetary [pieces/min]**
1/8	40 to 500	75 to 300	450 to 2000
1/4	40 to 400	60 to 150	250 to 1200
1/2	25 to 90	50 to 100	100 to 400
3/4	20 to 60	5 to 10	-
1	15 to 50	1 to 50	-

Thread casting and molding

In casting and molding the threads are directly formed by the geometry of the mold cavity in the mold or die. When the material freezes in the mold, it retains the shape after the mold is removed. The material is heated to a liquid, or mixed with a liquid that will either dry or cure (such as plaster or cement). Alternately, the material may be forced into a mold as a powder and compressed into a solid, as with graphite.

Although the first thoughts that come to mind for most machinists regarding threading are of thread *cutting* processes (such as tapping, single-pointing, or helical milling), Smid points out that, when plastic bottles for food, beverages, personal care products, and other consumer products are considered, it is actually plastic molding that is the principal method (by sheer volume) of thread generation in manufacturing today. Of course, this fact highlights the importance of the moldmaker's getting the mold just right (in preparation for millions of cycles, usually at high speed).

Cast threads in metal parts may be finished by machining, or may be left in the as-cast state. (The same can be said of cast gear teeth.) Whether or not to bother with the additional expense of a machining operation depends on the application. For parts where the extra precision and surface finish is not strictly necessary (although it might be nice), the machining is forgone in order to achieve a lower cost. With sand casting parts this means a rather rough finish; but with molded plastic or die-cast metal, the threads can be very nice indeed straight from the mold or die. A common example of molded plastic threads is on soda (pop) bottles. A common example of die-cast threads is on cable glands (connectors/fittings).

Additive methods

Many, perhaps most, threaded parts have *potential* to be generated via additive manufacturing, of which there are many variants, including fused deposition modeling, direct metal laser sintering, 3D printing, solid freeform fabrication, layered object manufacturing, and stereolithography. Most additive technologies are still on the laboratory end of their historical development, but further commercialization is picking up speed. Additive methods today generally produce a rough surface finish, which suggests that their earliest commercial wins will be in parts that don't require secondary finishing by subtractive methods.

Combinations of subtractive, additive, deformative, or transformative methods

Often subtractive, additive, deformative, or transformative methods are combined in whatever ways are advantageous. Such multidisciplinary manufacturing falls under classifications including rapid prototyping, desktop manufacturing, direct manufacturing, direct digital manufacturing, digital fabrication, instant manufacturing, or on-demand manufacturing.

Inspection

Inspection of the finished screw threads can be achieved in various ways, with the expense of the method tailored to the requirements of the product application. Shop-floor inspection of a thread is often as simple as running a nut onto it (for male threads) or a bolt into it (for female threads). This is plenty good enough for many applications (e.g., MRO or hobbyist work), although it is not good enough for most commercial manufacturing. Higher-precision methods are discussed below.

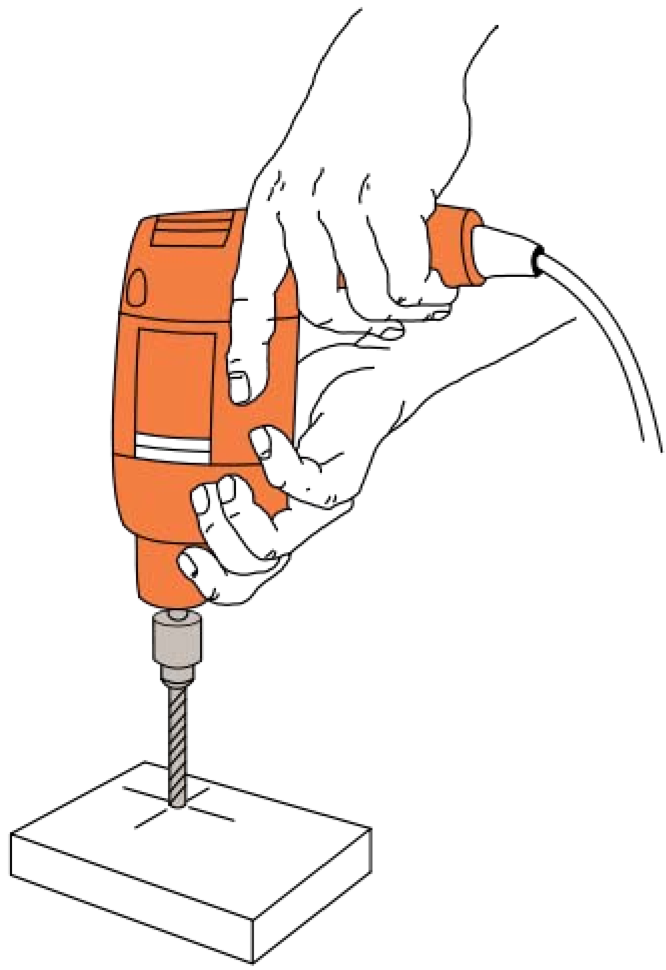
Commercial-grade inspection of screw threads can involve most of the same inspection methods and tools used to inspect other manufactured products, such as micrometers; vernier or dial calipers; surface plates and height gauges; gauge blocks; optical comparators; white light scanners; and coordinate-measuring machines (CMMs). Even industrial radiography (including industrial CT scanning) can be used, for example, to inspect internal thread geometry in the way that an optical comparator can inspect external thread geometry.

Conical micrometer anvils, specifically suited to resting on the sides of the thread, are made for various thread angles, with 60° being the most common. Mics with such anvils are usually called "thread mics". Users who lack thread mics rely instead on the "3-wire method", which involves placing 3 short pieces of wire (or gauge pins) of known diameter into the valleys of the thread and then measuring from wire to wire with standard (flat) anvils. A conversion factor (produced by a straightforward trigonometric calculation) is then multiplied with the measured value to infer a measurement of the thread's pitch diameter. Tables of these conversion factors were established many decades ago for all standard thread sizes, so today a user need only take the measurement and then perform the table lookup (as opposed to recalculating each time). Ball-shaped micrometer anvils can be used in similar fashion (same trigonometric relationship, less cumbersome to use). Digital calipers and micrometers can send each measurement datum as it occurs through an interface (commonly RS-232) to storage and as input to software, in which case the table lookup is done in an automated way.

Chapter 3

Drill

Use of a cordless drill in assembling a book case



Drill scheme

A **drill** or **drill motor** is a tool fitted with a cutting tool attachment or driving tool attachment, usually a drill bit or driver bit, used for drilling holes in various materials or fastening various materials together with the use of fasteners. The attachment is gripped by a chuck at one end of the drill and rotated while pressed against the target material. The tip, and sometimes edges, of the cutting tool does the work of cutting into the target material. This may be slicing off thin shavings (twist drills or auger bits), grinding off small particles (oil drilling), crushing and removing pieces of the workpiece (SDS masonry drill), countersinking, counterboring, or other operations.

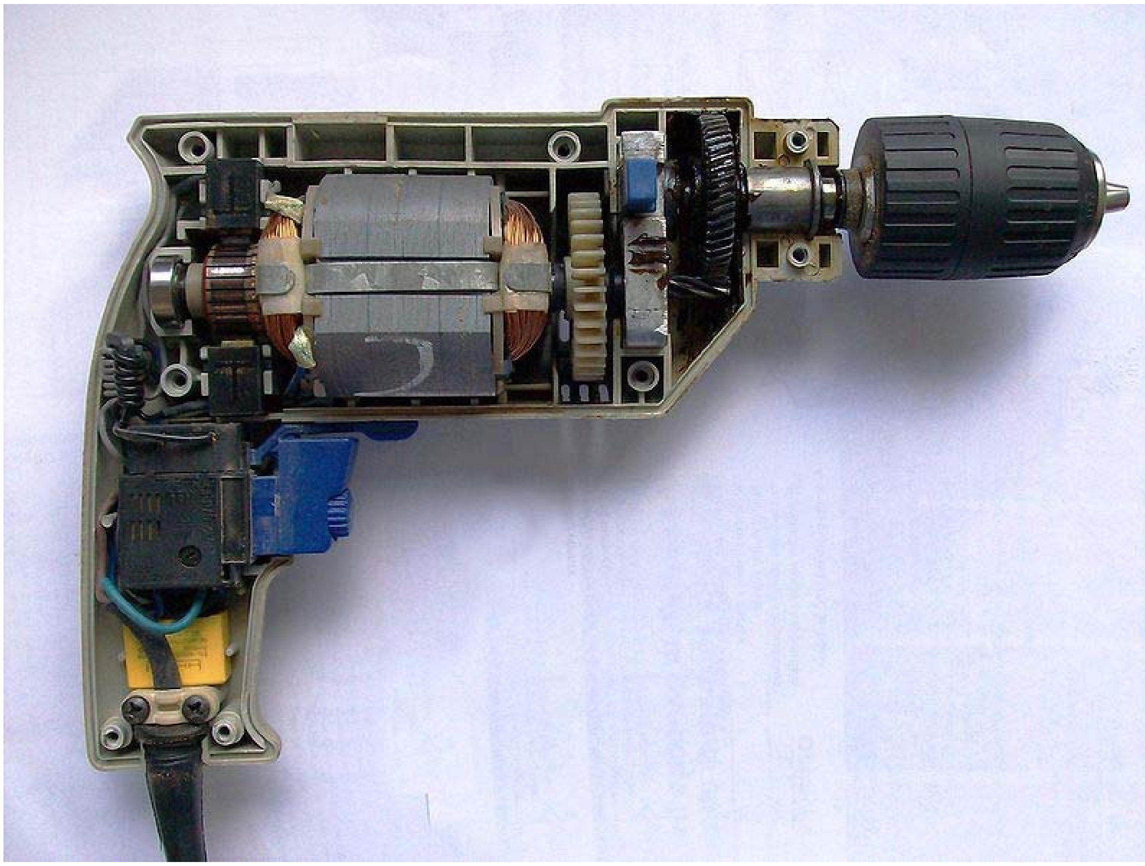
Drills are commonly used in woodworking, metalworking, construction and do-it-yourself projects. Specially designed drills are also used in medicine, space missions and other applications.

History

A wooden drill handle and other carpentry tools found on board the 16th century carrack *Mary Rose*.

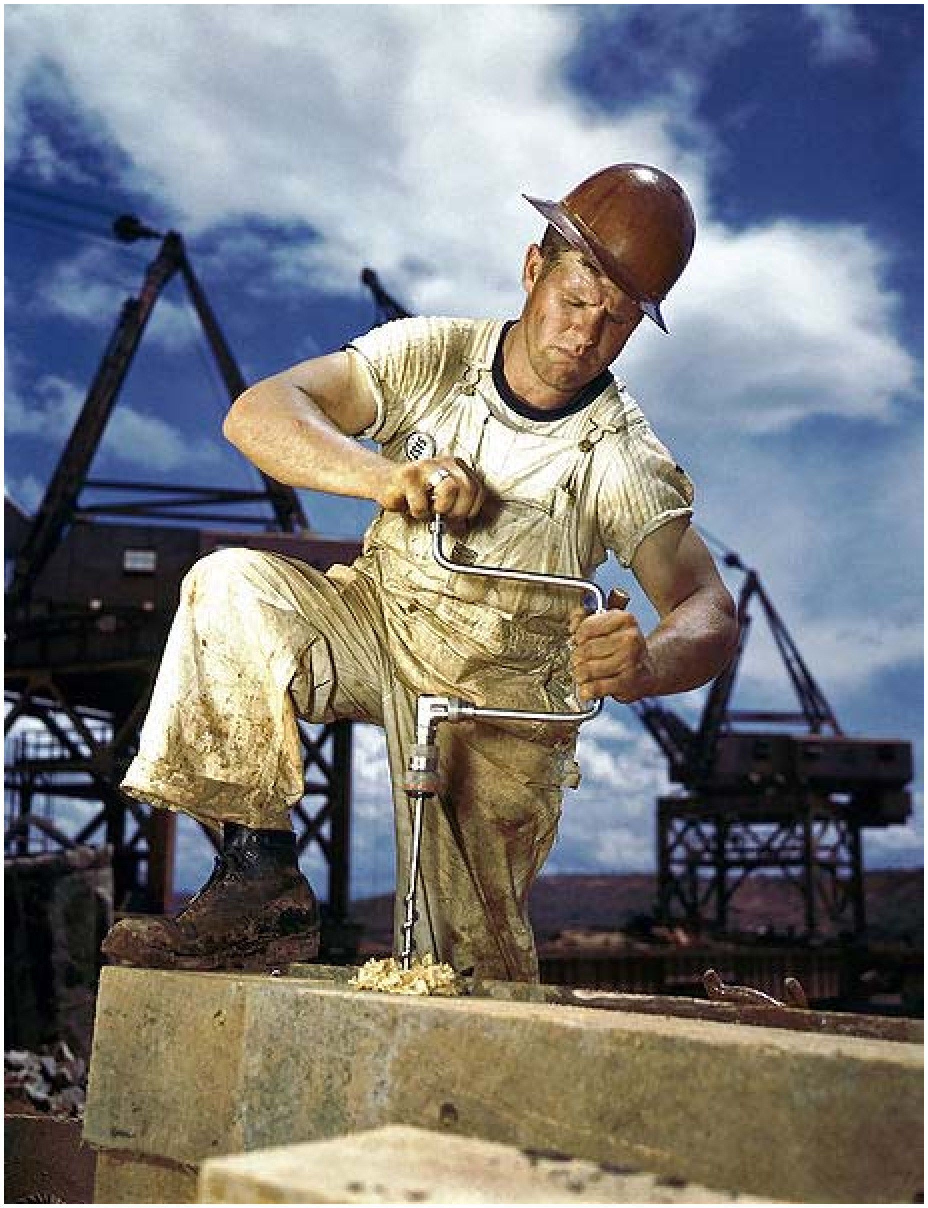
The earliest drills were bow drills which date back to the ancient Harappans and Egyptians. The drill press as a machine tool evolved from the bow drill and is many centuries old. It was powered by various power sources over the centuries, such as human effort, water wheels, and windmills, often with the use of belts. With the coming of the electric motor in the late 19th century, there was a great rush to power machine tools with such motors, and drills were among them. The invention of the first electric drill is credited to Arthur James Arnot and William Blanch Brain , in 1889, at Melbourne, Australia. Wilhelm Fein invented the portable electric drill in 1895, at Stuttgart, Germany. In 1917, Black & Decker patented a trigger-like switch mounted on a pistol-grip handle.

Types



Inside an electric drill

There are many types of drills: some are powered manually, others use electricity (electric drill) or compressed air (*pneumatic drill*) as the motive power, and a minority are driven by an internal combustion engine (for example, earth drilling augers). Drills with a percussive action (hammer drills) are mostly used in hard materials such as masonry (brick, concrete and stone) or rock. Drilling rigs are used to bore holes in the earth to obtain water or oil. Oil wells, water wells, or holes for geothermal heating are created with large drilling rigs. Some types of hand-held drills are also used to drive screws and other fasteners. Some small appliances that have no motor of their own may be drill-powered, such as small pumps, grinders, etc.



Carpenter using a crank-powered brace to drill a hole

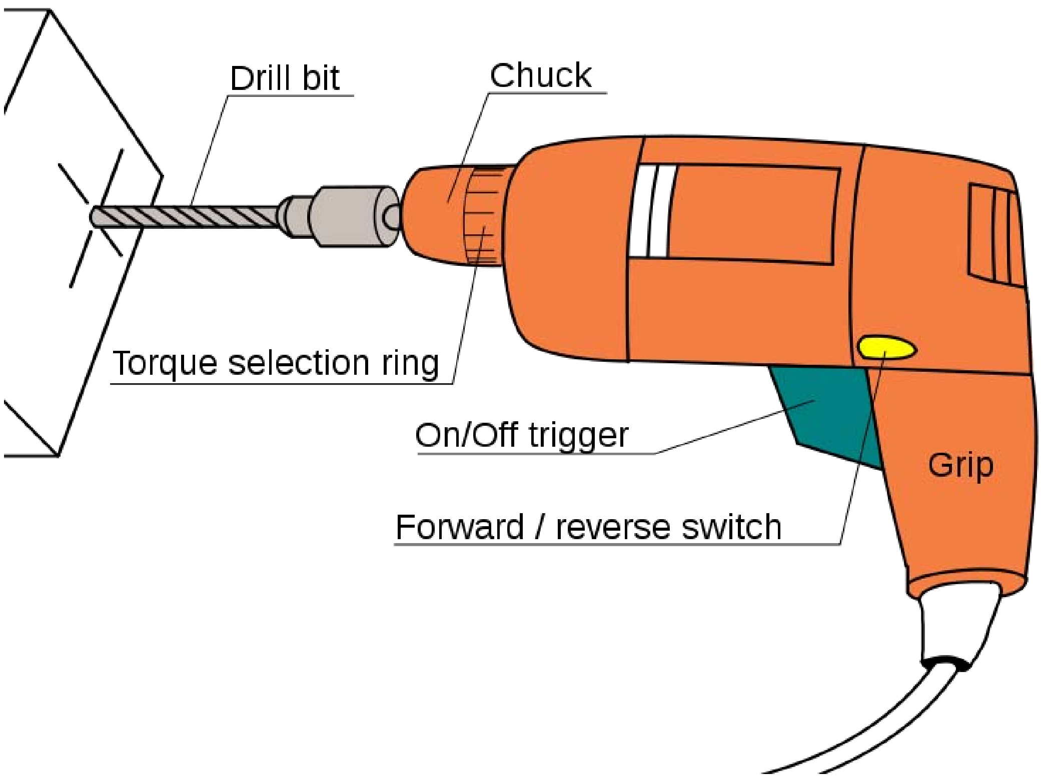
Hand tools

A variety of hand-powered drills have been employed over the centuries. Here are a few, starting with approximately the oldest:

- Bow drill
- Brace and bit
- Gimlet
- Breast drill, also known as "eggbeater" drill
- Push drill, a tool using a spiral ratchet mechanism
- Pin chuck, a small hand-held jewellers drill

An old hand drill or "eggbeater" drill. The hollow wooden handle, with screw-on cap, is used to store drill bits

Pistol-grip (corded) drill



Anatomy of a pistol-grip corded drill.

Drills with pistol grips are the most common type in use today, and are available in a huge variety of subtypes. A less common type is the right-angle drill, a special tool used by tradesmen such as plumbers and electricians.

For much of the 20th century, many attachments could commonly be purchased to convert corded electric hand drills into a range of other power tools, such as orbital sanders and power saws, more cheaply than purchasing conventional, self-contained versions of those tools (the greatest saving being the lack of an additional electric motor for each device). As the prices of power tools and suitable electric motors have fallen, however, such attachments have become much less common. A similar practice is currently employed for cordless tools where the battery, the most expensive component, is shared between various motorised devices, as opposed to a single electric motor being shared between mechanical attachments.

Hammer drill

The **hammer drill** is similar to a standard electric drill, with the exception that it is provided with a hammer action for drilling masonry. The hammer action may be engaged or disengaged as required. Most electric hammer drills are rated (input power) at between 600 and 1100 watts. The efficiency is usually 50-60% i.e. 1000 watts of input is converted into 500-600 watts of output (rotation of the drill and hammering action).

The hammer action is provided by two cam plates that make the chuck rapidly pulse forward and backward as the drill spins on its axis. This pulsing (hammering) action is measured in Blows Per Minute (BPM) with 10,000 or more BPMs being common. Because the combined mass of the chuck and bit is comparable to that of the body of the drill, the energy transfer is inefficient and can sometimes make it difficult for larger bits to penetrate harder materials such as poured concrete. The operator experiences considerable vibration, and the cams are generally made from hardened steel to avoid them wearing out quickly. In practice, drills are restricted to standard masonry bits up to 13 mm (1/2 inch) in diameter. A typical application for a hammer drill is installing electrical boxes, conduit straps or shelves in concrete.

In contrast to the cam-type hammer drill, a rotary/pneumatic hammer drill accelerates only the bit. This is accomplished through a piston design, rather than a spinning cam. Rotary hammers have much less vibration and penetrate most building materials. They can also be used as "drill only" or as "hammer only" which extends their usefulness for tasks such as chipping brick or concrete. Hole drilling progress is greatly superior to cam-type hammer drills, and these drills are generally used for holes of 19 mm (3/4 inch) or greater in size. A typical application for a rotary hammer drill is boring large holes for lag bolts in foundations, or installing large lead anchors in concrete for handrails or benches.

A standard hammer drill accepts 6 mm (1/4 inch) and 13 mm (1/2 inch) drill bits, while a rotary hammer uses SDS or Spline Shank bits. These heavy bits are adept at pulverising the masonry and drill into this hard material with relative ease.

However, there is a big difference in cost. In the UK a cam hammer typically costs £12 or more, while a rotary/pneumatic costs £35 or more. In the US a typical hammer drill costs between $70 and $120, and a rotary hammer between $150 and $500 (depending on bit size). For DIY use or to drill holes less than 13 mm (1/2 inch) in size, the hammer drill is most commonly used.

Rotary hammer drill

A rotary hammer drill used in construction

The rotary hammer drill (also known as a rotary hammer, roto hammer drill or masonry drill) combines a primary dedicated hammer mechanism with a separate rotation mechanism, and is used for more substantial material such as masonry or concrete. Generally, standard chucks and drills are inadequate and chucks such as SDS and carbide drills that have been designed to withstand the percussive forces are used. Some styles of this tool are intended for masonry drilling only and the hammer action cannot be disengaged. Other styles allow the drill to be used without the hammer action for normal drilling, or hammering to be used without rotation for chiselling.

Cordless drills

A cordless drill with clutch

A cordless drill is an electric drill which uses rechargeable batteries. These drills are available with similar features to an AC mains-powered drill. They are available in the hammer drill configuration and most have a clutch, which aids in driving screws into various substrates while not damaging them. Also available are right angle drills, which allow a worker to drive screws in a tight space. While 21st century battery innovations allow significantly more drilling, large diameter holes (typically 12–25 mm (0.5–1.0 in) or larger) may drain current cordless drills quickly.

For continuous use, a worker will have one or more spare battery packs charging while drilling, and quickly swap them instead of having to wait an hour or more for recharging, although there are now Rapid Charge Batteries that can charge in 10–15 minutes.

Early cordless drills used interchangeable 7.2 V battery packs, and over the years available battery voltages have increased, with 18 V drills being most common, and higher voltage drills, such as 24V, 28V, and 36V, are made also. This allows these tools to produce as much torque as some mains-powered drills. The drawback of most current models is the use of nickel-cadmium (NiCd) batteries, which have limited life, self-discharging and eventually internally short circuiting due to dendrite growth. This severely limits battery life, and poses a hazardous materials disposal problem.

Lithium ion batteries are becoming more common because of their short charging time, longer life, and low weight. Instead of charging a tool for an hour to get 20 minutes of use, 20 minutes of charge can run the tool for an hour. Lithium-ion batteries also have a constant discharge rate. The power output remains constant until the battery is depleted, something that nickel-cadmium batteries also lack, and which makes the tool much more versatile. Lithium-ion batteries also hold a charge for a significantly longer time than nickel-cadmium batteries, about two years if not used, vs. 1 to 4 months for a nickel-cadmium battery. There are three major drawbacks to Lithium Ion batteries. 1. They do not perform well in low temperatures 2. The batteries are very expensive to replace. 3. The overall batteries can only handle about 1/3 of the recharges over a lifetime as a NiCad or NiMH battery. NiCad batteries can also be rebuilt or upgraded, diminishing the benefits of Li-ion batteries.

A cordless drill with a high torque (in excess of 30 Nm) works well as a screw driver even if working on a hardwood. In drilling the high torque is needed when the diameter of the drill is large.

The handles of cordless drills are usually made from polyurethane which is easy and quick to mold to a comfortable shape for holding. The main body of the drill is usually made from polyethylene as it is able to withstand the high temperatures which the drill reaches.

Drill press

A drill press

A drill press (also known as pedestal drill, pillar drill, or bench drill) is a fixed style of drill that may be mounted on a stand or bolted to the floor or workbench. A drill press consists of a base, column (or pillar), table, spindle (or quill), and drill head, usually driven by an induction motor. The head has a set of handles (usually 3) radiating from a central hub that, when turned, move the spindle and chuck vertically, parallel to the axis of the column. The table can be adjusted vertically and is generally moved by a rack and pinion; however, some older models rely on the operator to lift and reclamp the table in position. The table may also be offset from the spindle's axis and in some cases rotated to a position perpendicular to the column. The size of a drill press is typically measured in terms of *swing*. Swing is defined as twice the *throat distance*, which is the distance from the center of the spindle to the closest edge of the pillar. For example, a 16-inch (410 mm) drill press will have an 8-inch (200 mm) throat distance.

Old industrial drill press designed to be driven from the power source by a flat belt

A drill press has a number of advantages over a hand-held drill:

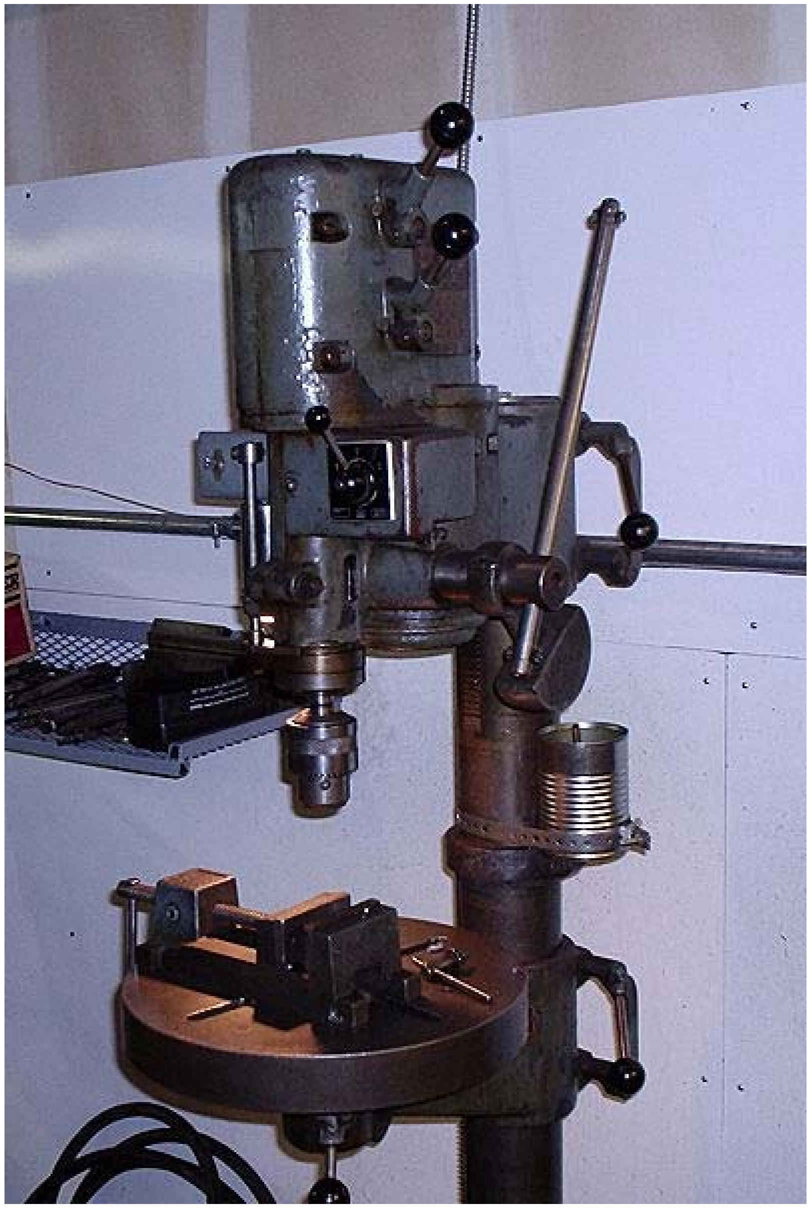
- Less effort is required to apply the drill to the workpiece. The movement of the chuck and spindle is by a lever working on a rack and pinion, which gives the operator considerable mechanical advantage
- The table allows a vise or clamp to be used to position and restrain the work, making the operation much more secure
- The angle of the spindle is fixed relative to the table, allowing holes to be drilled accurately and consistently

- Drill presses are almost always equipped with more powerful motors compared to hand-held drills. This enables larger drill bits to be used and also speeds up drilling with smaller bits.

Speed change is achieved by manually moving a belt across a stepped pulley arrangement. Some drill presses add a third stepped pulley to increase the speed range. Modern drill presses can, however, use a variable-speed motor in conjunction with the stepped-pulley system. Some machine shop (tool room) drill presses are equipped with a continuously variable transmission, giving a wide speed range, as well as the ability to change speed while the machine is running.

Drill presses are often used for miscellaneous workshop tasks such as sanding, honing or polishing, by mounting sanding drums, honing wheels and various other rotating accessories in the chuck. This can be unsafe in some cases, as the chuck arbor, which may be retained in the spindle solely by the friction of a taper fit, may dislodge during operation.

Geared head drill press

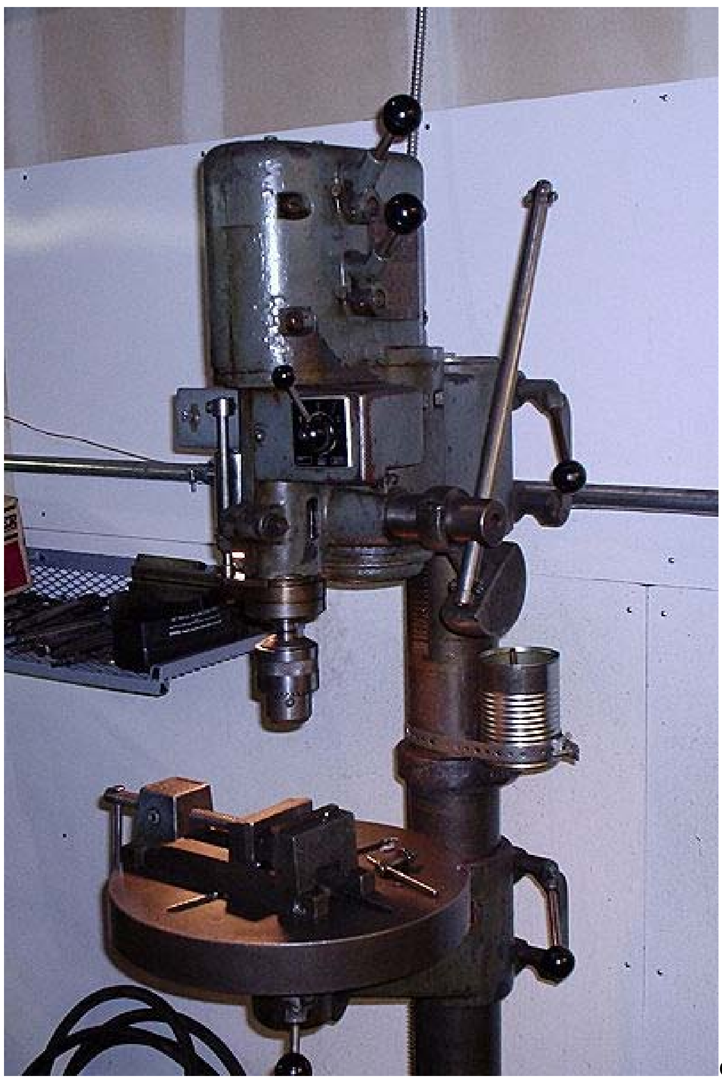


Geared head drill press. Shift levers on the head and a two speed motor control immediately in front of the quill handle select one of eight possible speeds

A geared head drill press is a drill press in which power transmission from the motor to the spindle is achieved solely through spur gearing inside the machine's head. No friction elements (e.g., belts) of any kind are used, which assures a positive drive at all times and minimizes maintenance requirements.

Levers attached to one side of the head are used to select different gear ratios to change the spindle speed, usually in conjunction with a two- or three-speed motor. Most machines of this type are designed to be operated on three phase power and are generally of more rugged construction than equivalent sized belt-driven units. Virtually all examples have geared racks for adjusting the table and head position on the column.

Geared head drill presses are commonly found in tool rooms and other commercial environments where a heavy duty machine capable of production drilling and quick setup changes is required. In most cases, the spindle is machined to accept Morse taper tooling for greater flexibility. Larger geared head drill presses are frequently fitted with power feed on the quill mechanism, with an arrangement to disengage the feed when a certain drill depth has been achieved or in the event of excessive travel. Some gear-head drill presses have the ability to perform tapping operations--a reversing mechanism drives the tap into the part under power and then backs it out of the threaded hole once the proper depth is reached. Coolant systems are also common on these machines to prolong tool life under production conditions.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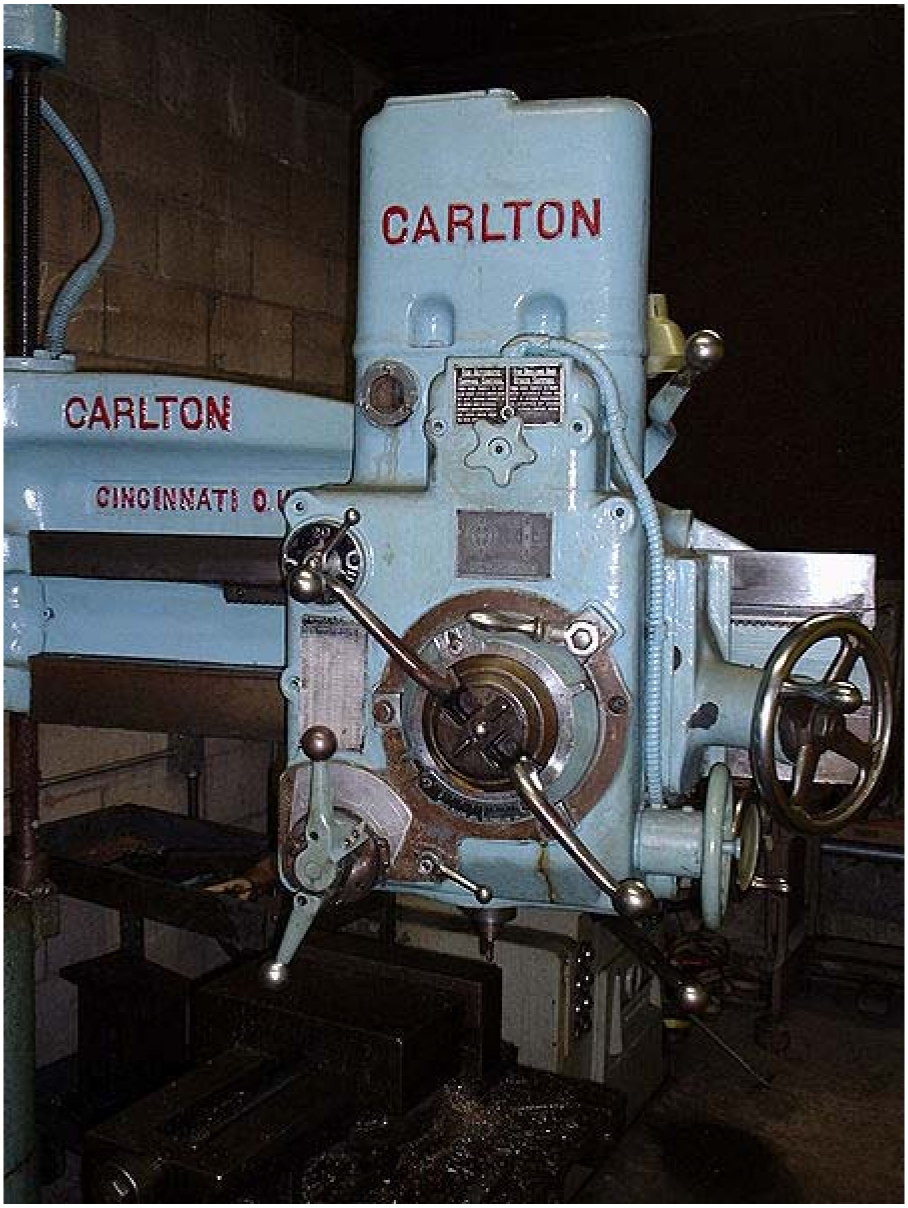
Radial arm drill press.

Radial arm drill press



Radial arm drill press controls

A radial arm drill press is a large geared head drill press in which the head can be moved along an arm that radiates from the machine's column. As it is possible to swing the arm relative to the machine's base, a radial arm drill press is able to operate over a large area without having to reposition the workpiece. The size of work that can be handled may be considerable, as the arm can swing out of the way of the table, allowing an overhead crane or derrick to place a bulky piece on the table or base. A vise may be used with a radial arm drill press, but more often the workpiece is secured directly to the table or base, or is held in a fixture. Power spindle feed is nearly universal with these machines and coolant systems are common. The biggest radial arm drill presses are able to drill holes as large as four inches (101.6 millimeters) diameter in solid steel or cast iron.

Mill drill

Mill drills are a lighter alternative to a milling machine. They combine a drill press (belt driven) with the X/Y coordinate abilities of the milling machine's table and a locking collet that ensures that the cutting tool will not fall from the spindle when lateral forces are experienced against the bit. Although they are light in construction, they have the advantages of being space-saving and versatile as well as inexpensive, being suitable for light machining that may otherwise not be affordable.

Unusual Uses

- A household drill was used to save a boy's life in Australia. The boy suffered from potentially fatal bleeding within the brain after a fall from his bike. Having no proper medical tools, the attending doctor decided to use a household drill stored in the hospital maintenance room to remove a clot. This was done in order to relieve the blood pressure in the boy's brain. If this had not been done, the boy would have died in minutes. The doctor performed the procedure and was guided by a neurosurgeon over the phone. The boy was later airlifted to a larger hospital and recovered within days.
- Paul Gilbert and Billy Sheehan of Mr. Big use a cordless drill for the solo of Daddy, Brother, Lover, Little Boy commonly known as "The Electric Drill Song". This was done by using 3.3mm plectrums on a wooden dowel.

Other perforation tools

- Milling machines, metal lathes and routers are also often used for drilling.

Chapter 4

Die (Manufacturing)

A **die** is a specialized tool used in manufacturing industries to cut or shape material using a press. Like molds, dies are generally customized to the item they are used to create. Products made with dies range from simple paper clips to complex pieces used in advanced technology.

Die forming

Progressive die with scrap strip and stampings

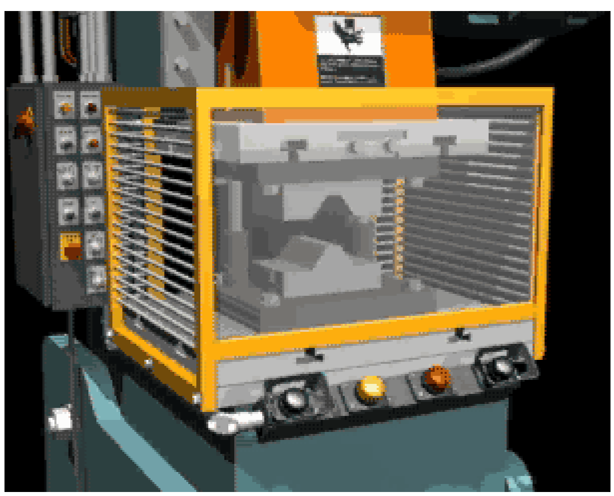
Forming dies are typically made by tool and die makers and put into production after mounting into a press. The die is a metal block that is used for forming materials like sheet metal and plastic. For the vacuum forming of plastic sheet only a single form is used, typically to form transparent plastic containers (called blister packs) for merchandise. Vacuum forming is considered a simple molding thermoforming process but uses the same principles as die forming. For the forming of sheet metal, such as automobile body parts, two parts may be used, one, called the *punch*, performs the stretching, bending, and/or blanking operation, while another part, called the *die block*, securely clamps the workpiece and provides similar, stretching, bending, and/or blanking operation. The workpiece may pass through several stages using different tools or operations to obtain the final form. In the case of an automotive component there will usually be a shearing operation after the main forming is done and then additional crimping or rolling operations to ensure that all sharp edges are hidden and to add rigidity to the panel.

Die components

- Die block
- Punch plate
- Blank punch
- Pierce punch
- Stripper plate
- Pilot
- Dowel Pin
- Back gage
- Finger stop
- Setting Block
- Hollow Dies

Die operations and types

Die operations are often named after the specific type of die that performs the operation. For example a bending operation is performed by a bending die. Operations are not limited to one specific die as some dies may incorporate multiple operation types:



Press with bending die.

- **Bending**: The bending operation is the act of bending blanks at a predetermined angle. An example would be an "L" bracket which is a straight piece of metal bent at a 90° angle. The main difference between a forming operation and a bending operation is the bending operation creates a straight line bend (such as a corner in a box) as where a form operation may create a curved bend (such as the bottom of a drink can).
- **Blanking**: A blanking die produces a flat piece of material by cutting the desired shape in one operation. The finish part is referred to as a blank. Generally a blanking die may only cut the outside contour of a part, often used for parts with no internal features.
  Three benefits to die blanking are:

1. *Accuracy*. A properly sharpened die, with the correct amount of clearance between the punch and die, will produce a part that holds close dimensional tolerances in relationship to the parts edges.
2. *Appearance*. Since the part is blanked in one operation, the finish edges of the part produces a uniform appearance as opposed to varying degrees of burnishing from multiple operations.
3. *Flatness*. Due to the even compression of the blanking process, the end result is a flat part that may retain a specific level of flatness for additional manufacturing operations.

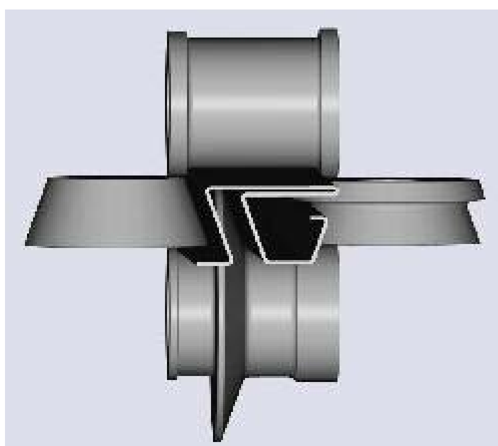
- **Broaching**: The process of removing material through the use of multiple cutting teeth, with each tooth cutting behind the other. A broaching die is often used to remove material from parts that are too thick for shaving.
- **Bulging**: A bulging die expands the closed end of tube through the use of two types of bulging dies. Similar to the way a chefs hat bulges out at the top from the cylindrical band around the chefs head.

1. **Bulging fluid dies**: Uses water or oil as a vehicle to expand the part.
2. **Bulging rubber dies**: Uses a rubber pad or block under pressure to move the wall of a workpiece.

- **Coining**: is similar to forming with the main difference being that a coining die may form completely different features on either face of the blank, these features being transferred from the face of the punch or die respectively. The coining die and punch flow the metal by squeezing the blank within a confined area, instead of bending the blank. For example: an Olympic medal that was formed from a coining die may have a flat surface on the back and a raised feature on the front. If the medal was formed (or embossed), the surface on the back would be the reverse image of the front.
- **Compound operations**: Compound dies perform multiple operations on the part. The compound operation is the act of implementing more than one operation during the press cycle.
- **Compound die**: A type of die that has the die block (matrix) mounted on a punch plate with perforators in the upper die with the inner punch mounted in the lower

die set. An inverted type of blanking die that punches upwards, leaving the part sitting on the lower punch (after being shed from the upper matrix on the press return stroke) instead of blanking the part through. A compound die allows the cutting of internal and external part features on a single press stroke.

- **Curling**: The curling operation is used to roll the material into a curved shape. A door hinge is an example of a part created by a curling die.
- **Cut off**: Cut off dies are used to cut off excess material from a finished end of a part or to cut off a predetermined length of material strip for additional operations.
- **Drawing**: The drawing operation is very similar to the forming operation except that the drawing operation undergoes severe plastic deformation and the material of the part extends around the sides. A metal cup with a detailed feature at the bottom is an example of the difference between formed and drawn. The bottom of the cup was formed while the sides were drawn.
- **Extruding**: Extruding is the act of severely deforming blanks of metal called slugs into finished parts such as an aluminum I-beam. Extrusion dies use extremely high pressure from the punch to squeeze the metal out into the desired form. The difference between cold forming and extrusion is extruded parts do not take shape of the punch.
- **Forming**: Forming dies bend the blank along a curved surface. An example of a part that has been formed would be the positive end(+) of a AA battery.
- **Cold forming (cold heading)**: Cold forming is similar to extruding in that it squeezes the blank material but cold forming uses the punch and the die to create the desired form, extruding does not.



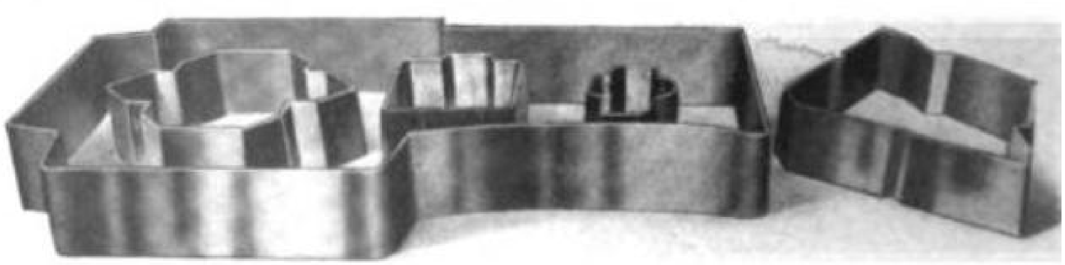
Roll Forming Stand

- **Roll forming**: a continuous bending operation in which sheet or strip metal is gradually formed in tandem sets of rollers until the desired cross-sectional configuration is obtained. Roll forming is ideal for producing parts with long lengths or in large quantities.
- **Horning**: A horning die provides an arbor or horn which the parts are place for secondary operations.

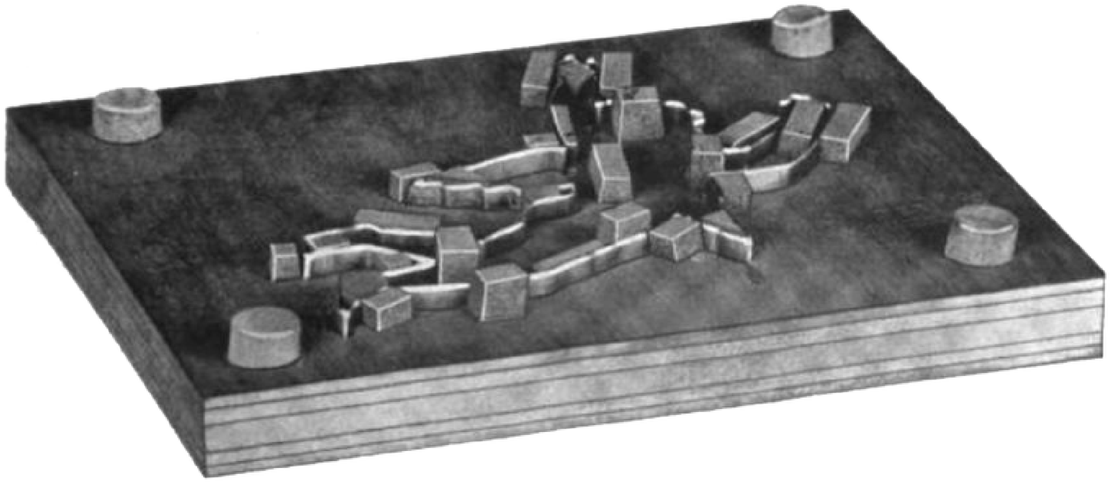
- **Hydroforming**: Forming of tubular part from simpler tubes with high water pressure.
- **Pancake die**: A Pancake die is a simple type of manufacturing die that performs blanking and/or piercing. While many dies perform complex procedures simultaneously, a pancake die may only perform one simple procedure with the finished product being removed by hand.
- **Piercing**: The **piercing** operation is used to pierce holes in stampings.
- **Progressive die**: Progressive dies provide different stations for operations to be performed. A common practice is to move the material through the die so it is progressively modified at each station until the final operation ejects a finished part.
- **Shaving**: The shaving operation removes a small amount of material from the edges of the part to improve the edges finish or part accuracy. (Compare to **Trimming**).
- **Side cam die**: Side cams transform vertical motion from the press ram into horizontal or angular motion.
- **Sub press operation**: Sub-press dies blank and/or form small watch, clock, and instrument parts.
- **Swaging**: Swaging (necking) is the process of "necking down" a feature on a part. Swaging is the opposite of bulging as it reduces the size of the part. The end of a shell casing that captures the bullet is an example of swaging.
- **Trimming**: Trimming dies cut away excess or unwanted irregular features from a part, they are usually the last operation performed.

Steel-rule die

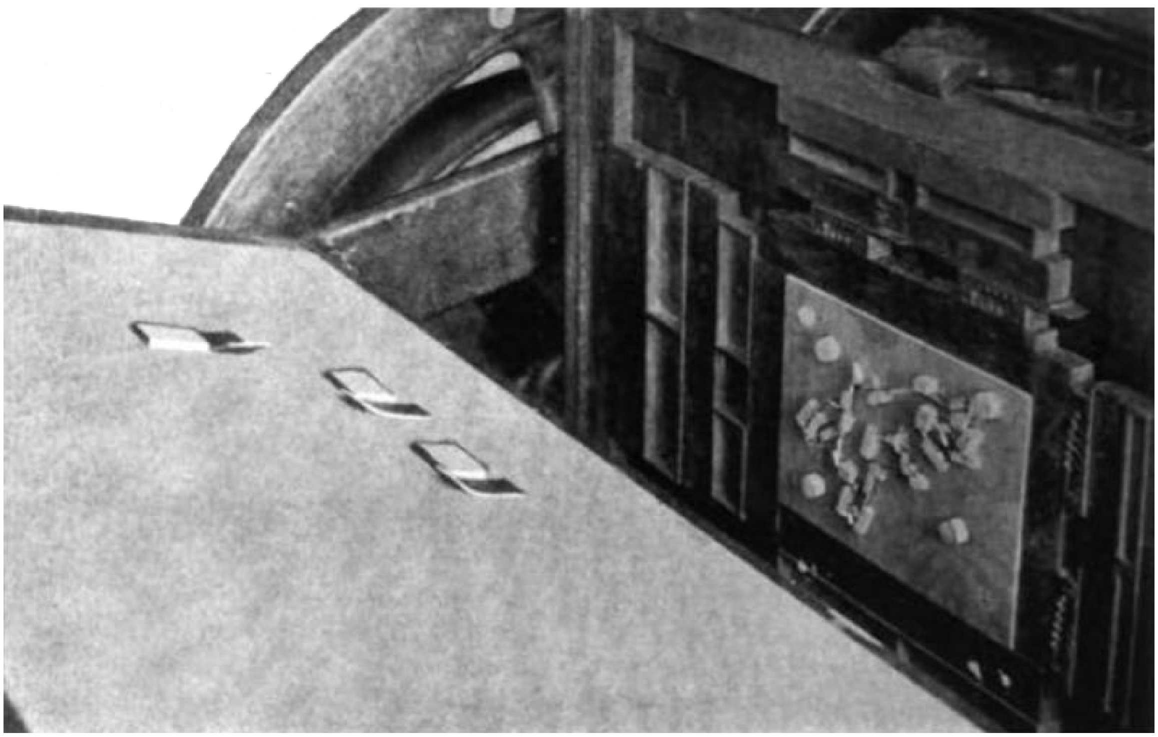
Steel-rule dies, also known as *cookie-cutter* dies, are used to cut sheet metal and softer webs, such as plastics, wood, cork, felt, fabrics, and cardboard. The cutting surface of the die is the edge of hardened steel strips, known as *steel rule*. These steel rules are usually located using saw-cut grooves in plywood. The mating die can be a flat pieces of hardwood or steel, a male shape that matches the workpiece profile, or it can have a matching groove that allows the rule to nest into. Rubber strips are wedged in with the steel rule to act as the stripper plate; the rubber compresses on the down-stroke and on the up-stroke it pushes the workpiece out of the die. The main advantage of steel-rule dies is the low cost to make them, as compared to solid dies; however, they are not as robust as solid dies, so they usually only used for short production runs.



A steel-rule die



A steel-rule die



Steel-rule die in a press

Rotary die

In the broadest sense, a *rotary die* is a circular shaped die that may be used in any manufacturing field. However, it most commonly refers to circular shaped dies used to process soft webs, such as paper and cardboard. Two dies are used, one has cutting and creasing rules, while the other acts as the anvil. Rotary dies are faster than flat dies, but not as accurate.

The term also refers to dies used in the roll forming process.

Wire pulling

Wire-making dies have a hole through the middle of them. A wire or rod of steel, copper, other metals, or alloy enters into one side and is lubricated and reduced in size. The leading tip of the wire is usually pointed in the process. The tip of the wire is then guided into the die and rolled onto a block on the opposite side. The block provides the power to pull the wire through the die.

The die is divided into several different sections. First is an entrance angle that guides the wire into the die. Next is the approach angle, which brings the wire to the nib, which facilitates the reduction. Next is the bearing and the back relief. Lubrication is added at the entrance angle. The lube can be in powdered soap form. If the lubricant is soap, the friction of the drawing of wire heats the soap to liquid form and coats the wire. The wire should never actually come in contact with the die. A thin coat of lubricant should prevent the metal to metal contact.

For pulling a substantial rod down to a fine wire a series of several dies is used to obtain progressive reduction of diameter in stages.

Standard wire gauges used to refer to the number of dies through which the wire had been pulled. Thus, a higher-numbered wire gauge meant a thinner wire. Typical telephone wires were 22-gauge, while main power cables might be 3- or 4-gauge.

Chapter 5

Anvil

Anvil

A blacksmith working iron with a hammer and anvil

An **anvil** is a basic tool. In the simplest terms it is a block with a hard surface on which another object is struck. The inertia of the anvil allows the energy of the striking tool to be transferred to the work piece. In most cases the anvil is used as a forging tool. Before the advent of modern welding technology, it was a primary tool of metal workers.

The great majority of modern anvils are made from steel though other types exist.

Because anvils are very ancient tools and were at one time very commonplace, they have acquired symbolic meaning beyond their use as utilitarian objects.

History

An anvil at the medieval construction site of Guédelon in Treigny, France.

In the past anvils were first made of stone as a lithic stone tool, then bronze, and later wrought iron. As steel became more readily available, anvils were faced with it. This was done to give the anvil a hard face and to stop the anvil from deforming from impact. Many regional styles of anvils evolved through time from the simple block that was first used by smiths. The majority of anvils found today in the US are based on the London pattern anvil of the mid-19th century.

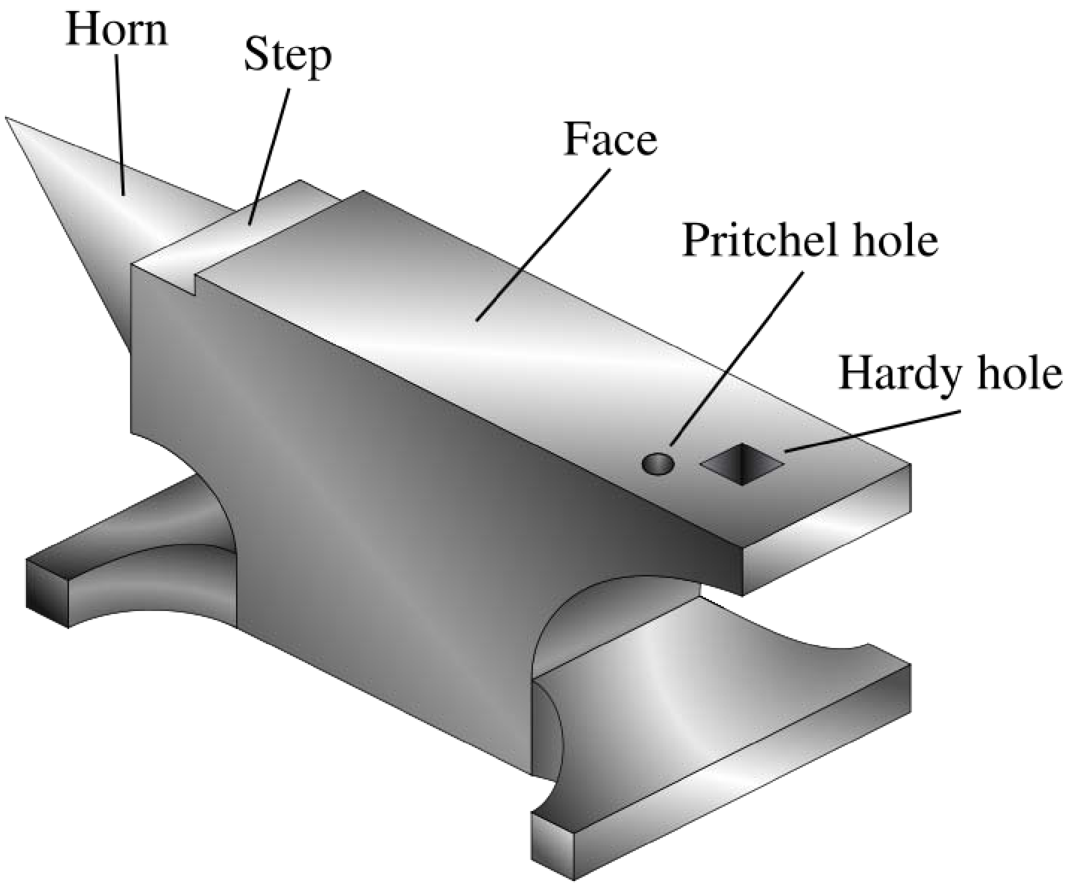
The wrought iron steel faced anvil was produced up until the early 20th century. Through the 19th and very early 20th centuries, this method of construction evolved to produce extremely high quality anvils. The basic process involved forge welding billets of wrought iron together to produce the desired shape. The sequence and location of the forge welds varied between different anvil makers and the kind of anvil being made. At the same time cast iron anvils with steel faces were being made in the United States. At the dawn of the 20th century solid cast steel anvils began to be produced, as well as two piece forged anvils made from closed die forgings. Modern anvils are generally made entirely from steel.

The concept of an anvil may predate humanity. Chimpanzees have been observed using large sticks as hammers to crack nuts, using logs as anvils.

There are many references to anvils in ancient Greek and Egyptian writings, including Homer's works. They have been found at the Calico Early Man Site in North America.

Anvils have since lost their former commonness, along with the smiths who used them. Mechanized production has made cheap and abundant manufactured goods readily available. The one-off hand-made products of the blacksmith are less economically viable in the modern world, while in the past they were an absolute necessity. However, anvils are still used by blacksmiths and metal workers of all kinds in producing custom work. They are also essential to the work done by farriers.

Structure



A single-horn anvil

The primary work surface of the anvil is known as the face. It is generally made of hardened steel and should be flat and smooth with rounded edges for most work. Any marks on the face will be transferred to the work. Also, sharp edges tend to cut into the metal being worked and may cause cracks to form in the workpiece. The face is hardened and tempered to resist the blows of the smith's hammer so the anvil face does not deform under repeated use. A hard anvil face also reduces the amount of force lost in each hammer blow. Hammers should never directly strike the anvil face, as they may damage it.

The horn of the anvil is a conical projection used to form various round shapes, and is generally unhardened steel or iron. The horn is used mostly in bending operations. It also is used by some smiths as an aid in drawing out stock, "making it longer and thinner". Some anvils, mainly European, are made with two horns, one square and one round. Also, some anvils are made with side horns or clips for specialized work.

The *step* or *pad*, commonly referred to as the *table* of the anvil, is used for cutting; its purpose is to prevent damaging the face by conducting such operations there, although most professional smiths shun this practice, as it can damage the anvil.

The *hardy hole* is a square hole into which specialized forming and cutting tools, called hardy tools, are placed. It is also used in punching and bending operations.

The *pritchel hole* is a small round hole that is present on most modern anvils. Some anvils have more than one. It is used mostly for punching. At times, smiths will fit a second tool to this hole to allow the smith more flexibility when using more than one anvil tool.

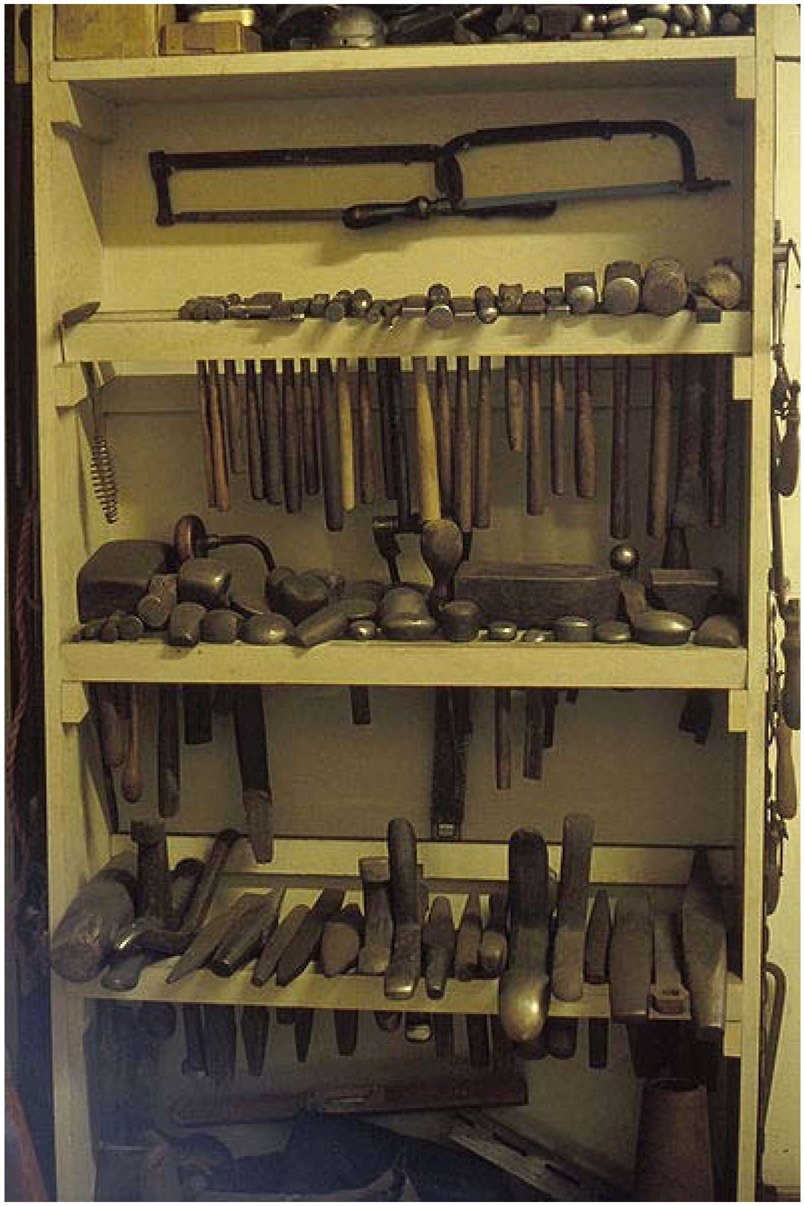
Placement

An anvil needs to be placed upon a sturdy base made from an impact resistant material. It requires being fastened firmly to the base so it will not move when struck with a hammer. A loose anvil is extremely unsafe, as it can fall off the base. Common methods of attaching an anvil are spikes, chains, steel or iron straps, clips, bolts where there are holes provided, and cables. A smith would use whatever was at hand, as long as it held the anvil firmly in place. It is a poor idea to weld an anvil to a base or drill holes into it, as many anvils are antiques; when properly used and cared for, they can last generations. The anvil should be placed as near to the forge as is convenient, generally no more than one step from the forge to prevent heat loss in the work piece.

The most common base traditionally was a hard wood log or large timber buried several feet into the floor of the forge shop floor. This was done to make the anvil immobile when heavy forging and bending were done upon the anvil. In the industrial era cast iron bases became available. They had the advantage of adding additional weight to the anvil, making it more stable while making the anvil movable. These bases are highly sought after by collectors today. When concrete became widely available, there was a trend to make steel reinforced anvil bases by some smiths, though this practice has largely been abandoned. In more modern times many anvils have been placed upon bases fabricated from steel, oftentimes a short thick section of large I-Beam. In addition, bases have been made from dimensional lumber bolted together to form a large block or steel drums full of oil-saturated sand to provide a damping effect.

Types

Anvil of a farrier



A silversmith's anvils and hammers, 1981

There are many designs for anvils, which are often tailored for a specific purpose or to meet the needs of a particular smith. Such designs have originated in diverse geographic locations.

The common blacksmith's anvil is made of either forged or cast steel, tool steel, or wrought iron (cast iron anvils are generally shunned, as they are too brittle for repeated use, and do not return the energy of a hammer blow like steel). Historically, some anvils have been made with a smooth top working face of hardened steel welded to a cast iron or wrought iron body, though this manufacturing method is no longer in use. It has at one end a projecting conical *bick* (*beak*, *horn*) used for hammering curved work pieces. The other end is typically called the heel. Occasionally the other end is also provided with a bick, partly rectangular in section. Most anvils made since the late 18th century also have a hardy hole and a pritchel hole where various tools, such as the anvil-cutter or hot chisel, can be inserted and held by the anvil. Some anvils have several hardy and pritchel holes, to accommodate a wider variety of hardy tools and pritchels. An anvil may also have a softer *pad* for chisel work.

An anvil for a power hammer is usually supported on a massive anvil block, sometimes weighing over 800 tons for a 12-ton hammer; this again rests on a strong foundation of timber and masonry or concrete.

An anvil may have a marking indicating its weight, manufacturer, or place of origin. American-made anvils were often marked in pounds. European anvils are sometimes marked in kilograms. English anvils were often marked in hundredweight, the marking consisting of three numbers, indicating hundredweight, quarter hundredweight and pounds. For example, a 3-1-5, if such an anvil existed, would be 3x112 lb + 1x28 lb + 5 lb = 369 lb ≈ 168 kg.

Cheap anvils made from inferior steel or cast iron, which are unsuitable for serious use, have been derisively referred to as "ASOs", or "Anvil Shaped Objects". Some amateur smiths have used a piece of railroad track as a makeshift anvil.

Top quality modern anvils are made of cast or forged tool steel and are heat treated for optimum hardness and toughness.

A metalworking vise may have a small anvil integrated in its design.

Anvils in art and entertainment

Historically

Anvil firing is the practice of firing an anvil into the air using gunpowder. It has been popular in California, the eastern United States and the southern United States, much like how fireworks are used today. There is a growing interest in re-enacting this "ancient tradition" in the USA, which has now spread to England.

The African Methodist Episcopal Church (AME) has the anvil in their logo. The AME's first services were held in a blacksmith shop.

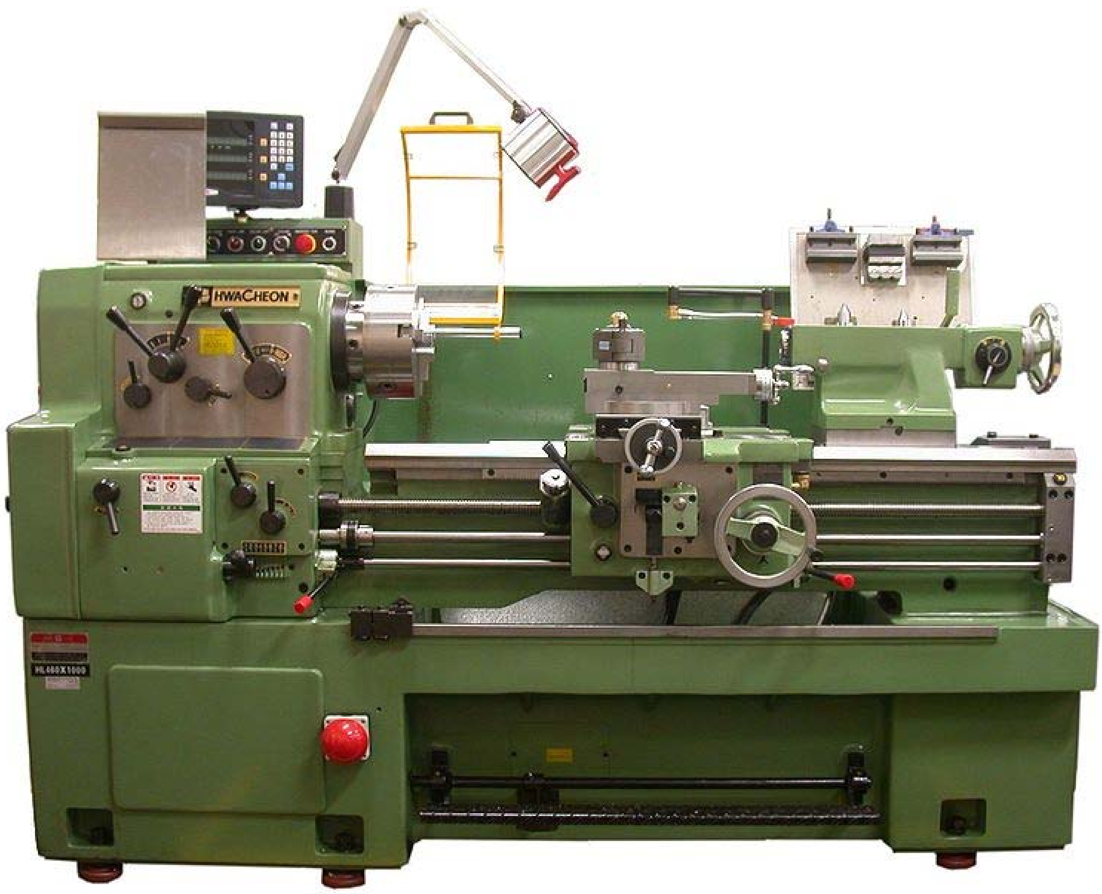
Television and film

A typical metalworker's anvil, with horn at one end and flat face at the other, is a standard prop for cartoon gags, as the epitome of a heavy and clumsy object that is perfect for dropping onto a villain. This visual metaphor is common, for example, in Warner Brothers' *Looney Tunes* and *Merrie Melodies* shorts, such as those with Wile E. Coyote and Road Runner. *Animaniacs* made frequent gags on the topic throughout its run, even having a kingdom named Anvilania, whose sole national product is anvils.

Anvils and ASO's were mentioned and shown in the *Mythbusters* episode on trying to see if hammers would shatter if made brittle enough. The Mythbusters spoke of the distinction between anvils and anvil shaped objects.

Chapter 6

Lathe (Metal)



Center lathe with DRO and chuck guard. Size is 460 mm swing x 1000 mm between centers

A **metal lathe** or **metalworking lathe** is a large class of lathes designed for precisely machining relatively hard materials. They were originally designed to machine metals; however, with the advent of plastics and other materials, and with their inherent versatility, they are used in a wide range of applications, and a broad range of materials.

In machining jargon, where the larger context is already understood, they are usually simply called *lathes*, or else referred to by more-specific subtype names (*toolroom lathe*, *turret lathe*, etc.). These rigid machine tools remove material from a rotating workpiece via the (typically linear) movements of various cutting tools, such as tool bits and drill bits.

Construction

The design of lathes can vary greatly depending on the intended application; however, basic features are common to most types. These machines consist of (at the least) a headstock, bed, carriage, and tailstock. Better machines are solidly constructed with broad bearing surfaces (*slides* or *ways*) for stability, and manufactured with great precision. This helps ensure the components manufactured on the machines can meet the required tolerances and repeatability.

Headstock

Headstock with legend, numbers and text within the description refer to those in the image

The **headstock (H1)** houses the main spindle **(H4)**, speed change mechanism **(H2,H3)**, and change gears **(H10)**. The headstock is required to be made as robust as possible due to the cutting forces involved, which can distort a lightly built housing, and induce harmonic vibrations that will transfer through to the workpiece, reducing the quality of the finished workpiece.

The main spindle is generally hollow to allow long bars to extend through to the work area. This reduces preparation and waste of material. The spindle runs in precision bearings and is fitted with some means of attaching workholding devices such as chucks or faceplates. This end of the spindle usually also has an included taper, frequently a Morse taper, to allow the insertion of tapers and centers. On older machines the spindle was directly driven by a flat belt pulley with lower speeds available by manipulating the bull gear. Later machines use a gear box driven by a dedicated electric motor. A fully geared head allows the operator to select speeds entirely through the gearbox.

Bed

The **bed** is a robust base that connects to the headstock and permits the carriage and tailstock to be aligned parallel with the axis of the spindle. This is facilitated by hardened and ground **ways** which restrain the carriage and tailstock in a set track. The carriage travels by means of a rack and pinion system, leadscrew of accurate pitch, or feedscrew.

Types of beds include inverted "V" beds, flat beds, and combination "V" and flat beds. "V" and combination beds are used for precision and light duty work, while flat beds are used for heavy duty work.

When a lathe is installed, the first step is to *level* it, which refers to making sure the bed is not twisted or bowed. There is no need to make the machine exactly horizontal, but it must be entirely untwisted to achieve accurate cutting geometry. A precision level is a useful tool for identifying and removing any twist. It is advisable also to use such a level along the bed to detect bending, in the case of a lathe with more than four mounting points. In both instances the level is used as a comparator rather than an absolute reference.

Feed and lead screws

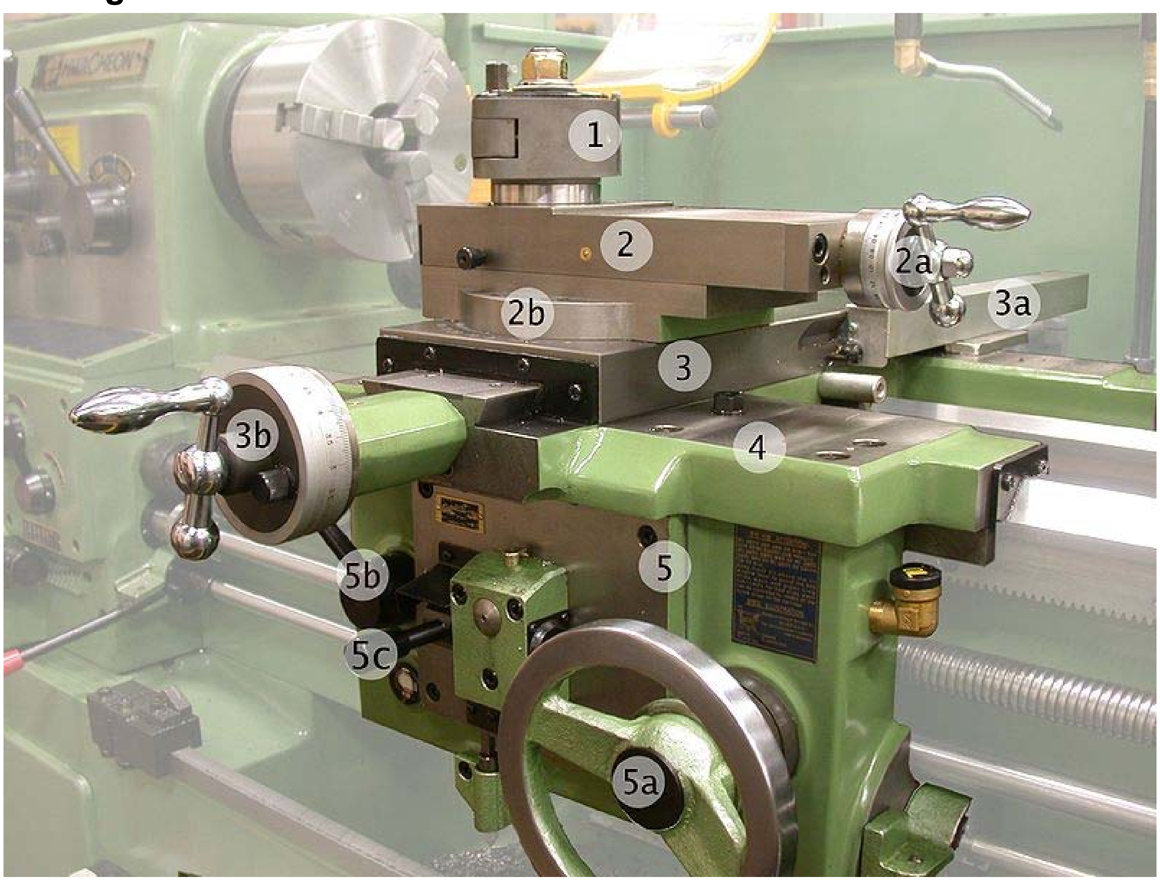
The **feedscrew (H8)** is a long driveshaft that allows a series of gears to drive the carriage mechanisms. These gears are located in the **apron** of the carriage. Both the feedscrew and **leadscrew (H7)** are driven by either the **change gears** (on the quadrant) or an intermediate gearbox known as a **quick change gearbox (H6)** or Norton gearbox. These intermediate gears allow the correct ratio and direction to be set for cutting threads or worm gears. Tumbler gears (operated by **H5**) are provided between the spindle and gear train along with a **quadrant** plate that enables a gear train of the correct ratio and direction to be introduced. This provides a constant relationship between the number of turns the spindle makes, to the number of turns the leadscrew makes. This ratio allows screwthreads to be cut on the workpiece without the aid of a die.

Some lathes have only one leadscrew that serves all carriage-moving purposes. For screw cutting, a **half nut** is engaged to be driven by the leadscrew's thread; and for general power feed, a key engages with a keyway cut into the leadscrew to drive a pinion along a rack that is mounted along the lathe bed.

The leadscrew will be manufactured to either imperial or metric standards and will require a conversion ratio to be introduced to create thread forms from a different family. To accurately convert from one thread form to the other requires a 127-tooth gear, or on lathes not large enough to mount one, an approximation may be used. Multiples of 3 and 7 giving a ratio of 63:1 can be used to cut fairly loose threads. This conversion ratio is often built into the *quick change gearboxes*.

The precise ratio required to convert a lathe with an Imperial (inch) leadscrew to metric (millimeter) threading is 100 / 127 = 0.7874... . The best approximation with the fewest total teeth is very often 37 / 47 = 0.7872... . This transposition gives a constant -0.020 percent error over all customary and model-maker's metric pitches (0.25, 0.30, 0.35, 0.40, 0.45, 0.50, 0.60, 0.70, 0.75, 0.80, 1.00, 1.25, 1.50, 1.75, 2.00, 2.50, 3.00, 3.50, 4.00, 4.50, 5.00, 5.50 and 6.00mm).

Carriage



Carriage with legend, numbers and text within the description refer to those in the image

In its simplest form the **carriage** holds the tool bit and moves it longitudinally (turning) or perpendicularly (facing) under the control of the operator. The operator moves the carriage manually via the *handwheel* **(5a)** or automatically by engaging the feed shaft with the carriage feed mechanism **(5c)**. This provides some relief for the operator as the movement of the carriage becomes power assisted. The handwheels **(2a, 3b, 5a)** on the carriage and its related slides are usually calibrated, both for ease of use and to assist in making reproducible cuts. The carriage typically comprises a top casting, known as the **saddle (4)**, and a side casting, known as the **apron (5)**.

Cross-slide

The **cross-slide (3)** rides on the carriage and has a feedscrew that travels perpendicular to the main spindle axis. This permits *facing* operations to be performed, and the depth of cut to be adjusted. This feedscrew can be engaged, through a gear train, to the feed shaft (mentioned previously) to provide automated 'power feed' movement to the cross-slide. On most lathes, only one direction can be engaged at a time as an interlock mechanism will shut out the second gear train.

Compound rest

The **compound rest** (or **top slide**) **(2)** is usually where the tool post is mounted. It provides a smaller amount of movement (less than the cross-slide) along its axis via another feedscrew. The compound rest axis can be adjusted independently of the carriage or cross-slide. It is used for turning tapers, to control depth of cut when screwcutting or precision facing, or to obtain finer feeds (under manual control) than the feed shaft permits. Usually, the compound rest has a protractor marked in its base **(2b)**, enabling the operator to adjust its axis to precise angles.

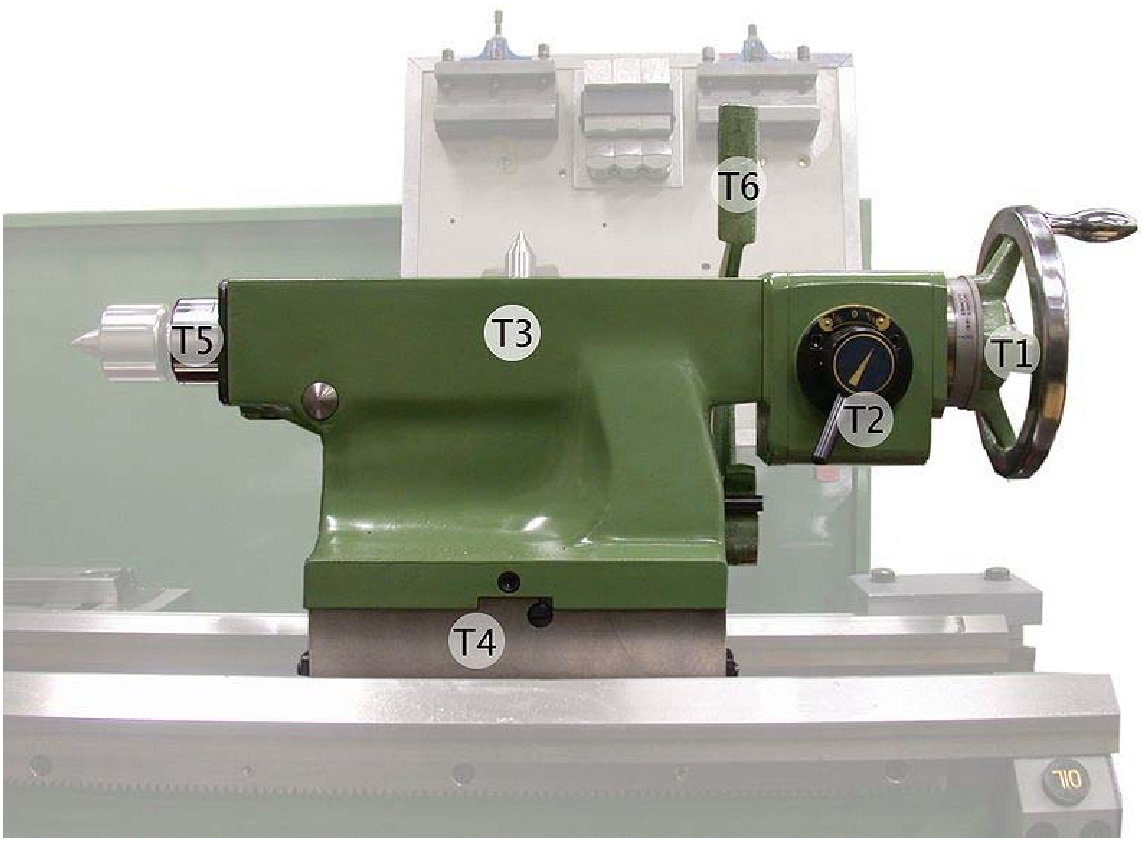
The slide rest can be traced to the fifteenth century. In 1718 the tool-supporting slide rest with a set of gears was introduced by a Russian inventor Andrey Nartov and had limited usage in the Russian industry. In the eighteenth century the slide rest was also used on French ornamental turning lathes. The suite of gun boring mills at the Royal Arsenal, Woolwich, in the 1780s by the Verbruggan family also had slide rests. The story has long circulated that Henry Maudslay invented it, but he did not (and never claimed so). The legend that Maudslay invented the slide rest originated with James Nasmyth, who wrote ambiguously about it in his *Remarks on the Introduction of the Slide Principle*, 1841; later writers misunderstood, and propagated the error. However, Maudslay did help to disseminate the idea widely. It is highly probable that he saw it when he was working at the Arsenal as a boy. In 1794, whilst he was working for Joseph Bramah, he made one, and when he had his own workshop used it extensively in the lathes he made and sold there. Coupled with the network of engineers he trained, this ensured the slide rest became widely known and copied by other lathe makers, and so diffused throughout British engineering workshops. A practical and versatile screw-cutting lathe incorporating the trio of leadscrew, change gears, and slide rest was Maudslay's most important achievement.

The first fully documented, all-metal slide rest lathe was invented by Jacques de Vaucanson around 1751. It was described in the Encyclopédie a long time before Maudslay invented and perfected his version. It is likely that Maudslay was not aware of Vaucanson's work, since his first versions of the slide rest had many errors that were not present in the Vaucanson lathe.

Toolpost

The tool bit is mounted in the **toolpost (1)** which may be of the American *lantern* style, traditional four-sided square style, or a quick-change style such as the multifix arrangement pictured. The advantage of a quick change set-up is to allow an unlimited number of tools to be used (up to the number of holders available) rather than being limited to one tool with the lantern style, or to four tools with the four-sided type. Interchangeable tool holders allow all tools to be preset to a *center* height that does not change, even if the holder is removed from the machine.

Tailstock



Tailstock with legend, numbers and text within the description refer to those in the image

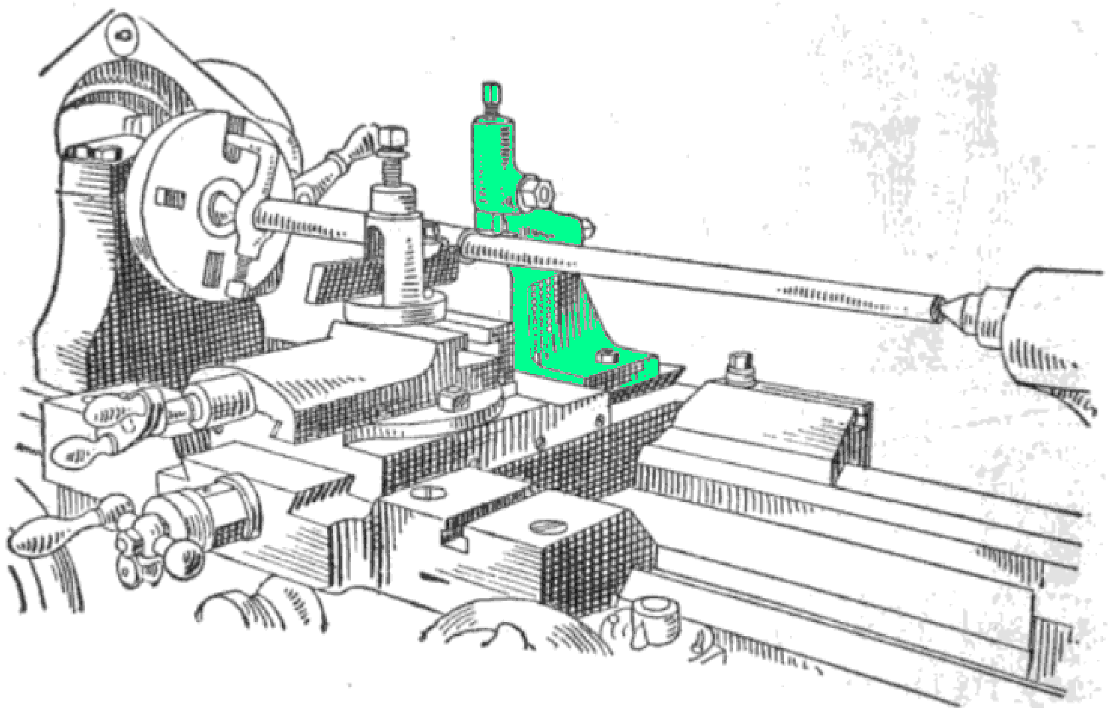
The **tailstock** is a toolholder directly mounted on the spindle axis, opposite the headstock. The spindle **(T5)** does not rotate but does travel longitudinally under the action of a leadscrew and handwheel **(T1)**. The spindle includes a taper to hold drill bits, centers and other tooling. The tailstock can be positioned along the bed and clamped **(T6)** in position as required. There is also provision to offset the tailstock **(T4)** from the spindles axis, this is useful for turning small tapers.

The image shows a reduction gear box **(T2)** between the handwheel and spindle, this is a feature found only in the larger center lathes, where large drills may necessitate the extra leverage.

Steady and follower rests

A steady rest

Workpieces often need to be supported more than the chuck and/or centers can support them, because cutting metal produces tremendous forces that tend to vibrate or even bend the workpiece. This extra support can be provided by a **steady rest** (also called a **steady**, a **fixed steady**, a **center rest**, or sometimes, confusingly, a **center**). It stands stationary from a rigid mounting on the bed, and it supports the workpiece at the rest's center, typically with three contact points 120° apart. A **follower rest** (also called a **follower** or a **travelling steady**) is similar, but it is mounted to the carriage rather than the bed, which means that as the tool bit moves, the follower rest "follows along" (because they are both rigidly connected to the same moving carriage). Follower rests can provide support that directly counteracts the springing force of the tool bit, right at the region of the workpiece being cut at any moment. In this respect they are analogous to a box tool.

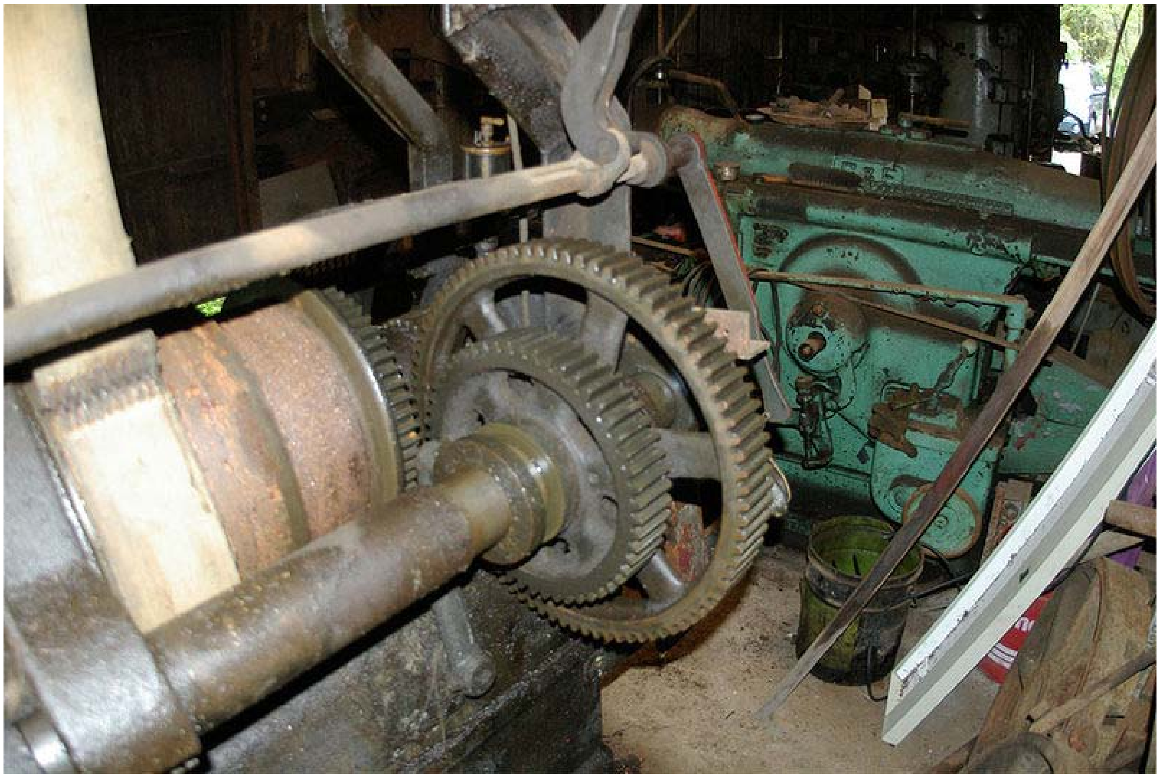


A follower rest

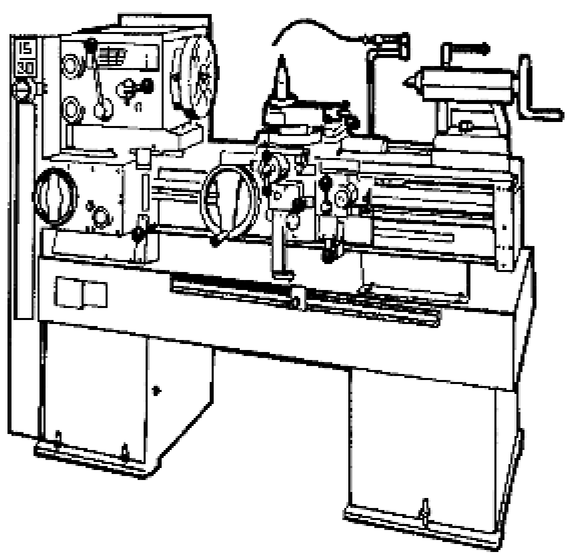
Types of metal lathes

There are many variants of lathes within the metalworking field. Some variations are not all that obvious, and others are more a niche area. For example, a **centering lathe** is a dual head machine where the work remains fixed and the heads move towards the workpiece and machine a center drill hole into each end. The resulting workpiece may then be used "between centers" in another operation. The usage of the term **metal lathe** may also be considered somewhat outdated these days, plastics and other composite materials are in wide use and with appropriate modifications, the same principles and techniques may be applied to their machining as that used for metal.

Center lathe / engine lathe / bench lathe



Two-speed back gears in a cone-head lathe.



A typical center lathe.

The terms **center lathe**, **engine lathe**, and **bench lathe** all refer to a basic type of lathe that may be considered the archetypical class of metalworking lathe most often used by the general machinist or machining hobbyist. The name *bench lathe* implies a version of this class small enough to be mounted on a workbench (but still full-featured, and larger than mini-lathes or micro-lathes). The construction of a center lathe is detailed above, but depending on the year of manufacture, size, price range, or desired features, even these lathes can vary widely between models.

Engine lathe is the name applied to a traditional late-19th-century or 20th-century lathe with automatic feed to the cutting tool, as opposed to early lathes which were used with hand-held tools, or lathes with manual feed only. The usage of "engine" here is in the mechanical-device sense, not the prime-mover sense, as in the steam engines which were the standard industrial power source for many years. The works would have one large steam engine which would provide power to all the machines via a line shaft system of belts. Therefore early engine lathes were generally 'cone heads', in that the spindle usually had attached to it a multi-step pulley called a *cone pulley* designed to accept a flat belt. Different spindle speeds could be obtained by moving the flat belt to different steps on the cone pulley. Cone-head lathes usually had a countershaft (layshaft) on the back side of the cone which could be engaged to provide a lower set of speeds than was obtainable by direct belt drive. These gears were called *back gears*. Larger lathes sometimes had two-speed back gears which could be shifted to provide a still lower set of speeds.

When electric motors started to become common in the early 20th century, many cone-head lathes were converted to electric power. At the same time the state of the art in gear and bearing practice was advancing to the point that manufacturers began to make fully geared headstocks, using gearboxes analogous to automobile transmissions to obtain various spindle speeds and feed rates while transmitting the higher amounts of power needed to take full advantage of high speed steel tools.

The inexpensive availability of electronics has again changed the way speed control may be applied by allowing continuously variable motor speed from the maximum down to almost zero RPM. (This had been tried in the late 19th century but was not found satisfactory at the time. Subsequent improvements have made it viable again.)

Toolroom lathe

A toolroom lathe is a lathe optimized for toolroom work. It is essentially just a top-of-the-line center lathe, with all of the best optional features that may be omitted from less expensive models, such as a collet closer, taper attachment, and others. There has also been an implication over the years of selective assembly and extra fitting, with every care taken in the building of a toolroom model to make it the smoothest-running, most-accurate version of the machine that can be built. However, within one brand, the quality difference between a regular model and its corresponding toolroom model depends on the builder and in some cases has been partly marketing psychology. For name-brand machine tool builders who made only high-quality tools, there wasn't necessarily any lack of quality in the base-model product for the "luxury model" to improve upon. In other cases, especially when comparing different brands, the quality differential between (1) an entry-level center lathe built to compete on price, and (2) a toolroom lathe meant to compete only on quality and not on price, can be objectively demonstrated by measuring

TIR, vibration, etc. In any case, because of their fully-ticked-off option list and (real or implied) higher quality, toolroom lathes are more expensive than entry-level center lathes.

Turret lathe and capstan lathe

Turret lathes and capstan lathes are members of a class of lathes that are used for repetitive production of duplicate parts (which by the nature of their cutting process are usually interchangeable). It evolved from earlier lathes with the addition of the *turret*, which is an indexable toolholder that allows multiple cutting operations to be performed, each with a different cutting tool, in easy, rapid succession, with no need for the operator to perform setup tasks in between (such as installing or uninstalling tools) nor to control the toolpath. (The latter is due to the toolpath's being controlled by the machine, either in jig-like fashion [via the mechanical limits placed on it by the turret's slide and stops] or via IT-directed servomechanisms [on computer numerical controlled (CNC) lathes].)

There is a tremendous variety of turret lathe and capstan lathe designs, reflecting the variety of work that they do.

Gang-tool lathe

A gang-tool lathe is one that has a row of tools set up on its cross-slide, which is long and flat and is similar to a milling machine table. The idea is essentially the same as with turret lathes: to set up multiple tools and then easily index between them for each part-cutting cycle. Instead of being rotary like a turret, the indexable tool group is linear.

Multispindle lathe

Multispindle lathes have more than one spindle and automated control (whether via cams or CNC). They are production machines specializing in high-volume production. The smaller types are usually called **screw machines**, while the larger variants are usually called **automatic chucking machines**, **automatic chuckers**, or simply **chuckers**. Screw machines usually work from bar stock, while chuckers automatically chuck up individual blanks from a magazine. Typical minimum profitable production lot size on a screw machine is in the thousands of parts due to the large setup time. Once set up, a screw machine can rapidly and efficiently produce thousands of parts on a continuous basis with high accuracy, low cycle time, and very little human intervention. (The latter two points drive down the unit cost per interchangeable part much lower than could be achieved without these machines.)

Rotary transfer machines might also be included under the category of multispindle lathes, although they defy traditional classification. They are large, expensive, modular machine tools with many CNC axes that combine the capabilities of lathes, milling machines, and pallet changers.

CNC lathe / CNC turning center

CNC lathe with milling capabilities

An example turned vase and view of the tool turret

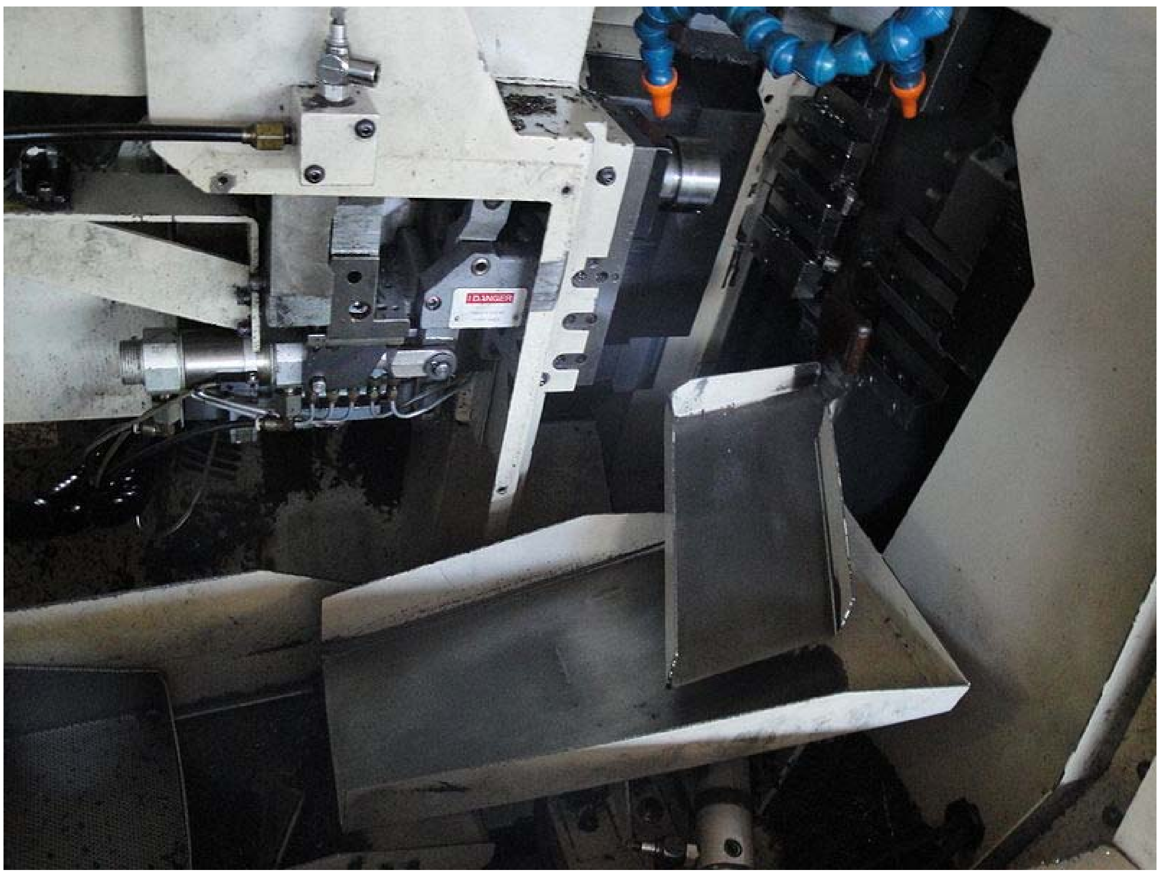
CNC lathes are rapidly replacing the older production lathes (multispindle, etc.) due to their ease of setting and operation. They are designed to use modern carbide tooling and fully use modern processes. The part may be designed and the toolpaths programmed by the CAD/CAM process, and the resulting file uploaded to the machine, and once set and trialled the machine will continue to turn out parts under the occasional supervision of an operator.

The machine is controlled electronically via a computer menu style interface, the program may be modified and displayed at the machine, along with a simulated view of the process. The setter/operator needs a high level of skill to perform the process, however the knowledge base is broader compared to the older production machines where intimate knowledge of each machine was considered essential. These machines are often set and operated by the same person, where the operator will supervise a small number of machines (cell).

The design of a CNC lathe has evolved yet again however the basic principles and parts are still recognizable, the turret holds the tools and indexes them as needed. The machines are often totally enclosed, due in large part to Occupational health and safety (OH&S) issues.

With the advent of cheap computers, free operating systems such as Linux, and open source CNC software, the entry price of CNC machines has plummeted.

Swiss-style lathe / Swiss turning center



A view inside the enclosure of a CNC Swiss-style lathe/screw machine.

For work requiring extreme accuracy (sometimes holding tolerances as small as a few tenths of a thousandth of an inch), a Swiss-style lathe is often used. A Swiss-style lathe holds the workpiece with both a collet and a guide bushing. The collet sits behind the guide bushing, and the tools sit in front of the guide bushing, holding stationary on the Z axis. To cut lengthwise along the part, the tools will move in and the material itself will move back and forth along the Z axis. This allows all the work to be done on the material near the guide bushing where it is more rigid, making them ideal for working on slender workpieces as the part is held firmly with little chance of deflection or vibration occurring.

This style of lathe is also available with CNC controllers to further increase its versatility.

Most CNC Swiss-style lathes today use two spindles. The main spindle is used with the guide bushing for the main machining operations. The secondary spindle is located behind the part, aligned on the Z axis. In simple operation it picks up the part as it is cut off (aka parted off) and accepts it for second operations, then ejects it into a bin, eliminating the need to have an operator manually change each part, as is often the case with standard CNC turning centers. This makes them very efficient, as these machines are capable of fast cycle times, producing simple parts in one cycle (i.e. no need for a second machine to finish the part with second operations), in as little as 10–15 seconds. This makes them ideal for large production runs of small-diameter parts.

Additionally, as many Swiss lathes incorporate a secondary spindle, or 'sub-spindle', they also incorporate 'live tooling'. Live tools are rotary cutting tools that are powered by a small motor independently of the spindle motor(s). Live tools increase the intricacy of components that can be manufactured by the Swiss lathe. For instance, automatically producing a part with a hole drilled perpendicular to the main axis (the axis of rotation of the spindles) is very economical with live tooling, and similarly uneconomical if done as a 'secondary operation' after machining by the Swiss lathe is complete. A 'Secondary operation' is a machining operation requiring a partially completed part to be secured in a second machine to complete the manufacturing process. Generally, advanced CAD/CAM software uses live tools in addition to the main spindles so that most parts that can be drawn by a CAD system can actually be manufactured by the machines that the CAD/CAM software support.

Combination lathe / 3-in-1 machine

A **combination lathe**, often known as a **3-in-1 machine**, introduces drilling or milling operations into the design of the lathe. These machines have a milling column rising up above the lathe bed, and they utilize the carriage and topslide as the X and Y axes for the milling column. The *3-in-1* name comes from the idea of having a lathe, milling machine, and drill press all in one affordable machine tool. These are exclusive to the hobbyist and MRO markets, as they inevitably involve compromises in size, features, rigidity, and precision in order to remain affordable. Nevertheless, they meet the demand of their niche quite well, and are capable of high accuracy given enough time and skill. They may be found in smaller, non-machine-oriented businesses where the occasional small part must be machined, especially where the exacting tolerances of expensive toolroom machines, besides being unaffordable, would be overkill for the application anyway from an engineering perspective.

Mini-lathe and micro-lathe

Mini-lathes and micro-lathes are miniature versions of a general-purpose center lathe (engine lathe). They typically have swings in the range of 3" to 7" (70 mm to 170 mm) diameter (in other words, 1.5" to 3.5" (30 mm to 80 mm) radius). They are small and affordable lathes for the home workshop or MRO shop. The same advantages and disadvantages apply to these machines as explained earlier regarding 3-in-1 machines.

As found elsewhere in English-language orthography, there is variation in the styling of the prefixes in these machines' names. They are alternately styled as **mini lathe, minilathe,** and **mini-lathe** and as **micro lathe, microlathe,** and **micro-lathe**.

Wheel lathe

A lathe for turning the wheels of railway locomotives and rolling stock

Brake lathe

A lathe specialized for the task of resurfacing brake drums and discs in automotive or truck garages.

Chapter 7

Parts Washer

A "lay-down door" and "roll-out basket" parts washer

Industrial parts washer with "swing-out" turntable

A **parts washer** is a piece of equipment used to remove contaminants or debris, such as dirt, grime, carbon, oil, grease, metal chips, cutting fluids, mold release agents, ink, paint, and corrosion from workpieces. They may be manually operated or full automatic.

A parts washer is distinctly different from a pressure washer in that parts washers typically cleans parts in an enclosed cabinet, while pressure washers typically have a single spray jet mounted at the end of a manually-operated wand.

History

Parts washers were originally developed for use in automotive transmission and engine repair shops as a way to improve the function of simple soak tanks. Soak tanks are vats filled with a mixture of water and detergent, which take hours to "soften" the built-up road grime, fluids, tars and oils enough to be manually rinsed off prior to disassembly and repair.

Since the early 1970s, many methods of parts cleaning have been developed with improved levels of safety and lessened environmental impact. Stoddard solvent, gasoline, diesel fuel, and kerosene were commonly used to clean and degrease parts. Then, chlorinated solvents in vapor degreasers became an industry standard. During the 1980s environmental and safety issues led to the banning of chlorinated solvents for parts cleaning. Aqueous-based cleaning systems took on new prominence that led to many improvements, in the systems and the processes. In 1971, Gary Minkin developed an aqueous based parts washer for degreasing automobile parts. The Minkin breakthrough used the force of hydraulic impact pressure to significantly improve the cleaning power of the aqueous parts washer.

Cleaning methods

Beside high mechanical energy, higher cleaning temperatures are one of the most effective methods of improving the cleaning results in a parts washer. In general, a 10 to 15 °F (5 to 8 °C) rise doubles the chemical reaction of the detergent. The increased chemical reaction between the greases and oils and the detergent delivers faster cleaning cycles and cleaner parts. Additionally, all greases and oils exhibit a lower viscosity at higher temperatures. Cleaning solution temperatures of 170 °F (77 °C) and above softens or melts most oils and greases causing them to flow like water so they are easily removed resulting in faster cleaning, better results and cleaner parts. Many parts washers are not capable of maintaining this operating temperature due to the lack of amply heating systems. Additionally, careful design is required of the pumping system so it can pull in and deliver cleaning solution at temperatures that approach boiling in the parts washer. All centrifugal pumps require a net positive suction head (NPSHr) in order to be able to pump solution. As the temperature of the solution approaches the NPSHr, the pump stops pumping because the cleaning solution flashes to steam in the pump intake. Careful design of the pump is required to minimize NPSHr and allow pumping of high temperature cleaning solution.

A typical parts washer may be aqueous based or use a solvent.

Solvent-based

Ben Palmer invented a solvent style parts washer in 1954. The parts washer was a success from the start, and he decided in the early 1960s not to sell his machine, but to lease it to the customer and service it by removing and replenishing the used solvent. Since the early 1990s there has been a significant shift towards aqueous based systems due to the environmental and safety hazards associated with solvent systems.

A solvent style parts washer is filled with several gallons of solvent that is stored in a settling pan at the bottom of the washer. A small flame-tight electric liquid pump is immersed in the solvent and skims clean solvent from near the top of the settling tank, and pumps it at low pressure through a stiff flexible nozzle onto a metal grating above the liquid where the metal components rest. Dirt and dissolved heavy greases fall into the bottom and settle to the bottom of the tank.

Originally, mixtures of oil distillates such as gasoline, diesel fuel, lacquer thinner or kerosene were used in solvent based manually-operated parts washers, but these are highly volatile and can ignite easily, potentially leading to an explosion and severe burns to the workers. For this reason, the solvent based "tub" washer typically has a large cover that is propped open by a lead fusible link. In the event of a fire, the lead will melt and the cover will slam shut to snuff out the fire before it can cause further damage to the building.

Aqueous-based

An aqueous based parts washer is much like a large dish washer. It uses water and detergent combined with heat and mechanical energy to provide the cleaning action. There are two main process styles of aqueous parts washers, the *jet spray process* and the *power wash process*. In a cabinet parts washer, the parts are placed on a turntable and the door is closed. During the cleaning cycle hot solution is flooded or blasted on the parts as the turntable rotates. Many systems have a wash, rinse and dry cycle. When the cycle is complete the door is opened and the parts removed.

There are four primary factors that affect the cleaning results in an aqueous parts washer. These factors are mechanical energy, temperature, detergent and time. Adjusting any one of these factors in a cleaning cycle changes the cleaning results. A parts washer with large amounts of mechanical energy and a high temperature delivers shorter cleaning cycles and uses less cleaning detergent. Mechanical energy is provided by the pump drive system. Most aqueous parts washers use an electric motor to drive a centrifugal pump. The mechanical energy delivered to the wash load is what defines the mechanical energy for cleaning and not the horsepower of the pump. Efficient use of the pump motor energy through a well designed centrifugal pump and attention to details of piping design and nozzle types are critical to put the most mechanical energy into the cleaning process. Additionally, one must consider the work volume of the parts washer. In order to achieve similar results, from one size machine to another, the power density must be the same for a given work volume, This factor requires that substantially higher horsepower pumping systems be used as the work volume increases exponentially on larger diameter machines.

Aqueous based parts washers use alkaline detergents mixed with water to clean parts. This solution is safer than solvent based systems because the risk of the cleaning solution catching fire is eliminated. The detergent for an aqueous parts washer may be in the form of a powder or a liquid. Each form has its advantages and the particular parts cleaning application will determine the best form. In general, powder detergents are the more aggressive and typically used in maintenance and rebuilding operations while liquids are more commonly found in lighter cleaning applications that were once commonly the domain of vapor degreasers.

Jet spray vs. power wash processes

A jet spray washer cleans by flooding the parts with hot chemical solution depending on the heat and high chemical concentration to clean the parts. In the power wash process the parts are blasted with hot chemical solution utilizing the hydraulic impact force of the cleaning solution as the primary cleaning mechanism. A parts washer utilizing the power washer process operates at a very low concentration of cleaning detergent. The lower concentration causes the cleaning solution to last longer before it becomes supersaturated and requires disposal. Additionally, a low concentration of cleaning chemicals allows for easier rinsing of the detergent from the parts thereby minimizing rinse cycle requirements thus saving water and cycle time. A final factor used in the power wash process is an oscillating manifold system that is non-synchronous to the rotation of the turntable. This system assures that the blasted solution reaches all areas of the parts load that are otherwise blinded by the stationary manifolds used in the jet spray process. All things considered the power wash process is superior to the jet spray process for faster more through parts cleaning cycles while minimizes detergent use and waste generation. The power wash process is generally effective for difficult soil removal applications such as burnt hydrocarbons, paint, scale, varnish, carbon, mastic, or rubber. Additional power wash types of applications generally include cleaning diesel engines, aerospace components, aluminum automobile engine parts and rolling mill equipment.

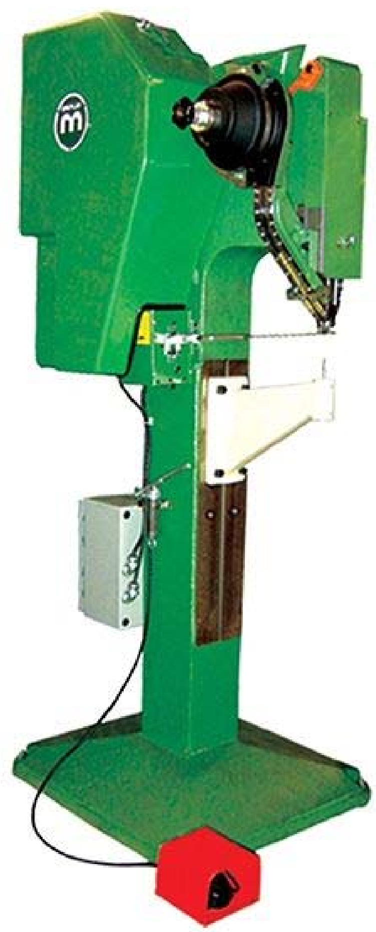
There are some considerations when using the "power wash" process in that comparatively high horsepower, thus high-current motors requiring an adequate power source, are utilized with correspondingly high washing pressures that require the parts to be adequately secured to the turntable. The "jet spray" process is found to be adequate for many cleaning applications that do not involve removal of difficult soils.

Power density

A parts washer can be characterized by its power density. The power density is calculated by dividing the total horsepower of all the pump systems providing the wash function by the total work volume for that washing function. Typical units are horsepower per cubic foot. The results of this calculation offer a beginning point in comparing various parts washing systems. The power density number is also useful when it is desired to achieve the same cleaning standard and throughput in a different work volume. Note that the power density calculation does not take into account the pump system efficiency and assumes that all of the energy delivered to the pump is delivered to the wash load. A more accurate power density would consider the pump system efficiency as efficiencies varying greatly even from an identical pump as the efficiency is highly dependent on the pump operating point, the piping design and the friction losses in the system.

Chapter 8

Riveting Machines



Impact riveting machine

Radial riveting machine

Riveting machines are used to automatically set (squeeze) rivets in order to join materials together. The riveting machine offers greater consistency, productivity, and lower cost when compared to manual riveting.

Types

Automatic feed riveting machines include a hopper and feed track which automatically delivers and presents the rivet to the setting tools which overcomes the need for the operator to position the rivet. The downward force required to deform the rivet with an automatic riveting machine is created by a motor and flywheel combination, pneumatic cylinder, or hydraulic cylinder. Manual feed riveting machines usually have a mechanical lever to deliver the setting force from a foot pedal or hand lever.

Riveting machines can be sub-divided into two broad groups — impact riveting machines and orbital (or radial) riveting machines.

Impact riveting

Impact riveting machines set the rivet by driving the rivet downwards, through the materials to be joined and on into a forming tool (known as a rollset). This action causes the end of the rivet to roll over in the rollset which causes the end of the rivet to flare out and thus join the materials together. Impact riveting machines are very fast and a cycle time of 0.5 seconds is typical.

Example of a 4-step orbital rivet

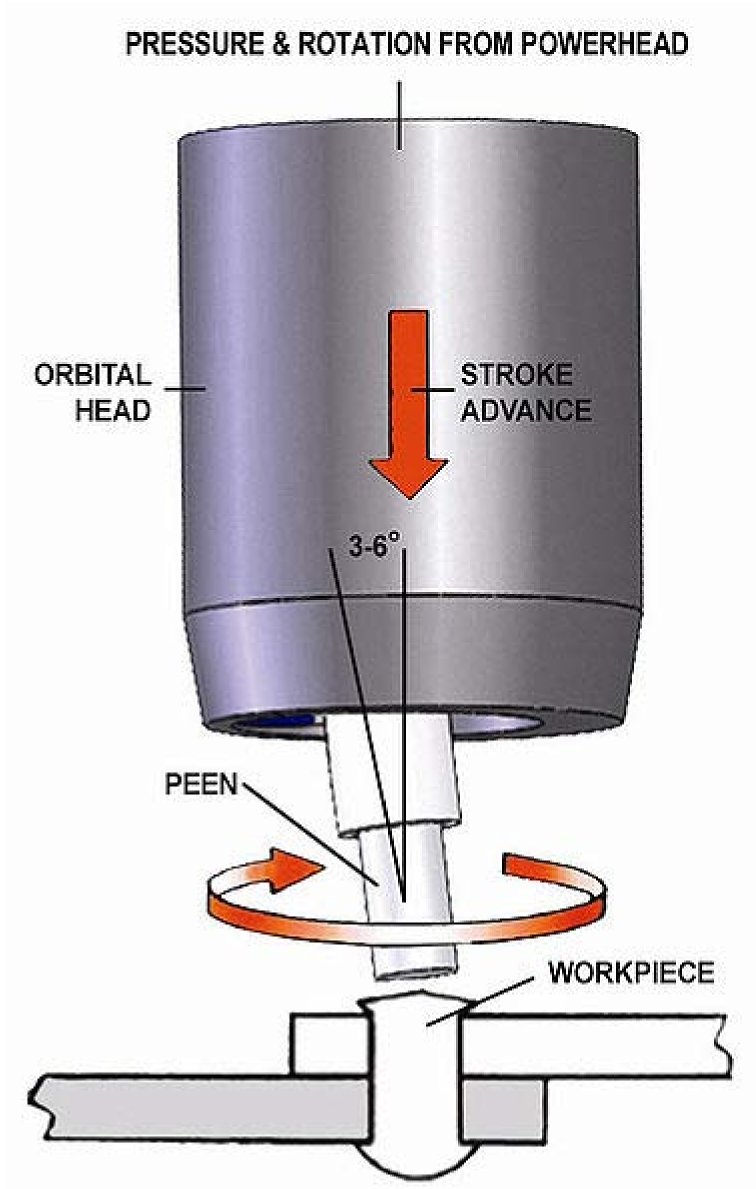


Diagram of how a orbital riveting works

Example of Rollerform process

Orbital riveting

Orbital riveting machines have a spinning forming tool (known as a peen) which is gradually lowered into the rivet which spreads the material of the rivet into a desired shape depending upon the design of the tool. Orbital forming machines offer the user more control over the riveting cycle but the trade off is in cycle time which can be 2 or 3 seconds.

There are different types of riveting machines. Each type of machine has unique features and benefits. The orbital riveting process is different from impact riveting and spiralform riveting. Orbital riveting requires less downward force than impact or spiral riveting. Also, orbital riveting tooling typically lasts longer.

Orbital riveting machines are used in a wide range of applications including brake linings for commercial vehicles, aircraft, and locomotives, textile and leather goods, metal brackets, window and door furniture, latches and even mobile phones. Many materials can be riveted together using orbital riveting machines including delicate and brittle materials, and sensitive electrical or electronic components.

The orbital riveting process uses a forming tool mounted at a 3 or 6° angle. The forming tool contacts the material and then presses it while rotating until the final form is achieved. The final form often has height and/or diameter specifications.

Pneumatic orbital riveting machines typically provide downward force in the 1,000–7,500 lb (450–3,400 kg) range. Hydraulic orbital riveting machines typically provide downward force in the 6,000–50,000 pounds (2,700–23,000 kg) range.

Radial (Spiralform) riveting

Radial riveting is subtly different from orbital forming. Radial riveting lightly peens (hammers) the rivet head into the desired shape whereas orbital forming spreads the rivet head in one, continuous contact, motion. While orbital forming is the superior process in most applications, spiralform riveting can produce better results when very small rivets are involved.

Rollerform riveting

Rollerforming is a subset of orbital forming. Rollerforming uses the same powerhead as orbital forming but instead of a peen has multiple wheels that circle the workpiece and combine two similar or non-similar materials together with a seamless and smooth gentle bonding via downward pressure as the rollers move downward or inward on the piece.

Automatic drilling and riveting machine

These machines take the automation one step farther by clamping the material and drilling or countersinking the hole in addition to riveting. They are commonly used in the aerospace industry because of the large number of holes and rivets required to assemble the aircraft skin.

Applications

Riveting machines are used in a wide range of applications including brake linings for commercial vehicles, aircraft, and locomotives, textile and leather goods, metal brackets, window and door furniture, latches and even mobile phones. Many materials can be riveted together using riveting machines including delicate and brittle materials, and sensitive electrical or electronic components.

Chapter 9

Tube Bending

Bent tubing

Shown is a trombone, it displays some U-bends

Tube bending is a metal forming process used to permanently form pipes or tubing into the shape of a die. Straight tube stock can be formed using a bending machine to create a variety of single or multiple bends and to shape the piece into the desired form. This process can be used to form complex shapes out of different types of ductile metal tubing. Generally, round stock is what is used in tube bending. However, square and rectangular tubes and pipes may also be bent to meet job specifications. Other factors involved in the tube bending process is the wall size, thickness, tooling and lubricants needed by the pipe and tube bender to best shape the material.

Geometry

A tube can be bent in multiple directions and angles. Common simple bends consist of forming *elbows*, which are bends that range from 2 to 90°, and *U-bends*, which are 180° bends. More complex geometries include multiple two-dimensional (2D) bends and three-dimensional (3D) bends. A 2D tube has the openings on the same plane; a 3D has openings on different planes.

One side effect of bending the workpiece is the wall thickness changes; the wall along the inner radius of the tube becomes thicker and the outer wall becomes thinner. To overcome this the tube may be supported internally or externally to preserve the cross section. Depending on the bend angle, wall thickness, and bending process the inside of the wall may wrinkle.

Processes

Tube bending as a process starts with loading a tube into a pipe bender and clamping it into place between two dies, the clamping block and the forming die. The tube is also loosely held by two other dies, the wiper die and the pressure die.

The process of tube bending involves using mechanical force to push stock material pipe or tubing against a die, forcing the pipe or tube to conform to the shape of the die. Often, stock tubing is held firmly in place while the end is rotated and rolled around the die. Other forms of processing including pushing stock through rollers that bend it into a simple curve. For some tube bending processing, a mandrel is placed inside the tube to prevent collapsing. The tube is also held in tension by a wiper die to prevent any creasing during stress. A wiper die is usually made of a softer alloy i.e. aluminum, brass to avoid scratching or damaging the material being bent.

Much of the tooling is made of hardened steel or tooled steel to maintain and prolong the tools life. However wherever there is a concern of scratching or gouging the work piece, a softer material such as aluminum or bronze is utilized. For example, the clamping block, rotating form block and pressure die are often formed from the hardened steel because the tubing is not moving past these parts of the machine. On the other hand, the pressure die and the wiping die are formed from aluminum or bronze to maintain the shape and surface of the workpiece as it slides by.

Pipe bending machines are typically human powered, pneumatic powered, hydraulic assisted, hydraulic driven, or electric servomotor.

Press bending

Probably the first bending process used on cold pipes and tubing. In this process a die in the shape of the bend is pressed against the pipe forcing the pipe to fit the shape of the bend. Because the pipe is not supported internally there is some deformation of the shape of the pipe giving an ovular cross section. This process is used where a consistent cross section of the pipe is not required. Although a single die can produce various shapes, it only works for one size tube and radius.

Rotary draw bending

Rotary draw bending (RDB) are precise in that they bend using tooling or "die sets" which have a constant center line radius (CLR). The die set consists of two parts: The *former die* creates the shape to which the material will be bent. The *counter die* does the work of pushing the material into the former die while traveling the length of the bend. Rotary draw benders can be programmable to store multiple bend jobs with varying degrees of bending. Often a positioning index table (IDX) is attached to the bender allowing the operator to reproduce complex bends which can have multiple bends and differing planes.

Rotary draw benders are the most popular machines for use in bending tube, pipe and solids for applications like: handrails, frames, motor vehicle roll cages, handles, lines and much more. Rotary draw benders create aesthetically pleasing bends when the right tooling is matched to the application.

Heat-induction

An induction coil is placed around a small section of the pipe at the bend point. It is then heated to between 800 and 2,200 degrees Fahrenheit (430 and 1,200 °C). While the pipe is hot, pressure is placed on the pipe to bend it. The pipe is then quenched with either air or water spray. Heat-Induction bending is used on large pipes such as freeway signs, power plants, and petroleum pipe lines.

Roll benders

During the roll bending process the pipe, extrusion, or solid is passed through a series of rollers (typically 3) that apply pressure to the pipe gradually changing the bend radius in the pipe. The pyramid style roll benders have one moving roll, usually the top roll. Double pinch type roll benders have two adjustable rolls, usually the bottom rolls, and a fixed top roll. This method of bending causes very little deformation in the cross section of the pipe. This process is suited to producing coils of pipe as well as long gentle bends like those used in truss systems.

Sand-packing/hot-slab forming

In the sand packing process the pipe is filled with fine sand and the ends are capped. The pipe is then heated in a furnace to 1,600 °F (870 °C) or higher. The pipe is then placed on a slab with pins set in it. The pipe is then bent around the pins using a winch, crane, or some other mechanical force. The sand in the pipe minimizes distortion in the pipe cross section.

Mandrels

A **mandrel** is a steel rod or linked ball inserted into the tube while it is being bent to give the tube extra support to reduce wrinkling and breaking the tube during this process. The different types of mandrels are as follows.

1. Plug mandrel, a solid rod used on normal bends.
2. Form mandrel, a solid rod with curved end used on bend when more support is need.
3. Ball mandrel without cable, unlinked steel ball bearings inserted into tube, used on critical and precise bends.
4. Ball mandrel with cable, linked ball bearings inserted into tube, used on critical bend and precise bends.
5. Sand, sand packed into tube.

In production of a product where the bend is not critical a plug mandrel can be used. A form type tapers the end of the mandrel to provide more support in the bend of the tube. When precise bending is needed a ball mandrel (or ball mandrel with steel cable) should be used. The conjoined ball-like disks are inserted into the tubing to allow for bending while maintaining the same diameter throughout. Other styles include using sand, cerrobend, or frozen water. These allow for a somewhat constant diameter while providing an inexpensive alternative to the aforementioned styles.

Performance automotive or motorcycle exhaust pipe is a common application for a mandrel.

Bending springs

These are strong but flexible springs inserted into a pipe to support the pipe walls during manual bending. They have diameters only slightly less than the internal diameter of the pipe to be bent. They are only suitable for bending 15-and-22 mm (0.6-and-0.9 in) soft copper pipe (typically used in household plumbing).

The spring is pushed into the pipe until its center is roughly where the bend is to be. A length of flexible wire can be attached to the end of the spring to facilitate its removal. The pipe is generally held against the flexed knee, and the ends of the pipe are pulled up to create the bend. To make it easier to retrieve the spring from the pipe, it is a good idea to bend the pipe slightly more than required, and then slacken it off a little. They are less cumbersome than rotary benders, but are not suitable for bending short lengths of piping when it is difficult to get the requires leverage on the pipe ends.

Bending springs for smaller diameter pipes (10 mm copper pipe) slide over the pipe instead of inside.

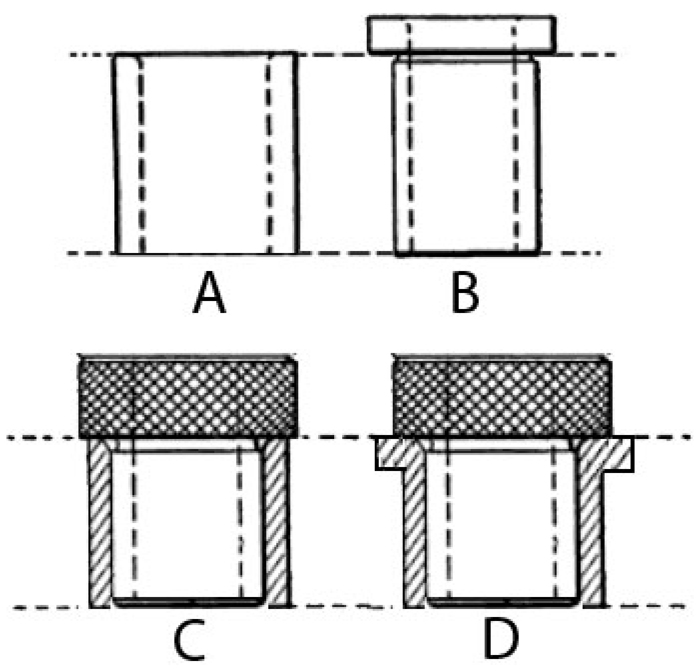
Chapter 10

Drill Bushing

A **drill bushing**, also known as a **jig bushing**, is a tool used in metalworking jigs to guide cutting tools, most commonly drill bits. Other tools that are commonly used in a drill bushing include counterbores, countersinks, and reamers. They are designed to guide, position, and support the cutting tool.

In the USA, Customary sized bushings are standardized via ASME B94.33 and metric bushings are standardized via ASME B94.33.1. There are over 50,000 standard configurations of customary sized bushings.

Types



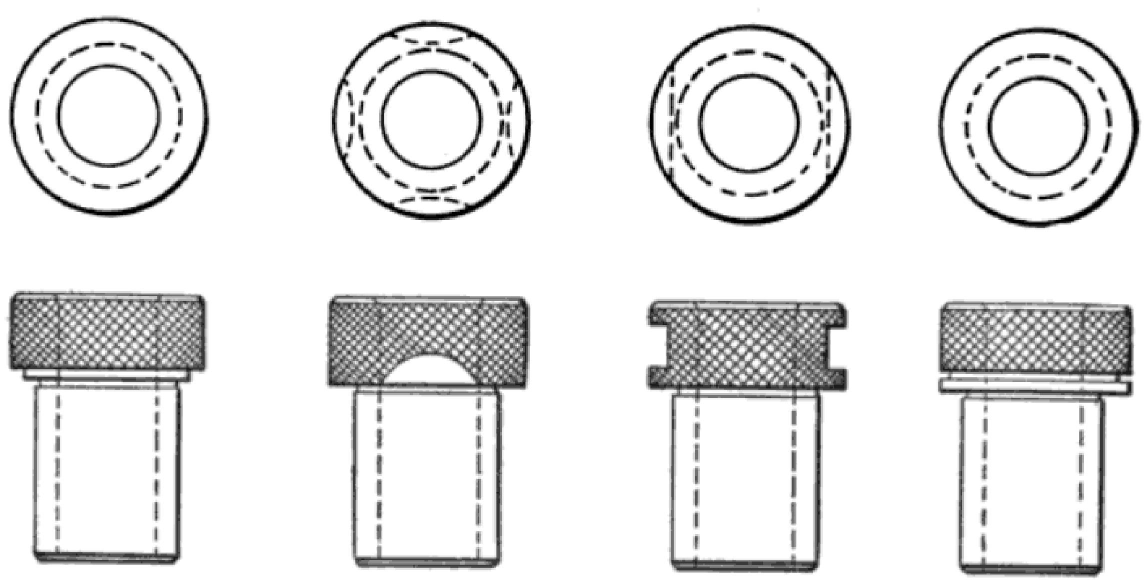
Types of drilling bushings: A. Headless wearing press-fit bushing B. Head wearing press-fit bushing C. Headless liner bushing with renewable bushing D. Head liner bushing with renewable bushing

Drill bushings can generally classified as: *press fit* bushings or *renewable* bushings. Other classification methods include by head type, by use, and by liner type (or lack thereof).

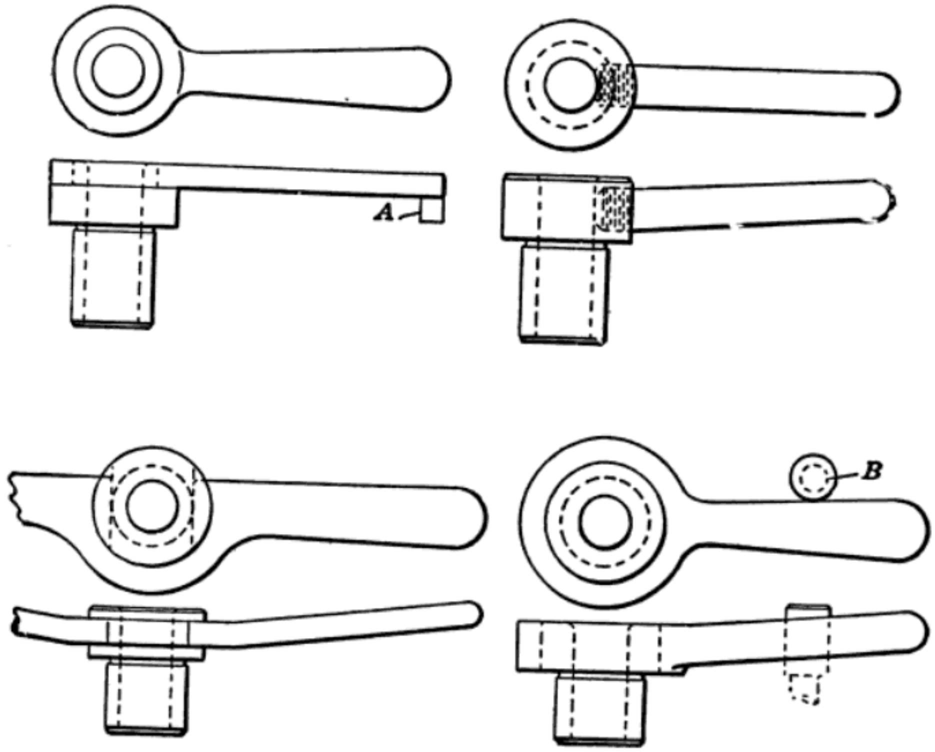
Press-fit bushings

Press fit bushings are available in two types with liners or without (*wearing* bushings). Liner bushings, sometimes called *master bushings*, are permanently installed into the jig and accept liners that can easily be replaced. Press-fit wearing bushings are used in short run applications or in applications where the tolerance on a hole location is so tight that it cannot facilitate the use of a liner bushing.

Renewable bushings



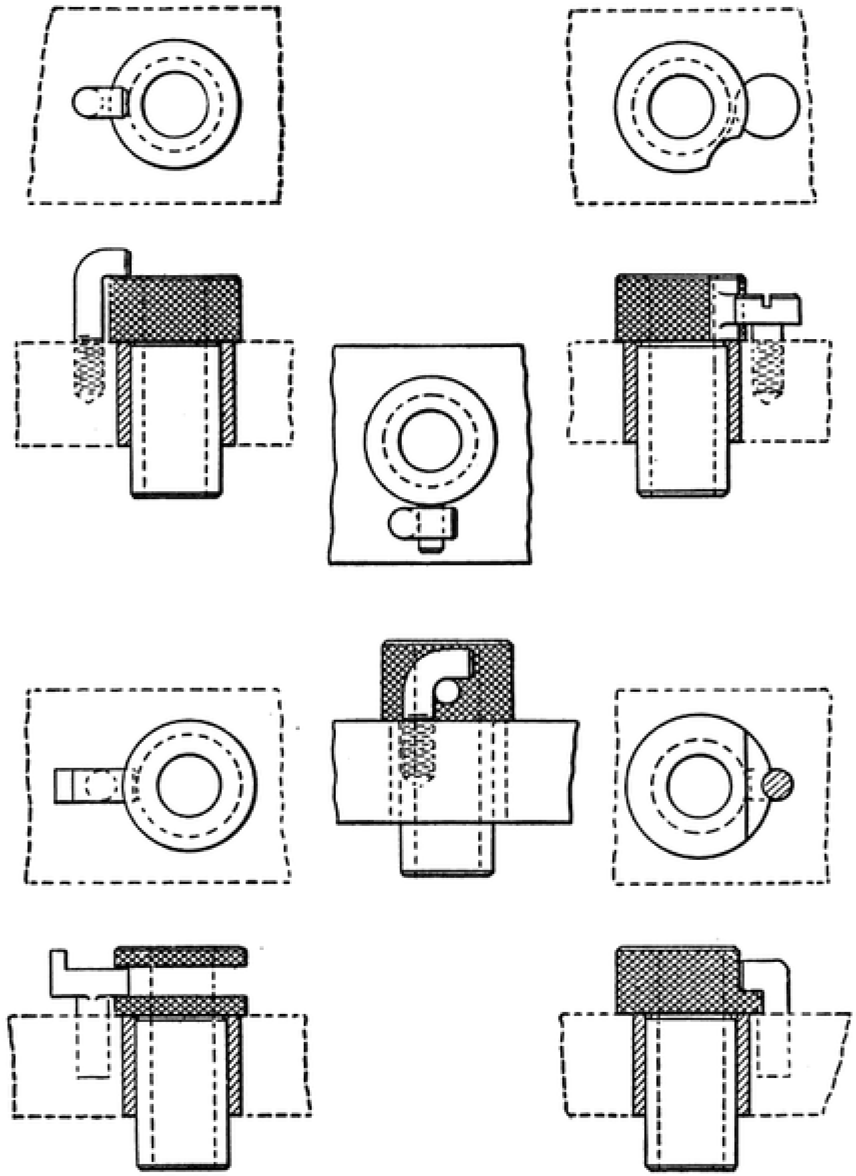
Four features that can be incorporated into small renewable bushings for easy removal with a screwdriver.



Four types of dogs. Key (A) shows how the end of the dog can be bent down to wrap around the edge of the jig plate; key (B) shows how a pin can be used to keep the dog from rotating.

Renewable bushings are installed in liner bushings. This type of bushing is used in large production runs where a bushing will wear out over time or when multiple renewable bushings are used in one liner to provide various sized holes. There are two types of renewable bushings: *fixed* and *slip*.

Fixed renewable bushings are used in applications where the liner is meant to be used until it wears out. Slip renewable bushings are designed to be interchangeable with a given sized liner so that two different sized slip renewable bushings can be used in one liner bushing. This facilitates the ability to do multiple machining operations that require different inner diameter (ID) bushings, such as drilling and reaming. They usually have knurled heads so they can be easily removed.



Various methods to lock renewable bushings

Renewable bushings must be secured in their liner bushing, otherwise the tool can cause it to spin, which rapidly wears out the liner, or chips can force the bushing out of the liner. There are many different types of locking systems for renewable bushings. One system is a *dog*, which is a collar that is pressed over the head of the bushing and has a long tail. The tail may be bent at the end so it can lock around the edge of the jig plate or it may be left straight if it can butt up against another object. Another option to keep the renewable bushing from rotating is to pin it, either by putting a pin in the renewable bushing and a hole in the liner or vice versa. A more complicated version uses a hole in the bushing collar and a pin with a head; the head on the pin holds the edge of the collar down, but for removal the bushing can be rotated so that the hole lines up with the pin.

Specification

Customary bushings are specified using the following specification layout:

ID-Type-OD-Length

Where the ID is specified as a decimal, drill letter size, drill number size, or fraction; the OD is an integer that relates to a multiple of a $^1/_{64}$th of an inch; the length is an integer that relates to a multiple of a $^1/_{16}$th of an inch. The lengths of press-fit bushings are standardized to typical jig plate thicknesses: $^5/_{16}$, $^3/_8$, $^1/_2$, $^3/_4$, 1, 1 $^3/_8$, and 1 $^3/_4$ inch. The letter "U" is used after the OD number to designate the that extra stock should be left on the OD for grinding to size. The type is a letter referring to the following:

- **S** - Slip renewable
- **F** - Fixed renewable
- **L** - Headless liner
- **HL** - Head liner
- **P** - Headless press-fit
- **H** - Head press-fit

The following two tables give the tolerances for the ID and OD.

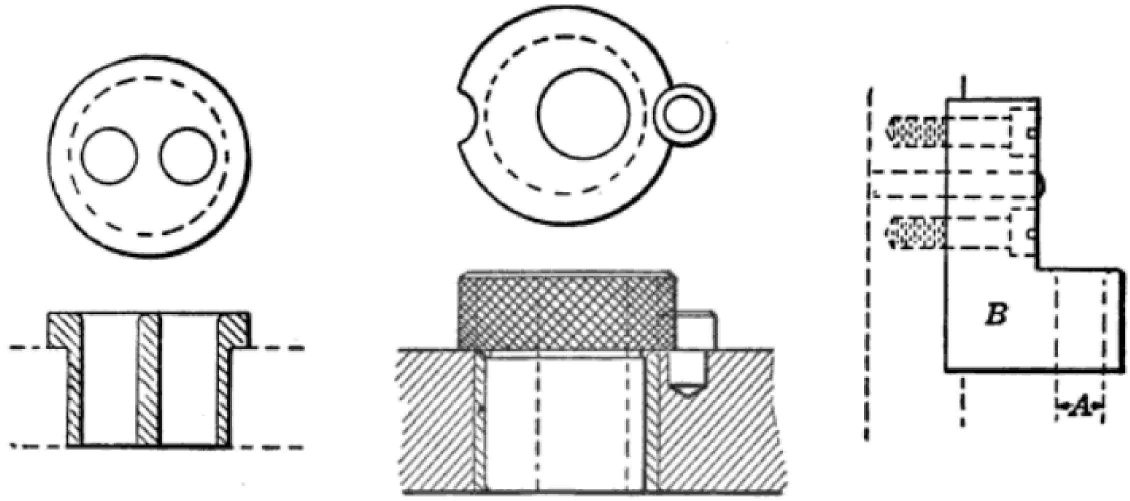
ID tolerances

Nominal ID [in]	Maximum [in]	Minimum [in]
0–0.25, including	+0.0004	+0.0001
0.25–0.75, incl.	+0.0005	+0.0001
0.75–1.5, incl.	+0.0006	+0.0002
Greater than 1.5	+0.0007	+0.0003

OD grinding tolerances

Nominal OD [in]	Maximum [in]	Minimum [in]
$^5/_{32}$–$^1/_4$	+0.005	+0.010
$^5/_{16}$ & $^{13}/_{64}$	+0.010	+0.015
Greater than $^1/_2$	+0.015	+0.020

Custom bushings



Three more common types of custom drill bushings

A common problem encountered is when two or more holes are too close for independent standard bushings. In this case one large renewable bushing can be made with two (or more) holes in the proper location (the first example in the image). Another possibility is to make a custom bushing with an eccentric hole and then notches on the outside of the head are used to locate the proper position of the bushing for each location (the middle example in the image). Another common need for a custom bushing is when the hole needed is perpendicular jig plate; in this case a *bracket bushing* is used. It is a hardened piece of right angle steel that bolts to the jig plate and is located with dowel pins.

Design

In general, a drill bushing's length should be at least 2 times the nominal ID.

Chapter 11

Grinding Wheel

Grinding wheel

Grinding wheels

A **grinding wheel** is an expendable wheel that is composed of an abrasive compound used for various grinding (abrasive cutting) and abrasive machining operations. They are used in grinding machines.

The wheels are generally made from a matrix of coarse particles pressed and bonded together to form a solid, circular shape, various profiles and cross sections are available depending on the intended usage for the wheel. They may also be made from a solid steel or aluminium disc with particles bonded to the surface.

The manufacture of these wheels is a precise and tightly controlled process, due not only to the inherent safety risks of a spinning disc, but also the composition and uniformity required to prevent that disc from exploding due to the high stresses produced on rotation.

Characteristics

There are five characteristics of a cutting wheel: material, grain size, wheel grade, grain spacing, and bond type. They will be indicated by codes on the wheel's label.

Material, the actual abrasive, is selected according to the hardness of the material being cut.

- Aluminum Oxide (A)
- Silicon Carbide (C)
- Diamond (D, MD, SD)
- Cubic Boron Nitride (B)

Grain size, from 8 (coarsest) 600 (finest), determines the physical size of the abrasive grains in the wheel. A larger grain will cut freely, allowing fast cutting but poor surface finish. Ultra-fine grain sizes are for precision finish work.

Wheel grade, from A (soft) to Z (hard), determines how tightly the bond holds the abrasive. Grade affects almost all considerations of grinding, such as wheel speed, coolant flow, maximum and minimum feed rates, and grinding depth.

Grain spacing, or structure, from 1 (densest) to 16 (least dense). Density is the ratio of bond and abrasive to air space. A less-dense wheel will cut freely, and has a large effect on surface finish. It is also able to take a deeper or wider cut with less coolant, as the chip clearance on the wheel is greater.

Wheel bond, how the wheel holds the abrasives, affects finish, coolant, and minimum/maximum wheel speed.

- Vitrified (v)
- Resinoid (R)
- Silicate (S)
- Shellac (E)
- Rubber (R)
- Oxychloride (O)

Types

Straight wheel

Straight wheel

To the right is an image of a **straight wheel**. These are by far the most common style of wheel and can be found on bench or pedestal grinders. They are used on the periphery only and therefore produce a slightly concave surface (*hollow ground*) on the part. This can be used to advantage on many tools such as chisels.

Straight Wheels are the kind of generally used for cylindrical, centreless, and surface grinding operations. Wheels of this form vary greatly in size, the diameter and width of face naturally depending upon the class of work for which is used and the size and power of the grinding machine.

Cylinder or wheel ring

Cylinder wheels provide a long, wide surface with no center mounting support (hollow). They can be very large, up to 12" in width. They are used only in vertical or horizontal spindle grinders. Cylinder or wheel ring is used for producing flat surfaces, the grinding being done with the end face of the wheel.

Tapered wheel

A straight wheel that tapers outward towards the center of the wheel. This arrangement is stronger than straight wheels and can accept higher lateral loads. Tapered face straight wheel is primarily used for grinding thread, gear teeth etc.

Straight cup

Straight cup wheels are an alternative to cup wheels in tool and cutter grinders, where having an additional radial grinding surface is beneficial.

Dish cup

A very shallow cup-style grinding wheel. The thinness allows grinding in slots and crevices. It is used primarily in cutter grinding and jig grinding.

Saucer wheel

A special grinding profile that is used to grind milling cutters and twist drills. It is most common in non-machining areas, as sawfilers use saucer wheels in the maintenance of saw blades.

Diamond wheel

Diamond wheel

Diamond wheels are grinding wheels with industrial diamonds bonded to the periphery.

They are used for grinding extremely hard materials such as carbide cutting tips, gemstones or concrete. The saw pictured to the right is a slitting saw and is designed for slicing hard materials, typically gemstones.

Diamond mandrels

Diamond mandrels are very similar to their counterpart, a diamond wheel. They are tiny diamond rasps for use in a jig grinder doing profiling work in hard material.

Cut off wheels

Cut off wheels, also known as *parting wheels*, are self-sharpening wheels that are thin in width and often have radial fibres reinforcing them. They are often used in the construction industry for cutting reinforcement bars (rebar), protruding bolts or anything that needs quick removal or trimming. Most handymen would recognise an angle grinder and the discs they use.

Use

To use the grinding wheel it must first be clamped to the grinding machine. The wheel type (*e.g.* cup or plain wheel below) fit freely on their supporting arbors, the necessary clamping force to transfer the rotary motion being applied to the wheels side by identically sized flanges (metal discs). The paper blotter shown in the images is intended to distribute this clamping force evenly across the wheels surface.

Dressing

Grinding wheels are self sharpening to a small degree, for optimal use they may be dressed and trued by the use of wheel or grinding dressers. *Dressing* the wheel refers to removing the current layer of abrasive, so that a fresh and sharp surface is exposed to the work surface. *Trueing* the wheel makes the grinding surface parallel to the grinding table or other reference plane, so the entire grinding wheel is even and produces an accurate surface.

Chapter 12

Pliers

Flat-nose pliers

Pliers are a hand tool used to hold objects firmly, for cutting, bending, or physical compression. Generally, pliers consist of a pair of metal first-class levers joined at a fulcrum positioned closer to one end of the levers, creating short *jaws* on one side of the fulcrum, and longer *handles* on the other side. This arrangement creates a mechanical advantage, allowing the force of the hand's grip to be amplified and focused on an object with precision. The jaws can also be used to manipulate objects too small or unwieldy to be manipulated with the fingers.

There are many kinds of pliers made for various general and specific purposes.

History

As pliers in the general sense are an ancient and simple invention, no single point in history, or single inventor, can be credited. Early metal working processes from several millennia BCE would have required plier-like devices to handle hot materials in the process of smithing or casting. Development from wooden to bronze pliers would have probably happened sometime prior to 3000 BCE. Among the oldest illustrations of pliers are those showing the Greek god Hephaestus in his forge. Today, pliers intended principally to be used for safely handling hot objects are usually called tongs. The number of different designs of pliers grew with the invention of the different objects which they were used to handle: horseshoes, fasteners, wire, pipes, electrical and electronic components.

Design

The basic design of pliers has changed little since their origins, with the pair of *handles*, the *pivot* (often formed by a rivet), and the *head* section with the gripping jaws or cutting edges forming the three elements. In distinction to a pair of scissors or shears, the plier's jaws always meet each other at one pivot angle.

The materials used to make pliers consist mainly of steel alloys with additives such as vanadium or chromium, to improve strength and prevent corrosion. Often pliers have insulated grips to ensure better handling and prevent electrical conductivity. In some lines of fine work (such as jewellery or musical instrument repair), some specialized pliers feature a layer of comparatively soft metal (such as brass) over the two plates of the head of the pliers to reduce pressure placed on some fine tools or materials. Making entire pliers out of softer metals would be impractical, reducing the force required to bend or break them.

Common types

Locking pliers

Needle-nose pliers

Gripping pliers

- Lineman's pliers (combination pliers)
- Flat-nose pliers (duckbill pliers) With long, narrow, flat jaws, they are stronger than needle-nose pliers, but less able to reach into really confined spaces
- Round-nose pliers (snub-nosed pliers)
- Needle-nose pliers (long-nose pliers, snipe-nose pliers) which have long, narrow jaws for gripping in confined spaces
- Locking pliers (vise grips, mole grips)
- Tongue-and-groove pliers (Channellock pliers)
- Parallel pliers which have jaws (usually smooth) which come together in a completely parallel motion, as opposed to regular pliers which rotate until contact. This design is intended to increase the surface area on materials the pliers are used on, decreasing pressure and potential for causing indentations.

Special purpose pliers

Breaker-grozier pliers

- Wire-stripping pliers - cuts and removes insulation on electrical wire while leaving the wire intact
- Fencing tools - include a hammer, wire cutter and nail puller on one tool
- Circlip pliers (retaining-ring pliers) - used for fixing or loosening retaining rings
- Nail-pulling pliers - an adaptation of the end nipper used for cutting wire; the jaws may be asymmetric, allowing the nail to be pulled out with a rocking motion on the surface in which it is embedded.
- Breaker-grozier pliers (Glass-breaking pliers, grozz pliers)
- Blacksmith tongs

Adjustable pliers

- Slip joint pliers, which are similar to combination pliers but whose pivot can be slipped between two holes when the jaws are fully open to change their sizecalled
- Tongue-and-groove pliers (groove-joint pliers, water-pump pliers, Channellocks), with adjustable jaw sizes, that are designed to grip various sizes of round, hexagon, flat or similarly shaped objects

Cutting pliers

- Lineman's pliers (combination pliers)
- Diagonal pliers (wire cutters, side-cutting pliers , side cutters)
- Pinching pliers (end-nippers)
- Needle-nose pliers designed for gripping, but typically incorporate a cutter for convenience.

Crimping pliers

- For crimping electrical connectors (solder-less connections)
- For crimping metal rings or tags on livestock
- For crimping metal security seals on cargo carriers
- For crimping an impression on a document - as in a notary's seal
- For crimping laboratory vials

- For crimping bottles with atomizer tops, such as perfume bottles
- For crimping "crimping beads" used in jewelry making

Rotational pliers

- Developed by NASA engineers to enable an astronaut to turn a nut in weightlessness. The linear motion of the hand is converted to rotational motion to drive a socket wrench.

Slip joint pliers

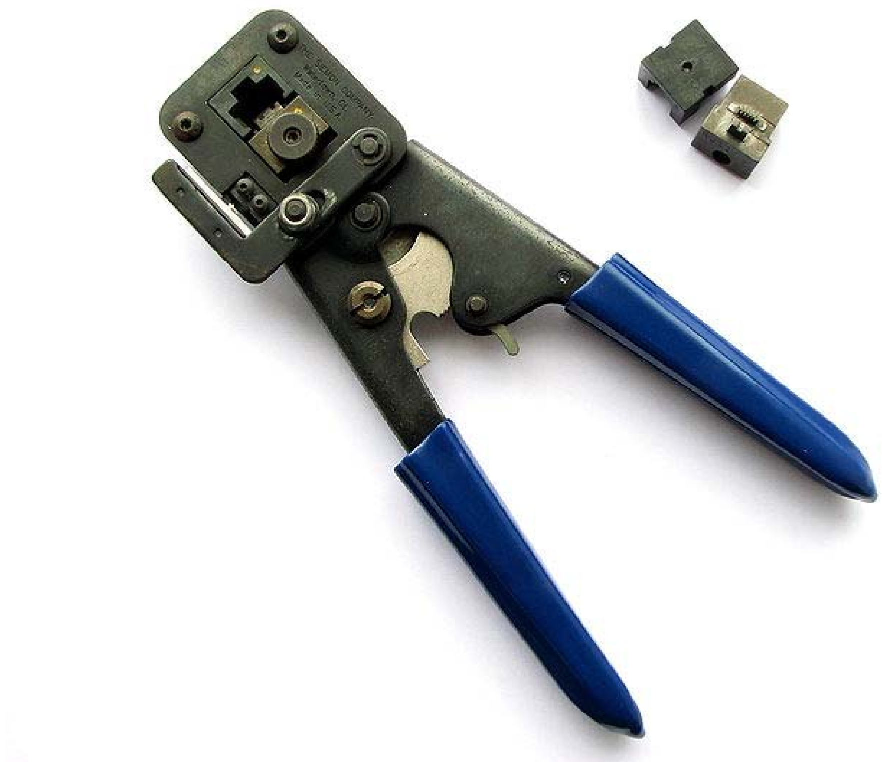
Diagonal pliers or side cutters

Lineman's pliers or combination pliers

Pincers

Electrical wire stripping and terminal crimping pliers

Crimptool for N, R-SMA, TNC connectors for RG174, RG58 and HDF/LMR200



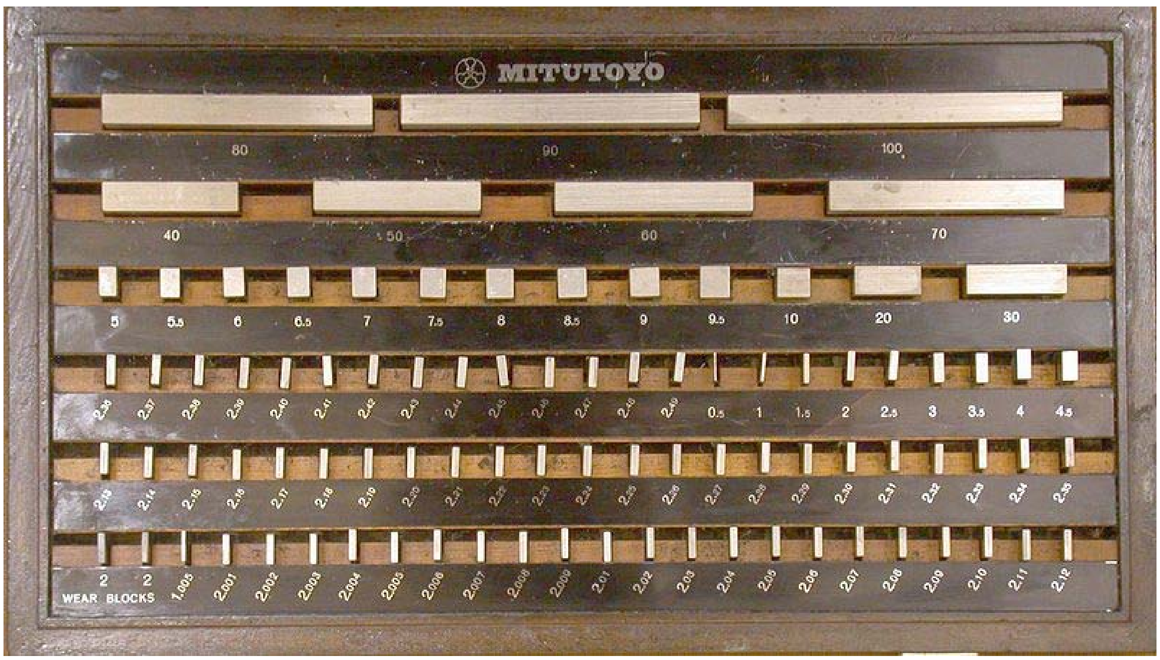
Heavy duty crimping pliers with interchangeable RJ heads

Hand crimp tool

Hand crimp tool for insulated terminals and non-insulated terminals; also has a wire cutter and stripper and screw cutters

Chapter 13

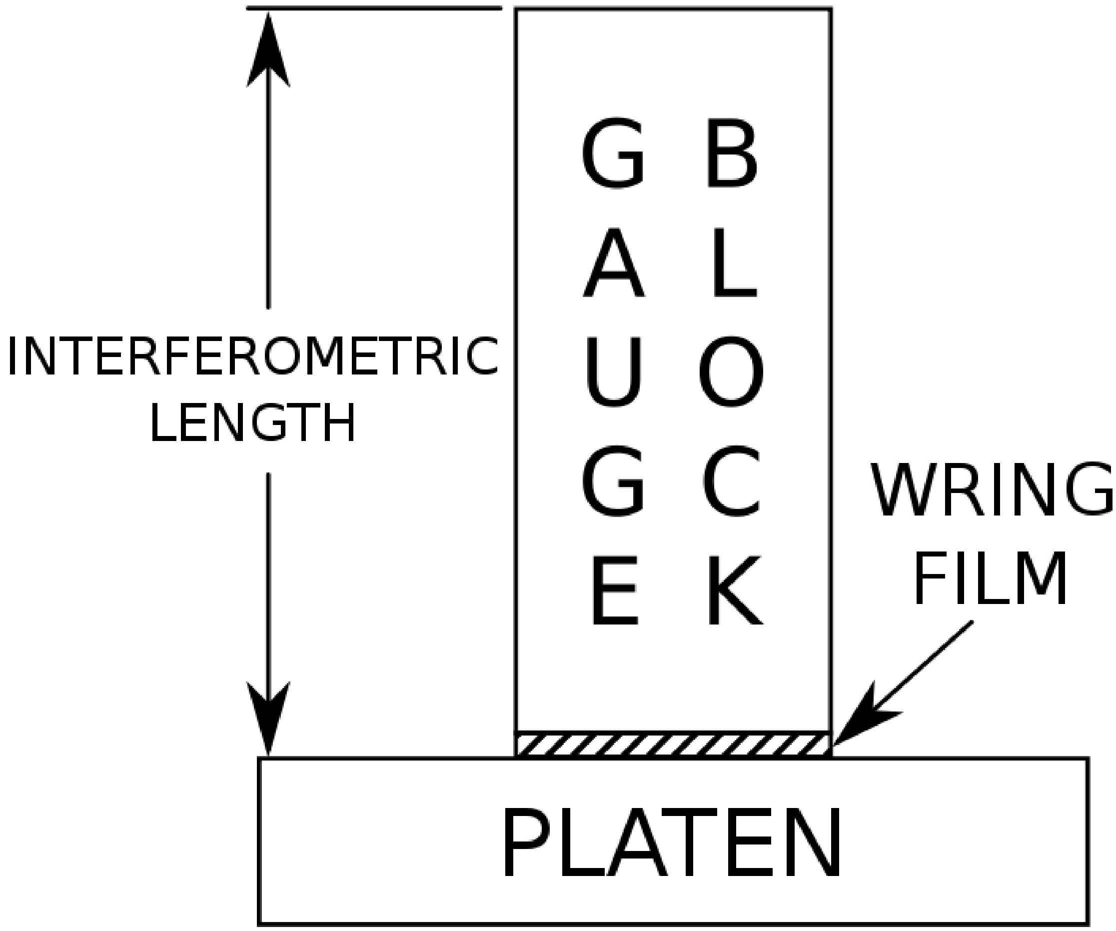
Gauge Block



Metric gauge block set

A **gauge block** (also known as a **gage block**, **Johansson gauge**, **slip gauge**, or **Jo block**) is a precision ground and lapped length measuring standard. Invented in 1896 by Swedish machinist Carl E. Johansson, they are used as a reference for the calibration of measuring equipment used in machine shops, such as micrometers, sine bars, calipers, and dial indicators (when used in an inspection role). Gauge blocks are the main means of length standardization used by industry.

Description

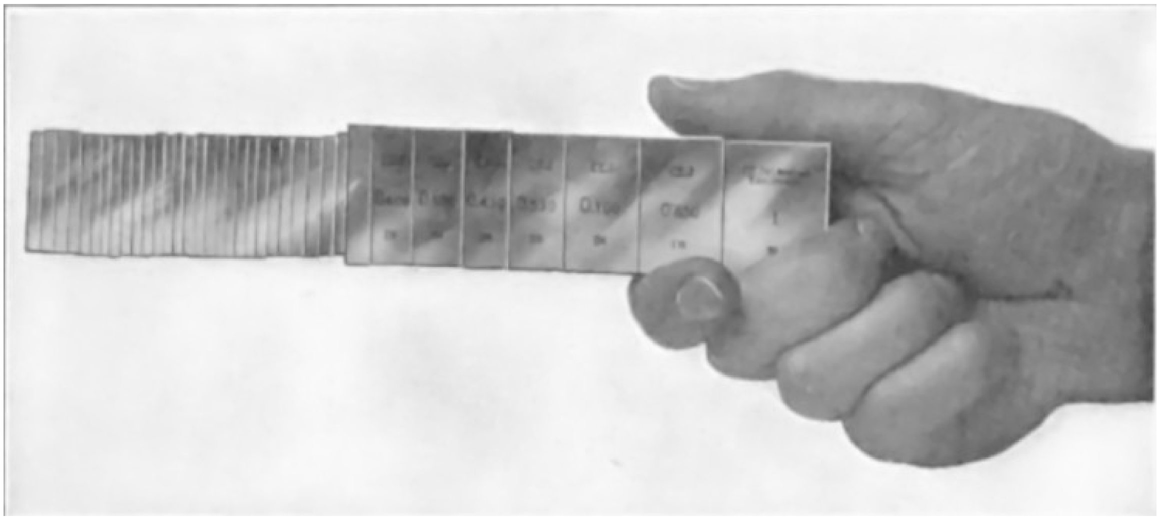


How gauge blocks are measured.

Each gauge block consists of a block of metal or ceramic with two opposing faces ground precisely flat and parallel, a precise distance apart. Standard grade blocks are made of a hardened steel alloy, while calibration grade blocks are often made of tungsten carbide or chromium carbide because it is harder and wears less. Gauge blocks come in sets of blocks of various lengths, along with two wear blocks, to allow a wide variety of standard lengths to be made up by stacking them. The length of each block is actually slightly shorter than the nominal length stamped on it, because the stamped length includes the length of one *wring film*, a film of lubricant which separates adjacent block faces in normal use. This nominal length is known as the *interferometric length*.

In use, the blocks are removed from the set, cleaned of their protective coating (petroleum jelly or oil) and *wrung together* to form a stack of the required dimension, with the minimum number of blocks. Gauge blocks are calibrated to be accurate at 68 °F (20 °C) and should be kept at this temperature when taking measurements. This mitigates the effects of thermal expansion. The wear blocks, made of a harder substance like tungsten carbide, are included at each end of the stack, whenever possible, to protect the gauge blocks from being damaged in use.

Wringing



36 Johansson gauge blocks wrung together.

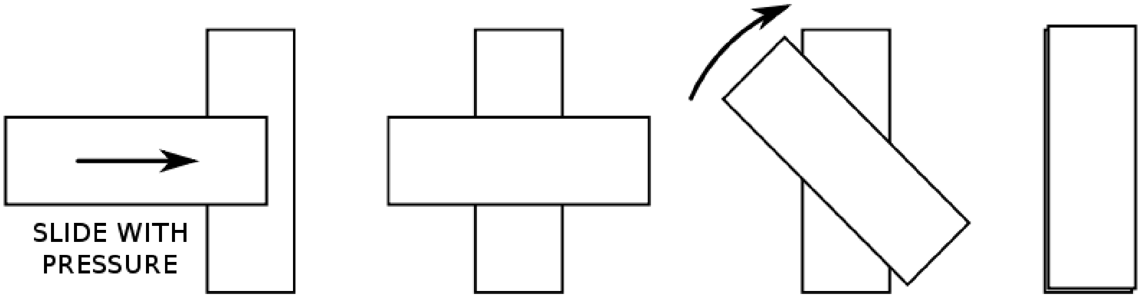
Wringing is the process of sliding two blocks together so that their faces lightly bond. Because of their ultraflat surfaces, when wrung, gauge blocks adhere to each other tightly. Properly wrung blocks may withstand a 75 lbf (330 N) pull. While the exact mechanism that causes wringing is unknown, it is believed to be a combination of:

- Air pressure applies pressure between the blocks because the air is squeezed out of the joint.
- Surface tension from oil and water vapor that is present between the blocks.
- Molecular attraction occurs when two very flat surfaces are brought into contact. This force causes gauge blocks to adhere even without surface lubricants, and in a vacuum.

It is believed that the last two sources are the most significant.

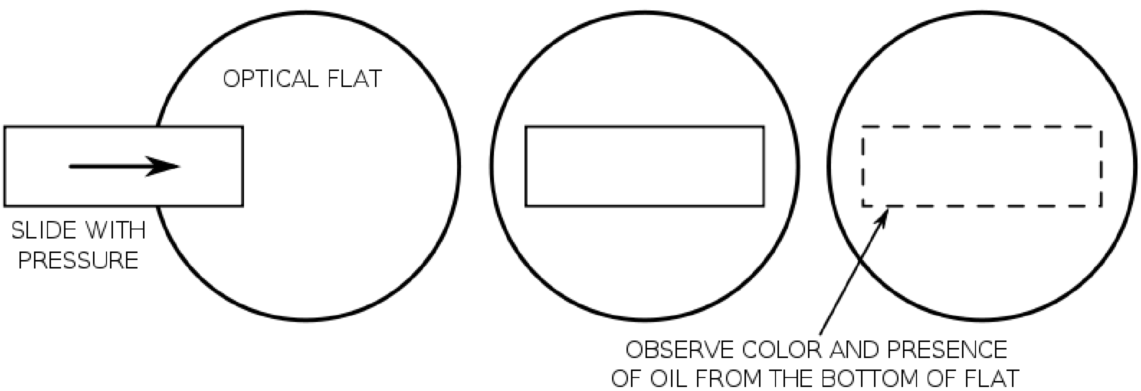
The process of wringing involves four steps:

1. Wiping a clean gauge block across an oiled pad.
2. Wiping any extra oil off the gauge block using a dry pad.
3. The block is then slid perpendicularly across the other block while applying moderate pressure until they form a cruciform.
4. Finally, the block is rotated until it is inline with the other block.

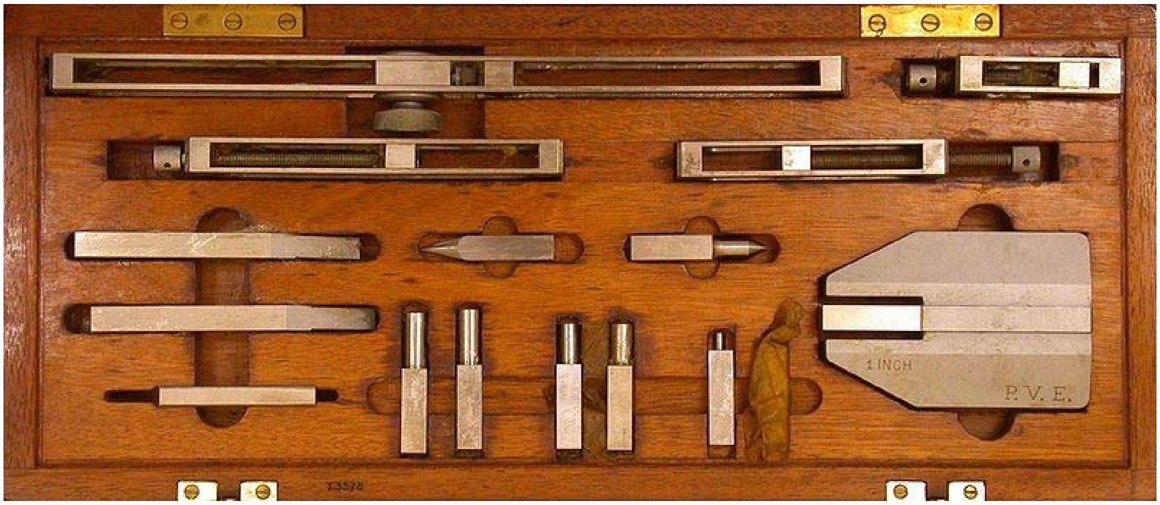


After use the blocks are re-oiled or greased to protect against corrosion. The ability for a given gauge block to wring is called *wringability*; it is officially defined as "the ability of two surfaces to adhere tightly to each other in the absence of external means." The minimum conditions for wringability are a surface finish of 1 microinch (0.025 µm) AA or better, and a flatness of at least 5 µin (0.13 µm).

There is a formal test to measure wringability. First, the block is prepared for wringing using the standard process. The block is then slid across a 2 in (51 mm) reference grade (1 µin (0.025 µm) flatness) quartz optical flat while applying moderate pressure. Then, the bottom of the gauge block is observed (through the optical flat) for oil or color. For Federal Grades 0.5, 1, and 2 and ISO grades K, 00, and 0 no oil or color should be visible under the gauge block. For Federal Grade 3 and ISO grades 1 and 2, no more than 20% of the surface area should show oil or color. Note that this test is hard to perform on gauge blocks thinner than 0.1 in (2.5 mm) because they tend not to be flat in the relaxed state.



Accessories



A gauge block accessory set

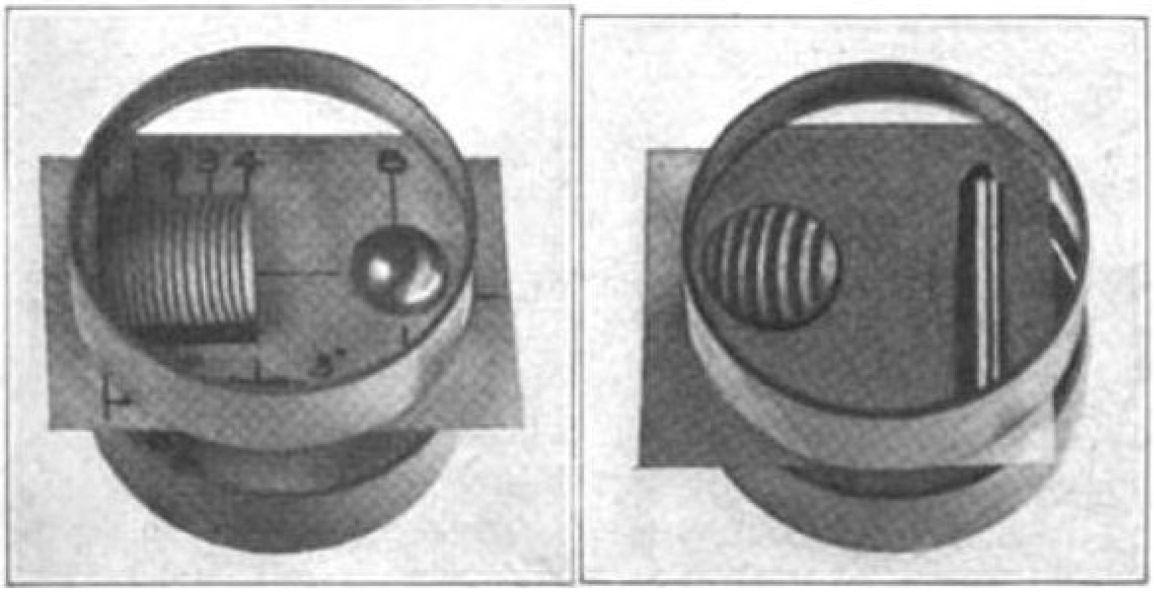
The pictured accessories provide a set of holders and tools to extend the usefulness of the gauge block set. They provide a means of securely clamping large *stacks* together along with reference points and scribers.

Slip gauges are made from a select grade of carbide with hardness of 1500 Vickers hardness. Long series slip gauges are made from high quality steel having cross section (35 x 9 mm) with holes for clamping two slips together.

A *gauge block stone* is used to remove nicks and burrs to maintain wringability.

There are two *wringing pads* used to prepare a gauge block for wringing. The first is an *oil pad*, which applies a light layer of oil to the block. The second is a *dry pad*, which removes any excess oil from the block after the oil pad has been used.

Grades



Gauge blocks *(left in each picture, under optical flats)* being used to measure the height of a ball bearing and a plug gage using interferometry.

They are available in various grades depending on their intended use. Various grading standards include: JIS B 7506-1997 (Japan)/DIN 861-1980 (Germany), ASME (US), BS 4311: Part 1: 1993 (UK). Tolerances will vary within the same grade as the thickness of the material increases.

- reference (AAA): small tolerance (±0.05 µm or ±0.000002 in) used to establish standards
- calibration (AA): (tolerance +0.10 µm to −0.05 µm) used to calibrate inspection blocks and very high precision gauging
- inspection (A): (tolerance +0.15 µm to −0.05 µm) used as toolroom standards for setting other gauging tools
- workshop (B): large tolerance (tolerance +0.25 µm to −0.15 µm) used as shop standards for precision measurement

More recent grade designations include (U.S. Federal Specification GGG-G-15C):

- 0.5 — generally equivalent to grade AAA
- 1 — generally equivalent to grade AA
- 2 — generally equivalent to grade A+
- 3 — compromise grade between A and B

and ANSI/ASME B89.1.9M, which defines both absolute deviations from nominal dimensions and parallelism limits as criteria for grade determination. Generally, grades are equivalent to former U.S. Federal grades as follows:

- 00 — generally equivalent to grade 1 (most exacting flatness and accuracy requirements)
- 0 — generally equivalent to grade 2
- AS-1 — generally equivalent to grade 3 (reportedly stands for American Standard - 1)
- AS-2 — generally less accurate than grade 3
- K — generally equivalent to grade 00 flatness (parallelism) with grade AS-1 accuracy

The ANSI/ASME standard follows a similar philosophy as set forth in ISO 3650.

History

The gauge block set, also known as "Jo Blocks", was developed by the Swedish inventor Carl Edvard Johansson. Johansson was employed in 1888 as an armourer inspector by the state arsenal Carl Gustafs stads Gevärsfaktori [Carl Gustaf Stad's Rifle Factory] in the town of Eskilstuna, Sweden. He was concerned with the expensive tools for measuring parts for the Remington rifles then in production under license at Carl Gustaf. When Sweden adopted a tailored variant of the Mauser carbine in 1894, Johansson was very excited about the chance to study Mauser's methods of measuring, in preparation for production under license at Carl Gustaf (which began several years later). However, a visit to the Mauser factory in Oberndorf am Neckar, Germany, turned out to be a disappointment. On the train home, he thought about the problem, and he came up with the idea of a set of blocks that could be combined to make up any measure.

There had already been a long history of increasing use of gauges up to this time, such as gauges for filing and go/no go gauges, which were custom-made individually in a toolroom for use on the shop floor; but there had never been super-precision gauge blocks that could be wrung together to make up different lengths, as Johansson now envisioned.

Back home, Johansson converted his wife's Singer sewing machine to a grinding and lapping machine. He preferred to carry out this precision work at home, as the grinding machines at the rifle factory were not good enough. His wife, Margareta, helped him a lot with the grinding besides the household work. Once Johansson had demonstrated his set at Carl Gustaf, his employer provided time and resources for him to develop the idea. Johansson was granted his first Swedish patent on 2 May 1901, SE patent No. 17017, called "Gauge Block Sets for Precision Measurement". Johansson formed the Swedish company CE Johansson AB (also known as 'CEJ') on 16 March 1917.

Johansson spent many years in America; during his life he crossed the Atlantic 22 times. The first CEJ gauge block set in America was sold to Henry M. Leland at the Cadillac Automobile Company around 1908. The first manufacturing plant in America for his gauge block sets was established in Poughkeepsie, Dutchess County, New York, in 1919. The economic environment of the post–World War I recession and depression of 1920–21 did not turn out so well for the company, so in 1923 he wrote a letter to Henry Ford of the Ford Motor Company, where he proposed a cooperation in order to save his company.

Henry Ford became interested, and on 18 November 1923 he began working for Henry Ford in Dearborn, Michigan. Hounshell (1984), citing Althin (1948) and various archive primary sources, says, "Henry Ford purchased the famous gaugemaking operation of the Swede C. E. Johansson in 1923 and soon moved it into the laboratory facility in Dearborn. Between 1923 and 1927, the Johansson division supplied 'Jo-blocks' to the Ford toolroom and any manufacturer who could afford them. It also made some of the Ford 'go' and 'no-go' gauges used in production as well as other precision production devices."

In 1936, at the age of 72, Johansson felt it was time to retire and go back to Sweden. He was awarded the large gold medal of the Royal Swedish Academy of Engineering Sciences in 1943, shortly after his death.

Gauge pins

Similar to gauge blocks, these are precision ground cylindrical bars for use in Go-NoGo gauges or similar applications.

Gauge rollers and balls

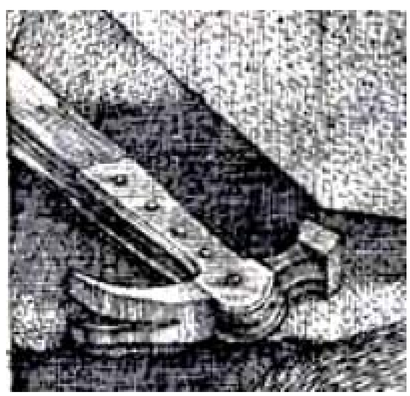
These are supplied as sets of individual rollers or balls as used in roller or ball bearings

Chapter 14

Hammer

A modern claw hammer

An early stone hammer



16th century claw hammer from Dürer's "Melencolia I" (1514)

A **hammer** is a tool meant to deliver an impact to an object. The most common uses are for driving nails, fitting parts, forging metal and breaking up objects. Hammers are often designed for a specific purpose, and vary widely in their shape and structure. The usual features are a handle and a head, with most of the weight in the head. The basic design is hand-operated, but there are also many mechanically operated models for heavier uses, such as steam hammers.

The hammer may be the oldest tool for which definite evidence exists. Stone hammers are known which are dated to 2,600,000 BCE.

The hammer is a basic tool of many professions. By analogy, the name **hammer** has also been used for devices that are designed to deliver blows, e.g. in the caplock mechanism of firearms.

History

The use of simple tools dates to about 2,400,000 BCE when various shaped stones were used to strike wood, bone, or other stones to break them apart and shape them. Stones attached to sticks with strips of leather or animal sinew were being used as hammers by about 30,000 BCE during the middle of the Paleolithic Stone Age. Its archeological record means it is perhaps the oldest human tool known.

Designs and variations

The essential part of a hammer is the head, a compact solid mass that is able to deliver the blow to the intended target without itself deforming.

The opposite side may have a ball, as in the ball-peen hammer and the cow hammer. Some upholstery hammers have a magnetized appendage, to pick up tacks. In the hatchet the hammer head is secondary to the cutting edge of the tool.

As the impact between steel hammer heads and the objects being hit can, and does, create sparks, which in some industries such as underground coal mining with methane gas, or in other hazardous environments containing flammable gases and vapours, can be dangerous and risk igniting the gases. In these environments, a variety of non-sparking metal tools are used, being principally, aluminium or beryllium copper-headed hammers.

In recent years the handles have been made of durable plastic or rubber. The hammer varies at the top; some are larger than others giving a larger surface area to hit different sized nails and such.

Popular hand-powered variations include:

- Ball-peen hammer, or mechanic's hammer
- Carpenter's hammers (used for nailing), such as the framing hammer and the claw hammer
- Construction hammers, including the sledgehammer
- Cross-peen hammer, or Warrington hammer
- Drilling hammer - a lightweight, short handled sledgehammer
- Gavel, used by judges and presiding authorities in general
- Geologist's hammer or rock pick
- Knife-edged hammer, its properties developed to aid a hammerer the act of slicing whilst bludgeoning
- Lump hammer, or club hammer
- Mallets, including the rubber hammer and dead blow hammer
- Soft-faced hammer

- Splitting maul
- Stonemason's hammer
- Tinner's Hammer
- Upholstery hammer

Mechanically powered hammer

Mechanically-powered hammers

Mechanically powered hammers often look quite different from the hand tools, but nevertheless most of them work on the same principle. They include:

- Hammer drill, that combines a jackhammer-like mechanism with a drill

- Jackhammer
- Steam hammer
- Trip hammer

In professional framing carpentry, the hammer has almost been completely replaced by the nail gun. In professional upholstery, its chief competitor is the staple gun.

Tools used in conjunction with hammers

- Masonry star drill
- Anvil
- Chisel
- Punch
- Woodsplitting maul - can be hit with a sledgehammer for splitting wood.
- Woodsplitting wedge - hit with a sledgehammer for splitting wood.

The physics of hammering

Hammer as a force amplifier

A hammer is basically a force amplifier that works by converting mechanical work into kinetic energy and back.

In the swing that precedes each blow, a certain amount of kinetic energy gets stored in the hammer's head, equal to the length D of the swing times the force f produced by the muscles of the arm and by gravity. When the hammer strikes, the head gets stopped by an opposite force coming from the target; which is equal and opposite to the force applied by the head to the target. If the target is a hard and heavy object, or if it is resting on some sort of anvil, the head can travel only a very short distance d before stopping. Since the stopping force F times that distance must be equal to the head's kinetic energy, it follows that F will be much greater than the original driving force f — roughly, by a factor D/d. In this way, great strength is not needed to produce a force strong enough to bend steel, or crack the hardest stone.

Effect of the head's mass

The amount of energy delivered to the target by the hammer-blow is equivalent to one half the mass of the head times the square of the head's speed at the time of impact ($E = \frac{mv^2}{2}$). While the energy delivered to the target increases linearly with mass, it increases geometrically with the speed. High tech titanium heads are lighter and allow for longer handles, thus increasing velocity and delivering more energy with less arm fatigue than that of a steel head hammer of the same weight. As hammers must be used in many circumstances, where the position of the person using them cannot be taken for granted, trade-offs are made for the sake of practicality. In areas where one has plenty of room, a long handle with a heavy head (like a sledge hammer) can deliver the maximum amount of energy to the target. It is not practical to use such a large hammer for all tasks, however, and thus the overall design has been modified repeatedly to achieve the optimum utility in a wide variety of situations.

Effect of the handle

The handle of the hammer helps in several ways. It keeps the user's hands away from the point of impact. It provides a broad area that is better-suited for gripping by the hand. Most importantly, it allows the user to maximize the speed of the head on each blow. The primary constraint on additional handle length is the lack of space in which to swing the hammer. This is why sledge hammers, largely used in open spaces, can have handles that are much longer than a standard carpenter's hammer. The second most important constraint is more subtle. Even without considering the effects of fatigue, the longer the handle, the harder it is to guide the head of the hammer to its target at full speed. Most designs are a compromise between practicality and energy efficiency. Too long a handle: the hammer is inefficient because it delivers force to the wrong place, off-target. Too short a handle: the hammer is inefficient because it doesn't deliver enough force, requiring more blows to complete a given task. Recently, modifications have also been made with respect to the effect of the hammer on the user. A titanium head has about 3% recoil and can result in greater efficiency and less fatigue when compared to a steel head with about 27% recoil. Handles made of shock-absorbing materials or varying angles attempt to make it easier for the user to continue to wield this age-old device, even as nail guns and other powered drivers encroach on its traditional field of use.

Effect of gravity

Gravity will exert a force on the hammer head. If hammering downwards gravity will increase the acceleration during the hammer stroke and increase the energy delivered with each blow. If hammering upwards gravity will reduce the acceleration during the hammer stroke and therefore reduce the energy delivered with each blow. Some hammering methods rely entirely on gravity for acceleration on the down stroke.

War hammers

A war hammer is a late medieval weapon of war intended for close combat action.

Symbolic hammers

The hammer, being one of the most used tools by *Homo sapiens*, has been used very much in symbols and arms. In the Middle Ages it was used often in blacksmith guild logos, as well as in many family symbols. The most recognised symbol with a hammer in it is the Hammer and Sickle, which was the symbol of the former Soviet Union and is very interlinked with Communism/Socialism. The hammer in this symbol represents the industrial working class (and the sickle the agricultural working class). The hammer is used in some coat of arms in (former) socialist countries like East Germany.

In Norse Mythology, Thor, the god of thunder and lightning, wields a hammer named Mjolnir. Many artifacts of decorative hammers have been found, leading modern practitioners of this religion to often wear reproductions as a sign of their faith.

Claw hammer

Framing hammer

Geologist's hammer

Upholstery hammer

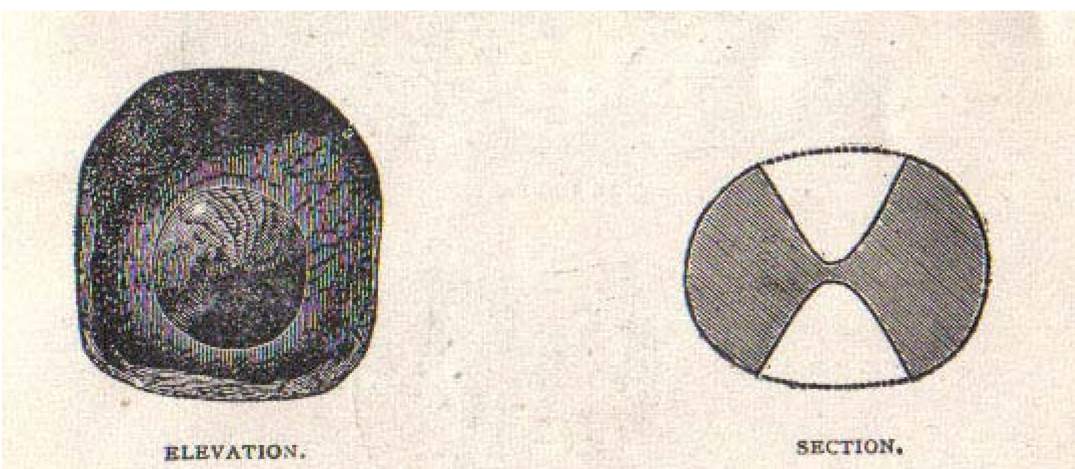
Cross-peen hammer

Ball-peen hammer

Rubber mallet

Wooden mallet

Sledgehammer



Stone tapping hammer