= Broaching (metalworking) =

Broaching is a machining process that uses a toothed tool , called a broach , to remove material . There are two main types of broaching : linear and rotary . In linear broaching , which is the more common process , the broach is run linearly against a surface of the workpiece to effect the cut . Linear broaches are used in a broaching machine , which is also sometimes shortened to broach . In rotary broaching , the broach is rotated and pressed into the workpiece to cut an axis symmetric shape . A rotary broach is used in a lathe or screw machine . In both processes the cut is performed in one pass of the broach , which makes it very efficient .

Broaching is used when precision machining is required , especially for odd shapes . Commonly machined surfaces include circular and non @-@ circular holes , splines , keyways , and flat surfaces . Typical workpieces include small to medium @-@ sized castings , forgings , screw machine parts , and stampings . Even though broaches can be expensive , broaching is usually favored over other processes when used for high @-@ quantity production runs .

Broaches are shaped similar to a saw , except the height of the teeth increases over the length of the tool . Moreover , the broach contains three distinct sections : one for roughing , another for semi @-@ finishing , and the final one for finishing . Broaching is an unusual machining process because it has the feed built into the tool . The profile of the machined surface is always the inverse of the profile of the broach . The rise per tooth (RPT) , also known as the step or feed per tooth , determines the amount of material removed and the size of the chip . The broach can be moved relative to the workpiece or vice versa . Because all of the features are built into the broach no complex motion or skilled labor is required to use it . A broach is effectively a collection of single @-@ point cutting tools arrayed in sequence , cutting one after the other ; its cut is analogous to multiple passes of a shaper .

= = Process = =

The process depends on the type of broaching being performed . Surface broaching is very simple as either the workpiece is moved against a stationary surface broach , or the workpiece is held stationary while the broach is moved against it .

Internal broaching is more involved . The process begins by clamping the workpiece into a special holding fixture , called a workholder , which mounts in the broaching machine . The broaching machine elevator , which is the part of the machine that moves the broach above the workholder , then lowers the broach through the workpiece . Once through , the broaching machine 's puller , essentially a hook , grabs the pilot of the broach . The elevator then releases the top of the pilot and the puller pulls the broach through the workpiece completely . The workpiece is then removed from the machine and the broach is raised back up to reengage with the elevator . The broach usually only moves linearly , but sometimes it is also rotated to create a spiral spline or gun @-@ barrel rifling .

Cutting fluids are used for three reasons ;

to cool the workpiece and broach

to lubricate cutting surfaces

to flush the chips from the teeth .

Fortified petroleum cutting fluids are the most common . However , heavy @-@ duty water @-@ soluble cutting fluids are being used because of their superior cooling , cleanliness , and non @-@ flammability .

= = Usage = =

Broaching was originally developed for machining internal keyways . However , it was soon discovered that broaching is very useful for machining other surfaces and shapes for high volume workpieces . Because each broach is specialized to cut just one shape either the broach must be specially designed for the geometry of the workpiece or the workpiece must be designed around a

standard broach geometry . A customized broach is usually only viable with high volume workpieces , because the broach can cost US $ 15 @,@ 000 to US $ 30 @,@ 000 to produce .

Broaching speeds vary from 20 to 120 surface feet per minute (SFPM) . This results in a complete cycle time of 5 to 30 seconds . Most of the time is consumed by the return stroke , broach handling , and workpiece loading and unloading .

The only limitations on broaching are that there are no obstructions over the length of the surface to be machined , the geometry to be cut does not have curves in multiple planes , and that the workpiece is strong enough to withstand the forces involved . Specifically for internal broaching a hole must first exist in the workpiece so the broach can enter . Also , there are limits on the size of internal cuts . Common internal holes can range from 0 @.@ 125 to 6 in (3 @.@ 2 to 152 @.@ 4 mm) in diameter but it is possible to achieve a range of 0 @.@ 05 to 13 in (1 @.@ 3 to 330 @.@ 2 mm) . Surface broaches ' range is usually 0 @.@ 075 to 10 in (1 @.@ 9 to 254 @.@ 0 mm) , although the feasible range is 0 @.@ 02 to 20 in (0 @.@ 51 to 508 @.@ 00 mm) .

Tolerances are usually ± 0 @.@ 002 in (± 0 @.@ 05 mm) , but in precise applications a tolerance of ± 0 @.@ 0005 in (± 0 @.@ 01 mm) can be held . Surface finishes are usually between 16 and 63 microinches (?in) , but can range from 8 to 125 ?in . There may be minimal burrs on the exit side of the cut .

Broaching works best on softer materials , such as brass , bronze , copper alloys , aluminium , graphite , hard rubbers , wood , composites , and plastic . However , it still has a good machinability rating on mild steels and free machining steels . When broaching , the machinability rating is closely related to the hardness of the material . For steels the ideal hardness range is between 16 and 24 Rockwell C (HRC) ; a hardness greater than HRC 35 will dull the broach quickly . Broaching is more difficult on harder materials , stainless steel and titanium , but is still possible .

= = Types = =

Broaches can be categorized by many means :
Use : internal , or surface
Purpose : single , or combination
Motion : push , pull , or stationary
Construction : solid , built @-@ up , hollow or shell
Function : roughing , sizing , or burnishing

If the broach is large enough the costs can be reduced by using a built @-@ up or modular construction . This involves producing the broach in pieces and assembling it . If any portion wears out only that section has to be replaced , instead of the entire broach .

Most broaches are made from high speed steel (HSS) or an alloy steel ; TiN coatings are common on HSS to prolong life . Except when broaching cast iron , tungsten carbide is rarely used as a tooth material because the cutting edge will crack on the first pass .

= = = Surface broaches = = =

The slab broach is the simplest surface broach . It is a general purpose tool for cutting flat surfaces .

Slot broaches (G & H) are for cutting slots of various dimensions at high production rates . Slot broaching is much quicker than milling when more than one slot needs to be machined , because multiple broaches can be run through the part at the same time on the same broaching machine .

Contour broaches are designed to cut concave , convex , cam , contoured , and irregular shaped surfaces .

Pot broaches are cut the inverse of an internal broach ; they cut the outside diameter of a cylindrical workpiece . They are named after the pot looking fixture in which the broaches are mounted ; the fixture is often referred to as a " pot " . The pot is designed to hold multiple broaching tools concentrically over its entire length . The broach is held stationary while the workpiece is pushed or pulled through it . This has replaced hobbing for some involute gears and cutting external splines

and slots .

Straddle broaches use two slab broaches to cut parallel surfaces on opposite sides of a workpiece in one pass . This type of broaching holds closer tolerances than if the two cuts were done independently . It is named after the fact that the broaches " straddle " the workpiece on multiple sides .

= = = Internal broaches = = =

Solid broaches are the most common type ; they are made from one solid piece of material . For broaches that wear out quickly shell broaches are used ; these broaches are similar to a solid broach , except there is a hole through the center where it mounts on an arbor . Shell broaches cost more initially , but save the cost overall if the broach must be replaced often because the pilots are on the mandrel and do not have to be reproduced with each replacement .

Modular broaches are commonly used for large internal broaching applications . They are similar to shell broaches in that they are a multi @-@ piece construction . This design is used because it is cheaper to build and resharpen and is more flexible than a solid design .

A common type of internal broach is the keyway broach (C & D) . It uses a special fixture called a horn to support the broach and properly locate the part with relation to the broach .

A concentricity broach is a special type of spline cutting broach which cuts both the minor diameter and the spline form to ensure precise concentricity .

The cut @-@ and @-@ recut broach is used to cut thin @-@ walled workpieces . Thin @-@ walled workpieces have a tendency to expand during cutting and then shrink afterward . This broach overcomes that problem by first broaching with the standard roughing teeth , followed by a " breathing " section , which serves as a pilot as the workpiece shrinks . The teeth after the " breathing " section then include roughing , semi @-@ finishing , and finishing teeth .

= = = Design = = =

For defining the geometry of a broach an internal type is shown below . Note that the geometries of other broaches are similar .

where :

The most important characteristic of a broach is the rise per tooth (RPT) , which is how much material is removed by each tooth . The RPT varies for each section of the broach , which are the roughing section (tr) , semi @-@ finishing section (ts) , and finishing section (tf) . The roughing teeth remove most of the material so the number of roughing teeth required dictates how long the broach is . The semi @-@ finishing teeth provide surface finish and the finishing teeth provide the final finishing . The finishing section 's RPT (tf) is usually zero so that as the first finishing teeth wear the later ones continue the sizing function . For free @-@ machining steels the RPT ranges from 0 @.@ 006 to 0 @.@ 001 in (0 @.@ 152 to 0 @.@ 025 mm) . For surface broaching the RPT is usually between 0 @.@ 003 to 0 @.@ 006 in (0 @.@ 076 to 0 @.@ 152 mm) and for diameter broaching is usually between 0 @.@ 0012 to 0 @.@ 0025 in (0 @.@ 030 to 0 @.@ 064 mm) . The exact value depends on many factors . If the cut is too big it will impart too much stress into the teeth and the workpiece ; if the cut is too small the teeth rub instead of cutting . One way to increase the RPT while keeping the stresses down is with chip breakers . They are notches in the teeth designed to break the chip and decrease the overall amount of material being removed by any given tooth (see the drawing above) . For broaching to be effective , the workpiece should have 0 @.@ 020 to 0 @.@ 025 in (0 @.@ 51 to 0 @.@ 64 mm) more material than the final dimension of the cut .

The hook (?) angle is a parameter of the material being cut . For steel , it is between 15 and 20 ° and for cast iron it is between 6 and 8 ° . The back @-@ off (?) provides clearance for the teeth so that they don 't rub on the workpiece ; it is usually between 1 and 3 ° .

When radially broaching workpieces that require a deep cut per tooth , such as forgings or castings

, a rotor @-@ cut or jump @-@ cut design can be used ; these broaches are also known as free egress or nibbling broaches . In this design the RPT is designated to two or three rows of teeth . For the broach to work the first tooth of that cluster has a wide notch , or undercut , and then the next tooth has a smaller notch (in a three tooth design) and the final tooth has no notch . This allows for a deep cut while keeping stresses , forces , and power requirements low .

There are two different options for achieving the same goal when broaching a flat surface . The first is similar to the rotor @-@ cut design , which is known as a double @-@ cut design . Here four teeth in a row have the same RPT , but each progressive tooth takes only a portion of the cut due to notches in the teeth (see the image gallery below) . The other option is known as a progressive broach , which completely machines the center of the workpiece and then the rest of the broach machines outward from there . All of these designs require a broach that is longer than if a standard design were used .

For some circular broaches , burnishing teeth are provided instead of finishing teeth . They are not really teeth , as they are just rounded discs that are 0 @.@ 001 to 0 @.@ 003 in (0 @.@ 025 to 0 @.@ 076 mm) oversized . This results in burnishing the hole to the proper size . This is primarily used on non @-@ ferrous and cast iron workpieces .

The pitch defines the tooth construction , strength , and number of teeth in contact with the workpiece . The pitch is usually calculated from workpiece length , so that the broach can be designed to have at least two teeth in contact with the workpiece at any time ; the pitch remains constant for all teeth of the broach . One way to calculate the pitch is :

<formula>

= = Broaching machines = =

Broaching machines are relatively simple as they only have to move the broach in a linear motion at a predetermined speed and provide a means for handling the broach automatically . Most machines are hydraulic , but a few specialty machines are mechanically driven . The machines are distinguished by whether their motion is horizontal or vertical . The choice of machine is primarily dictated by the stroke required . Vertical broaching machines rarely have a stroke longer than 60 in (1 @.@ 5 m) .

Vertical broaching machines can be designed for push broaching , pull @-@ down broaching , pull @-@ up broaching , or surface broaching . Push broaching machines are similar to an arbor press with a guided ram ; typical capacities are 5 to 50 tons . The two ram pull @-@ down machine is the most common type of broaching machine . This style machine has the rams under the table . Pull @-@ up machines have the ram above the table ; they usually have more than one ram . Most surface broaching is done on a vertical machine .

Horizontal broaching machines are designed for pull broaching , surface broaching , continuous broaching , and rotary broaching . Pull style machines are basically vertical machines laid on the side with a longer stroke . Surface style machines hold the broach stationary while the workpieces are clamped into fixtures that are mounted on a conveyor system . Continuous style machines are similar to the surface style machines except adapted for internal broaching .

Horizontal machines used to be much more common than vertical machines ; however , today they represent just 10 % of all broaching machines purchased . Vertical machines are more popular because they take up less space .

Broaching is often impossible without the specific broaching or keyway machines unless you have a system that can be used in conjunction with a modern machining centre or driven tooling lathe ; these extra bits of equipment open up the possibility of producing keyways , splines and torx through one @-@ hit machining .

= = Rotary broaching = =

A somewhat different design of cutting tool that can achieve the irregular hole or outer profile of a broach is called a rotary broach or wobble broach . One of the biggest advantages to this type of

broaching is that it does not require a broaching machine , but instead is used on lathes , milling machines , screw machines or Swiss lathes .

Rotary broaching requires two tooling components : a tool holder and a broach . The leading (cutting) edge of the broach has a contour matching the desired final shape . The broach is mounted in a special tool holder that that allows it to freely rotate . The tool holder is special because it holds the tool so that its axis of rotation is inclined slightly to the axis of rotation of the work . A typical value for this misalignment is 1 ° . This angle is what produces a rotating edge for the broach to cut the workpiece . Either the workpiece or the tool holder is rotated . If the tool holder is rotated , the misalignment causes the broach to appear as though it is " wobbling " , which is the origin of the term wobble broach .

For internal broaching the sides of the broach are drafted inward so it becomes thinner ; for external broaching the sides are drafted outward , to make the pocket bigger . This draft keeps the broach from jamming ; the draft must be larger than the angle of misalignment . If the work piece rotates , the broach is pressed against it , is driven by it , and rotates synchronously with it . If the tool holder rotates , the broach is pressed against the workpiece , but is driven by the tool holder .

Ideally the tool advances at the same rate that it cuts . The ideal rate of cut is defined as :

Rate of cut [inches per rotation (IPR)] = (diameter of tool [inches]) × sin (Angle of misalignment [degrees])

If it advances much faster , then the tool becomes choked ; conversely , if it advances much slower , then an interrupted or zig @-@ zag cut occurs . In practice the rate of cut is slightly less than the ideal rate so that the load is released on the non @-@ cutting edge of the tool .

There is some spiraling of the tool as it cuts , so the form at the bottom of the workpiece may be rotated with respect to the form at the top of the hole or profile . Spiraling may be undesirable because it binds the body of the tool and prevents it from cutting sharply . One solution to this is to reverse the rotation in mid cut , causing the tool to spiral in the opposite direction . If reversing the machine is not practical , then interrupting the cut is another possible solution .

In general , a rotary broach will not cut as accurately as a push or pull broach . However , the ability to use this type of cutting tool on common machine tools is highly advantageous .

= = History = =

The concept of broaching can be traced back to the early 1850s , with the first applications used for cutting keyways in pulleys and gears . After World War I , broaching was used to rifle gun barrels . In the 1920s and 30s the tolerances were tightened and the cost reduced thanks to advances in form grinding and broaching machines .