The Broaching of Gears

Don Kosal

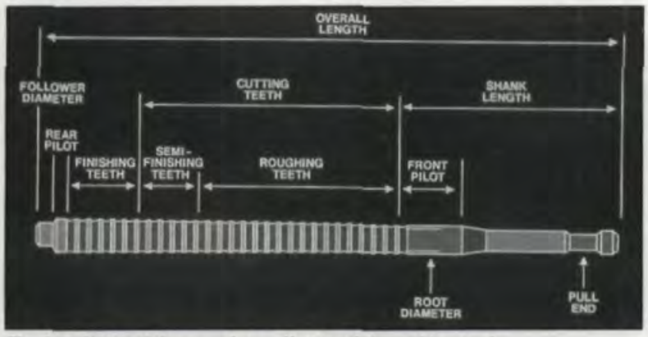


Fig. 1 — Parts of the round or spline tooth broaching tool.

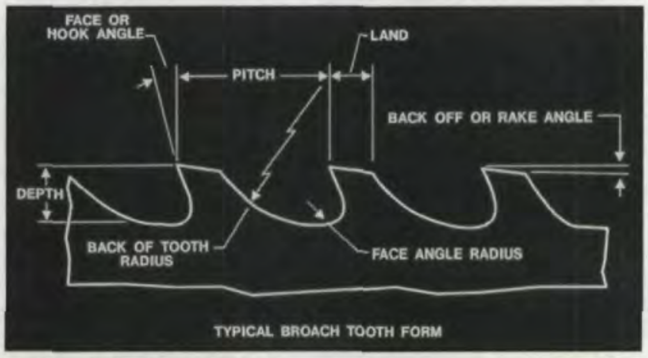
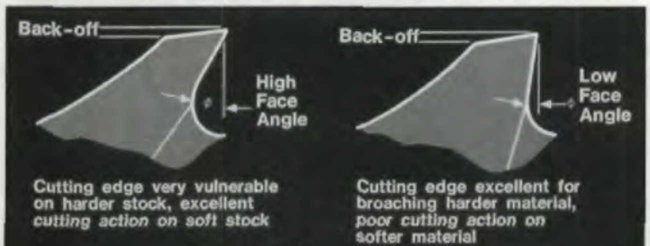


Fig. 2 — Parts of a broach tooth.



HARDNESS ROCKWELL "C"	HARDNESS BRINELL	HOOK ANGLE
40 TO 45	375 TO 429	5°
37 TO 39	352 TO 369	10°
33 TO 36	311 TO 341	12°
22 TO 32	235 TO 302	15°
12 TO 21	192 TO 229	18°
0 TO 11	153 TO 190	20°
UNDER 0	UNDER 153	22°

Fig. 3 — The face angle of a broach tooth is dependent on the type and hardness of the material being cut.

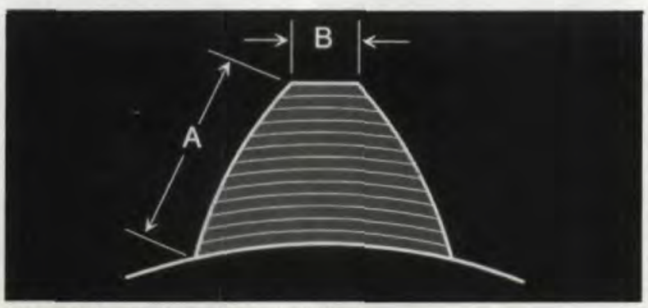


Fig. 4 — Diametral stepping or "nibbling."

Broaching is a process in which a cutting tool passes over or through a part piece to produce a desired form. A broach removes part material with a series of teeth, each one removing a specified amount of stock.

Broached parts come in various shapes and sizes. Diameters under .100" and over 11" can be produced by broaching. Lengths of cut vary from under .125" to over 12". Helical teeth, spur teeth, involutes, gears, straight-sided splines, cam splines and radius lobes can all be cut to tight tolerances using the broaching process. Broaching is often used to generate internal or external gear teeth and splines.

Nomenclature

First, let us discuss some basic nomenclature of the round or spline tooth broaching tool (see Fig. 1). The front end of the broach is called the *pull shank*. This is where the broach machine grabs the tool and pulls it through the part. The *shank length* is the distance from the front end of the broach to the cutting edge of the first tooth. This length is determined from the part face width, the broach puller length and the fixture setup on the machine. The *front pilot* guides the part onto the broach and acts as a gage so as not to accept any parts that may be undersized. The *rough*, *semi-finish* and *finishing* teeth generate the desired tooth form. The *rear pilot* guides the part off the broach, and the *follower* or *retriever* end supports the tail end of the tool during broaching.

The parts of a broach tooth are shown in Fig. 2. The distance between the cutting teeth is the *pitch*. This is determined by the length of cut of the part. Ideally, the designer will try to get one tooth to enter the cut of the part as another one exits. The *land* is the length of any particular cutting tooth. The length of the land reflects the amount of tool life the user can expect. The *depth* determines the amount of area available for the part chip.

The *face angle radius* (the radius just below the cutting edge that blends into the back of the tooth radius) must be kept constant through the life of the tool. The *back radius* (that on the back of the tooth in the chip space) should be polished and must blend smoothly with the face angle radius. Any mismatch between these two radii will increase the chances of the broach chips sticking in the gullet or chip space. This could lead to extensive damage on the tool.

The *face angle* is the angle of the cutting edge of the broach tooth. It is dependent upon the type of material being cut and in steels, the hardness of the material (see Fig. 3). The *backoff angle* (the relief angle behind the cutting edge of the tooth) provides clearance from the cutting edge and prevents the top of the broach from dragging through the part. The degree of backoff is determined by the part configuration and part tolerances.

Broaching Methods

The most common method of broaching is *diametral stepping*, or "nibbling," shown in Fig 4. The broach tooth corners generate the involute profile "A." The finishing teeth of the broach produce the major diameter portion "B." When generating the involute, the starting hole of the part guides the front pilot of the broach. Each successive cutting tooth increases in diameter until the desired form is generated. Since the corners of these teeth develop the profile form, it is crucial that these corners be properly maintained. There could be as many as 20,000 or more cutting corners on a broach. If these corners are not maintained, and one should become deformed, then the quality of the part finish suffers. Also, if one cutting corner is not functioning as designed, the following corner begins to "work" to a higher degree than was intended. This causes premature wear on that tooth, and this pattern will carry on progressively.

Nibbling leaves a poor surface, however. To correct this problem, another method of tooth form generation was developed. This is the *side shaving method* of finishing shown in Fig. 5. This method, used in conjunction with nibbling, increases the tooth thickness and full form shaves the entire involute profile.

Broaching Tools

The most common gear finishing broach tool used today is the *broach assembly*. The assembly consists of both a conventional form generating roughing bar, which performs the nibbling phase, and a full form finishing shell, which does the side shaving. In most applications, the full form shell offers the following advantages:

1. Low production cost when properly maintained. A full form cutting tool can produce a finished part in one simple operation.

2. Quality surface finish. The full form shell has an automatic shearing action and produces finishes as low as 7μ, RMS. Conventional generation broaches usually range between 50–80μ/inches.

3. Modified and precise involute profiles. Since the full form is being cut by the shell, it is possible to hold the desired profile form and required tooth thickness to high degrees of accuracy.

4. Extremely accurate tooth spacing and lead. Since the shell is a smaller piece, controlling of the manufacturing is much easier, and this control will be reflected in the quality of the part.

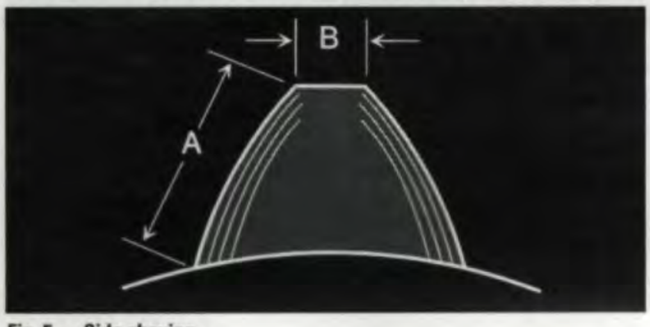


Fig. 5 — Side shaving.

Fig. 6 shows a typical assembly. Part B shows the arbor section of the roughing bar. The side shaving shell shown in Part C will be positioned on this arbor. Part D is the rear pilot locknut, which holds the shell in place.

One major requirement on most part prints and process sheets is a concentricity tolerance. As shown in Fig. 7, good concentricity can be obtained between the outside diameter and inside diameter. This is done with a dwell tooth section or alternating round and spline section. In this case, the spline teeth generate along the O.D. and qualify the major diameter. The full round teeth between the spline teeth remove stock in the spaces of the splines or minor diameter. Since both of the diameters are manufactured in the same operation, the concentricity between the O.D. and I.D. are virtually perfect.

The most requested type of concentricity is between the minor diameter and the pitch diameter, as shown in Fig. 8. The P.D./I.D. concentricity broach looks identical to the O.D./I.D. concentricity broach. However, instead of the spline teeth increasing on diameter, they step out on the spline tooth width. The full round teeth still generate on the diameter. Since the tooth thickness at the pitch diameter is being held with the minor diameter, the two will be concentric.

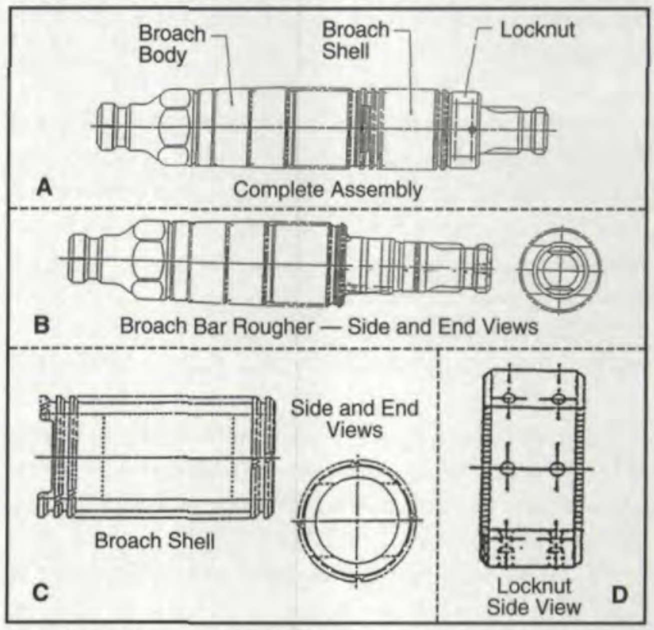


Fig. 6 Typical broach tool assembly.

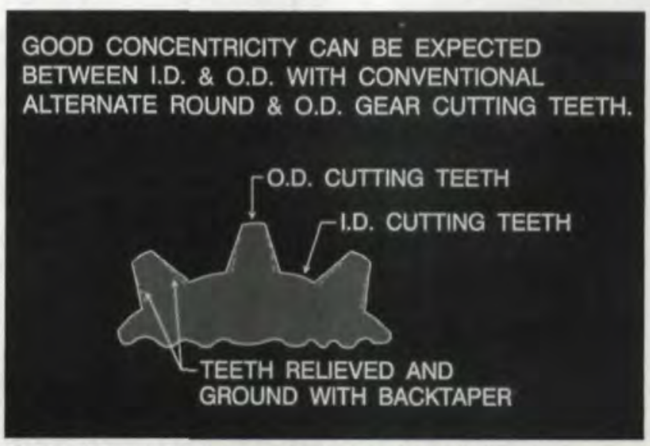


Fig. 7 — Concentricity between the inside and outside diameters.

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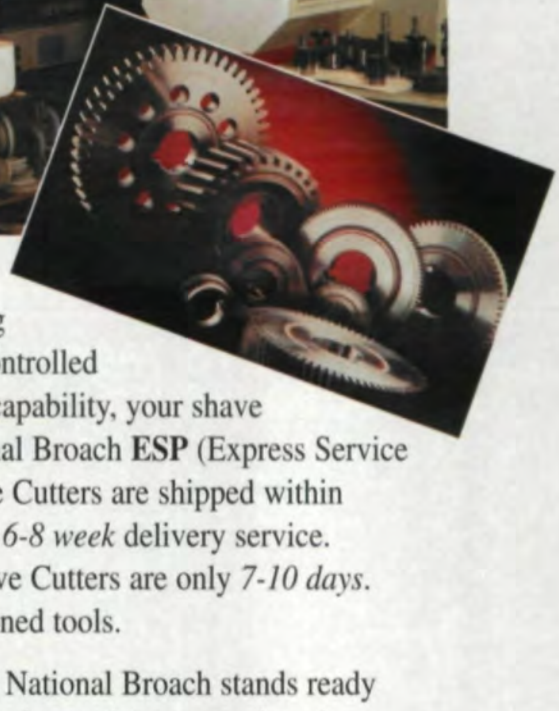

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If the diameter of the tool is large enough, the most effective means of supplying a P.D./I.D. concentricity tool is with the body and shell method. In that case, the rougher body generates a form with a smaller tooth thickness. It also cuts to a full depth and generates a protuberance tip to provide clearance for the shell outside diameter. The shell then qualifies the minor diameter and circular space width in the part simultaneously.

Internal running gears are good candidates for broaching. Because of broaching's suitability in high production applications, the quality demands of customers and the low cost per piece that broaching can offer, most automotive ring gears, both spur and helical, are manufactured by this process.

When broaching these ring gears, the pull broach assembly is recommended. The roughing bar in this assembly generates the basic involute form, leaving stock for the side shaving shell to finish (see Fig. 9).

Right or Left Hand?

The traditional helical broach can be identified for obtuse or acute and right- or left-hand helix by following some basic rules. The helix angles, shown in Figs. 10–11, distinguish the acute side of the broach cutting face. Conversely, the obtuse side produces an obtuse angle with the cutting face. To determine a right- or left-hand helix on the broach tool, simply look from one end of the cutting tool to the other. Whichever direction the spiral of the teeth run in is the hand of the helix angle. You can use the following methods to determine the hand and acute or obtuse side of the part:

1. When holding the part, the side of the broach entry should be facing you. Looking at the lower section of the part, the side of the teeth which can be seen is the obtuse side.

2. When you hold the part and look in the same manner, whichever shoulder the spiral of the splines points to indicates the hand of the helix.

Lead Bar and Drawbar Assemblies

Production of the helical ring gear requires some additional tooling—the lead bar and nut assembly shown in Fig. 12. As the broach passes through the part, the lead bar and nut assembly spin the broach on the identical lead of the teeth. Most helical broaching is performed on a vertical pull down machine; therefore, the driving flats on the broach are placed in the retriever end. The lead bar and broach bar must have identical leads. Otherwise increased torsional forces are applied, and the broach will cut an exaggerated form. For this reason, both bars should be manufactured from the same tooling.

Industry has demanded larger diameter tools to coincide with the increased number of splines in the ring gears. Therefore, new tooling designs, especially for earth moving vehicles, have been developed. Thus, the drawbar assembly was created. The reason a new concept was necessary was the ultimate weight of the tool. What the engineers designed was a long arbor called a drawbar (see Fig. 13). The drawbar can range up to a 6" maximum O.D. and 108" in length. The rougher body section is loaded from the front end of the drawbar. This roughing body has been made up

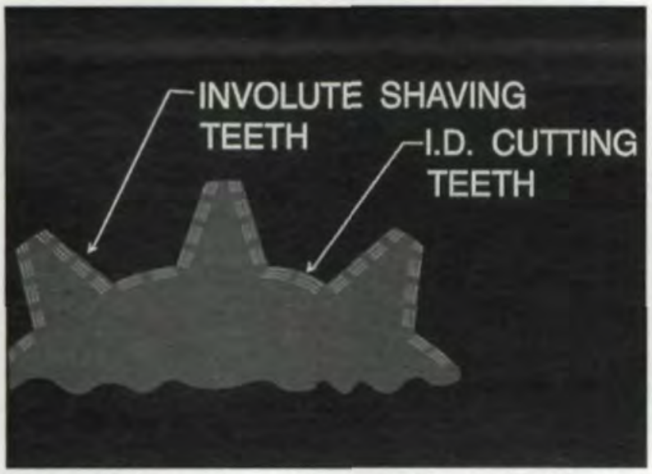

Fig. 8 — Good concentricity can be expected between I.D. & P.D. with special alternate round & involute shaving teeth.

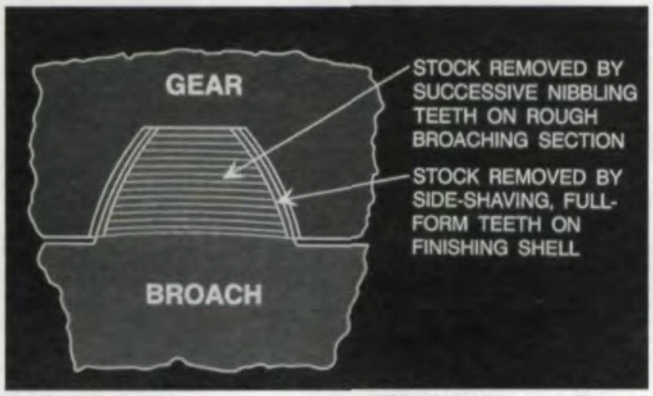

Fig. 9 — Successive stock removal by a full form finishing tool. The tool has both roughing and finishing sections. Nibbling teeth remove most of the material; then special side-shaving teeth remove 0.005" of stock or more from the entire thickness of the teeth. Only one operation is needed.

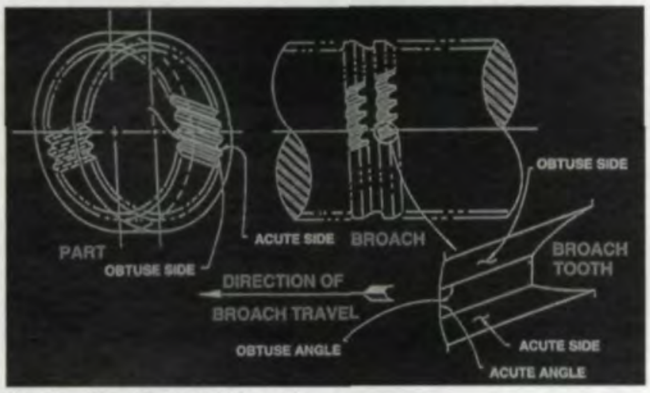

Fig. 10 — The left-hand helix angle.

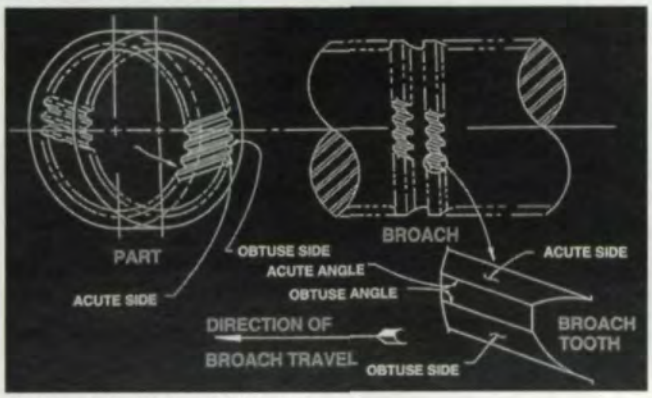

Fig. 11 — The right-hand helix angle.

Fig. 12 — A lead bar and nut assembly.

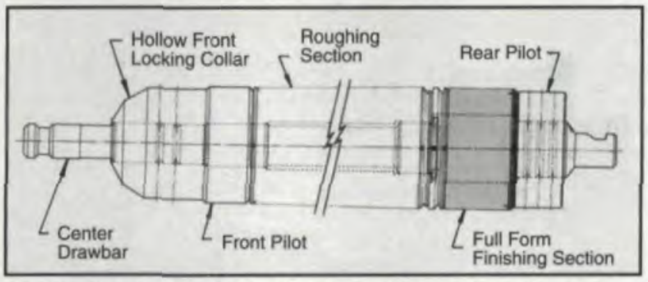

Fig. 13 — Construction details of a tensioned drawbar broaching tool.

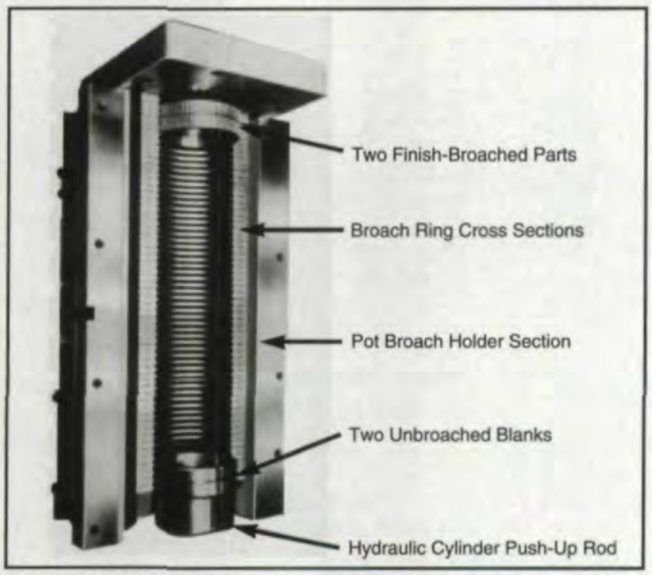

Fig. 14 — Cutaway view of pushup pot broaching process showing how two parts can be produced at a time.

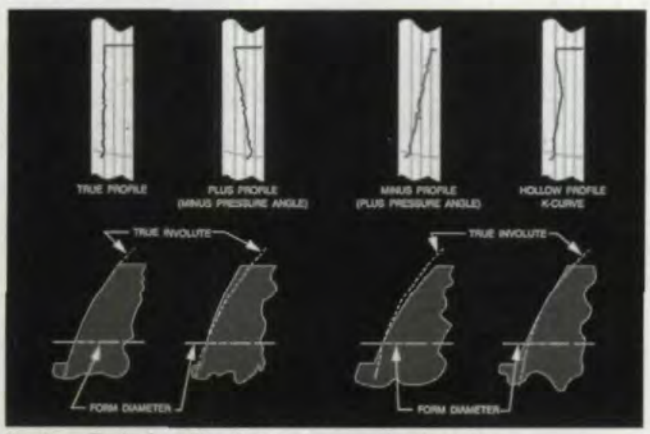

Fig. 15 — Typical profiles that can be ground on broaches.

to 11" in diameter and almost 70" in length with a 3" hole bored through the center. A front pilot and front locknut contain the roughing section against a positive stop designed in the drawbar. The full form finishing shell is mounted from the rear end of the drawbar. Then a rear pilot locknut is mounted and secured.

External Spline or Pot Broaching

The engineer has several options when choosing tools for broaching external splines. First, an all-broach ring or wafer assembly can be used. In this method, a set of rings each cut progressively into the outside diameter of the part. Therefore, the first cutting ring, having the largest minor diameter in the set, begins to break the surface of the part. Then each following ring gets smaller until the desired spline or involute form has been generated. The set of rings is assembled into a pot.

There are different types of pots, but the one shown in Fig. 14 will be the model used. Each ring has a precision cut location slot machined in its outside diameter. This slot provides the proper lineup from ring to ring as the cutting tools are mounted into the pot shell with the locating key. The O.D. of the rings rests on four precision ground rails, two in each pot shell half. A flat surface, ground off-center on the O.D. of the ring, is used as a visual check to make sure the rings were properly assembled. Once all the rings are placed in the half, the assembler can tell whether one ring was mistakenly put in backwards. If all the flats line up, the rings are in the same direction.

Broach rings can also be made to rough-cut a spline first. Then, using a few rings at the end of the assembly, it can be side shaved. This procedure gives a better involute form and better control of the circular tooth thickness.

Another means of generating teeth is the broach insert method. In this method broach inserts are mounted into holder rings, which are set in the pot shell halves in the same manner as in the broach ring method. From the outside of the hold ring, set screws are used to lock down the insert. Broach inserts offer more flexibility, but the spacing is not as accurate as a broach ring.

The third way is a combination of the two. This method offers the best of both worlds. Broach inserts can "hog out" the material and then give it a fine finish with a few side cutting rings. The deep splined sprocket gear is an ideal application. Some pots range in length from 10" of cutting teeth to 60". Part outside diameters of over 6" have been pot broached.

Manufacturing Broach Tools

Manufacturing of spline or gear toothed broaches has become an art with the increasing demand for tighter part tolerances. The broach tool must be processed carefully from the lathe through shipment. Once the certified tool stock is delivered to the manufacturing facility, this tender, loving care begins.

First the broach is turned, leaving a predetermined amount of grind stock, which is dependent on the diameter of the bar. The puller and retriever ends are roughed out. Then the spacing of cutting teeth and taper of the bar are established.

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From the green operations, the broach tool is sent to heat treat, where the cutting section is brought up to an approximate hardness of 64 Rockwell "C." The puller and retriever ends are then drawn down to about a 50 Rockwell "C." This is done to make the ends more durable so they can withstand the constant pounding applied during the broaching process.

After heat treatment, the broach goes to the O.D. grinder where all the diameters are finish ground. Tolerances of .0002" on diameter can be held at this operation. Next is the spline grind operation.

For gear teeth, a master template is used to generate the involute form (true or modified) on the broach tool. The template can reproduce the involute form within .0002" variation. For a sliding spline tooth, the tolerance of the involute profile is usually less critical. For this application, a radius and offset dressing is adequate. The radius approximates the involute and can be held within .0005" variation from a true involute.

Once the method of trimming the form on the grinding wheel has been decided, the operator will grind a "dummy" or a blank on which the profile can actually be inspected. Minor adjustments may be necessary. After the operator is satisfied with the form ground in the "dummy," the broach is ground and inspected.

Should the customer desire, the broach may be coated with one of the various types of surface treatments available. When completed, the broach tool is placed in a wooden box tailor-made for that particular tool. This prevents any unnecessary damage to the crafted broach.

True profiles, plus and minus profiles and hollow profiles all can be ground on broaches (See Fig. 15).

Given current technology, broaching cannot intentionally produce a crown on the flank of a gear tooth or a tapered hole. This is usually a product of the part configuration, such as a hub on one end of the part. From spline grind, the broach tool is face-ground or sharpened. Caution must be taken to apply the correct hook (face) angle, blend the gullet radii smoothly and minimize burrs.

From the beginning, broach manufacturers have steadily progressed to meet the challenges set before them. New and improved techniques for both design and manufacturing are always being developed. The main goal is to keep broaching a viable source for producing parts.

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Don Kosal *is a sales engineer with National Broach & Machine in Macomb, MI. He has many years' experience in broaching and has presented papers at SME and AGMA technical conferences.*

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