Back To Basics

Shaper Cutters–Design & Application Part 1

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Field of Application

Gear shaping is one of the most popular production choices in gear manufacturing. While the gear shaping process is really the most versatile of all the gear manufacturing methods and can cut a wide variety of gears, certain types of gears can only be cut by this process. These are gears closely adjacent to shoulders; gears adjacent to other gears, such as on countershafts; internal gears, either open or blind ended; crown or face gears; herringbone gears of the solid configuration or with a small center groove; racks; parts with filled-in spaces or teeth removed; and gears or splines with thick and thin teeth, such as are used in some clutches. Fig. 1 graphically illustrates the flexibility of the shaping process, and Fig. 2 shows some examples of gears which are mainly suitable to the shaping process, as well as some which may suit alternate methods, such as the rack. External spur and helical gears and pinions are the other conventional gears widely manufactured by the shaper cutter process.

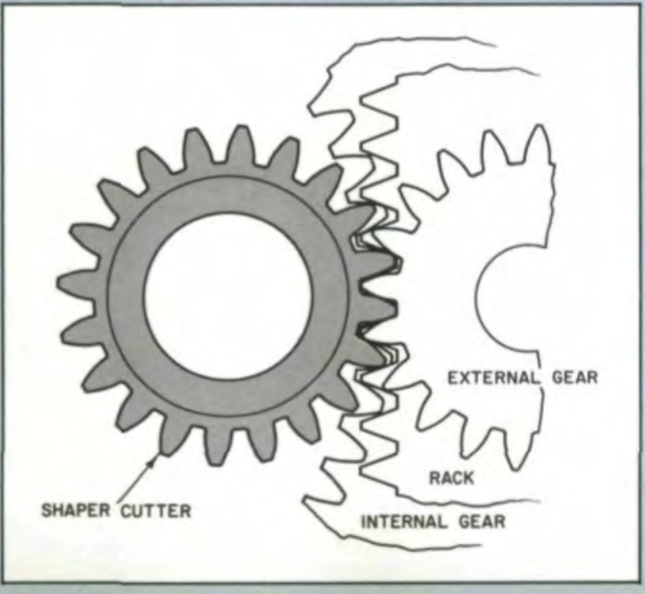

Fig. 1 – A single cutter can cut various gear types.

Other special involute and non-involute forms that can be shaped are roller chain sprockets, silent chain sprockets, and timing belt pulleys, as well as ratchets, saws, parallel key splines, involute splines, and many miscellaneous items.

Another shaper cutter type tool is used with a special machine to produce worms and similar screw items. In this configuration the tools are called thread generators.

The Shaping Method

The machining or cutting of gears with gear shaper cutters is a planing or shaping process involving a reciprocating motion of the tool, with chips being removed only on the forward direction of the stroke. On the return portion of the stroke no metal is cut, and the cutter and work must be separated so that the cutting edges are not dulled or damaged by dragging them backwards through the cut. This is a positive relieving action and is controlled by both the direction and amount of relief and must be established for each different application. On internal gears, with the enveloping of the gear around the cutter, it can be critical. The direction of work and cutter rotation also influence the direction or angle of the relieving motion and must be considered. On some machines the angle of relief is controlled by a cutter offset setting, and on others by a cam guide. The motions to develop the relieving action also can vary on different machines, with some moving the work away from the cutter and others moving the cutter away from the work.

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Fig. 2 – Group of gears cut by the shaping method.

For every stroke of the cutter ram, the cutter travels down, taking a cut, retracts, then returns to the top of the stroke cycle, and advances back into depth positioned for the next cut.

The cutting tool, that is, the shaper cutter, resembles a pinion or gear in appearance. It is relieved to create cutting edges and is usually constructed of one of the various tool steels. The machine contributes the reciprocating or stroking action and also steers the cutter in a timed rotary relation to the gear being cut, indexing the cutter-gear pair in a ratio according to the tooth numbers in cutter and tool and providing the plunging and feeding control.

The cutting edges of the cutter, if reciprocated along the cutter axis, sweep out an enveloping gear surface as seen in the phantom view in Fig. 3. This represents the cutting domain of the cutter.

The action provided by the gear cutting machine provides the motion needed to roll the cutter and blank together so that a generating action is developed. The generated result from a gear shaped involute cutting tool is a mating involute gear.

The length of stroke of the cutter must be just long enough to sweep from above the top face of the gear to just beyond the bottom face to allow the chip to separate, and the machine is adjusted to suit this requirement.

As the cutter approaches the circular blank at the initiation of the cut, it is gradually plunged into depth, while at the same time the circular indexing is taking place. The cutting process gradually removes material, and teeth are formed progressively on the blank periphery, until that point is reached where the teeth overlap and a complete gear is seen. Usually a second small infeed takes place, and a light finishing cut is made, duplicating the cycle and passing completely around the gear again. At this time the cutting action is relieved from most of the cutting load and freed from some of the blank material stresses.

It is not unusual when cutting herringbone gears that several roughing passes are made before the last final cut.

Body Types of Shaper Cutters

There are four basic types of gear shaper cutters in use.

Disk Type. This is the most common body type for shaper cutters. It is an arbor type cutter in the form of a disk with a central mounting hole, which is counterbored. It represents the optimum configuration for accuracy and use of tool steel in its construction. See Fig. 4.

Deep Counterbore Type. This is the second most used type of gear shaper cutter and is similar to the disk type, except it has a greater overall axial length to permit the use of a deeper counterbore for complete retention of the locking nut throughout the cutter life. See Fig. 5.

Deep counterbore cutters are used to cut into a clearance groove adjacent to a shoulder, to clear a raised hub or obstruction in the center of an internal gear, or to extend the

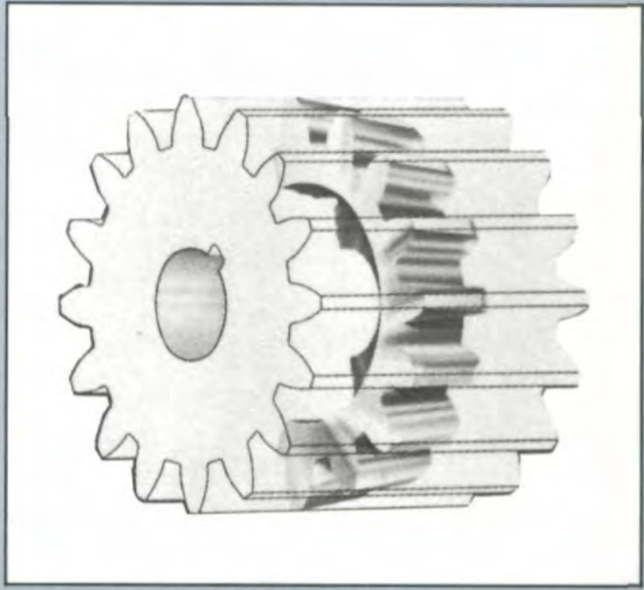

Fig. 3 – Envelope of reciprocated cutter.

Fig. 4 – Disk type cutter.

Fig. 5 – Deep counterbore cutter.

Fig. 6 – Shank type cutter.

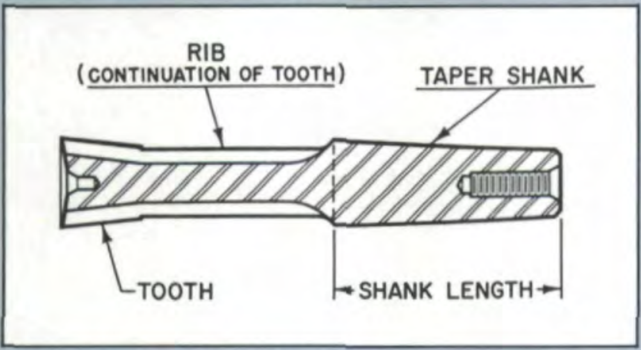

Fig. 7 – Shank type cutter with ribbed neck.

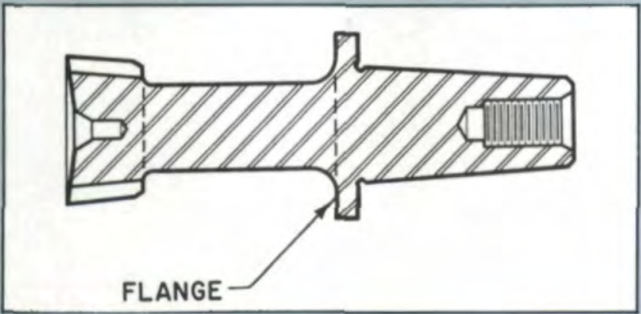

Fig. 8 – Shank type cutter with flange.

Fig. 9 – Straight shank cutter.

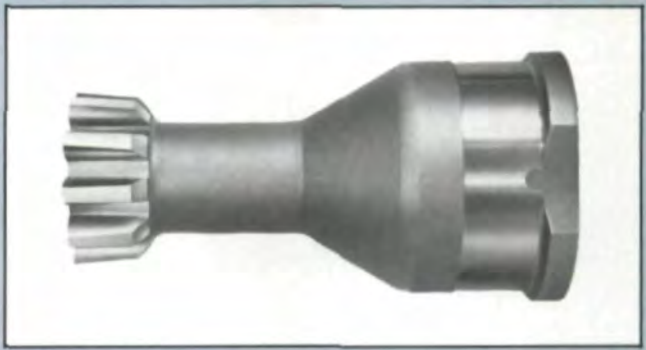

Fig. 10 – Hub type cutter.

reach of the cutter spindle. This cutter requires more tool steel to manufacture and slightly larger tolerances than a disk type.

Shank Type. This configuration is generally selected to cut a gear in a restricted space or for internal gears. The number of teeth is generally small, and the shank diameter size is picked accordingly from one of the four different standardized taper shank sizes. See Fig. 6.

If the cutter neck becomes too small and is weakened, a fluted or ribbed neck is used. The fluting lies just inside of the cutter form at the back face, thus increasing cutter strength. See Fig. 7.

Flange type shank cutters have a secondary mounting surface that comes into contact with the face of the cutter spindle, providing extra strength and stability of the cutter mounting. Taper diameter and flange must be sized closely so that the taper seats just prior to the flange making contact. See Fig. 8.

Most all taper shank cutters are made with a suitable standard sized tapped draw bar hole for securing the cutter in the spindle.

While straight or cylindrical shanks may be used, they are not a popular method of holding a shank type cutter. See Fig. 9.

Hub Type. This design is particularly adaptable to those sizes of cutters that fit between shank and hole type, and it can be mounted directly on the machine spindle without the use of a shank adapter. See Fig. 10.

Spur and Helical Cutters

Spur and helical gear shaper cutters look like spur and helical gears and are identified the same way. Spur cutter teeth have zero helix angle, and the teeth are aligned parallel to the cutter axis. Helical cutters have their teeth inclined at a helix angle to the cutter axis and follow along a helical path.

A right hand (RH) helical cutter is described the same way as a RH helical gear; that is, the teeth twist away from the observer in a clockwise direction. Likewise, on a left hand (LH) helical cutter, the teeth twist away from the observer in a counterclockwise direction.

A RH cutter produces LH external gears or RH internal gears. A LH cutter produces a RH external gear or a LH in-

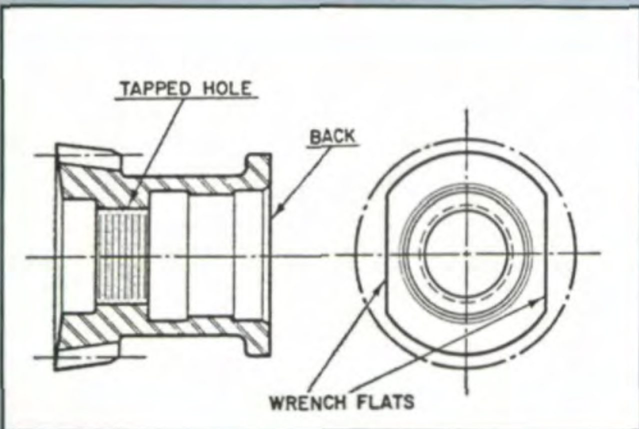

Fig. 10


Fig. 11 – RH helical cutter cutting a LH helical gear.

ternal gear. Fig. 11 shows a RH cutter engaged with a LH helical gear.

Herringbone Cutters

These are disk type cutters and are used in matched pairs of one RH and one LH cutter to generate true herringbone gears with solid continuous teeth. Sometimes a thin clearance groove is cut in the center of the gear face, which reduces the critical cutter stroke settings required with the solid style.

These cutters are also known as Sykes cutters in reference to the firm that originated this gear cutting process. See Fig. 12.

The gear geometry requires that the cutter face be flat, and a special groove and lip sharpening is used to have equal shear faces do the cutting.

Special herringbone machines are used to cut this type of true herringbone gear.

Cutter Blank Sizes

A source for some fundamental data on shaper cutter blank sizes is included in the ANSI Gear Shaper Cutters Standard. Besides giving the tolerance levels on the various elements, it gives suggested blank dimensions on nominal PD, bore, minimum counterbore, web, thickness, and nominal tooth length for spur and helical, disk and deep counterbore cutters for various diametral pitches. It also gives similar blank dimensions for herringbone cutters and, besides giving the four basic taper shank sizes, it gives some values for overall cutter length, pitch diameter, and tooth length based on the cutter diametral pitch.

These blank sizes are not fixed, but only a suggestion for a starting point and are usually fitted to the special circumstances encountered. At least if they are referenced, some realistic dimensions can be determined. Since the sizes usually minimize blank material, it is prudent to layout the planned dimensions for assurance of suitable strength and fit.


Fig. 12 – Set of RH and LH helical herringbone cutters.

Tooth Shape Change

As a shaper cutter is used and sharpened back, it changes in size. We can compare the profile at the front with that at the back and see a difference. Not only does the outside diameter become smaller, but also due to the side clearance, the tooth becomes thinner, and the tip width changes. Fig. 13 shows the profile of a spur cutter compared when new and at end of life.

The base circle does not change, but the cutter does use a lower segment of the involute curve. The base pitch remains constant, so during the entire life of the cutter a correct involute is cut.

If the base circle lies above the root of the cutter at the back, it is possible that the flank portion of the form below the base may come into action on the gear and cause a tip trimming or tip relief on the gear tooth. Fig. 14 illustrates an example of this action for a cutter with a small number of teeth at end of life.

If the base circle lies below the cutter root no involute trimming will occur at any time during the cutter life. Fig. 15 shows a cutter with these conditions. This is the preferred form for a good operating shaper cutter if other elements of geometry and circumstances permit.

Another area that is affected by the change in cutter size is the shape of the root fillet produced on the part. On an external gear the larger diameter, new cutter will produce a fillet with a larger radius of curvature. At end of life, the smaller diameter cutter produces a smaller radius fillet. Under normal circumstances the difference in actual fillet size is usually small and can be tolerated or, if necessary, adjustments made in the design parameters, such as cutter useful life, to minimize the effect.

Tooth Forms

Intentional modifications to the involute profile of the cut-

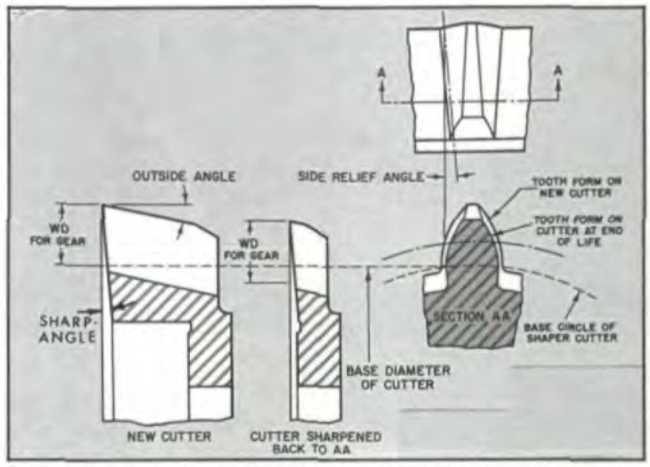

Fig. 13 – Illustrates change in profile from front to back on a spur cutter.

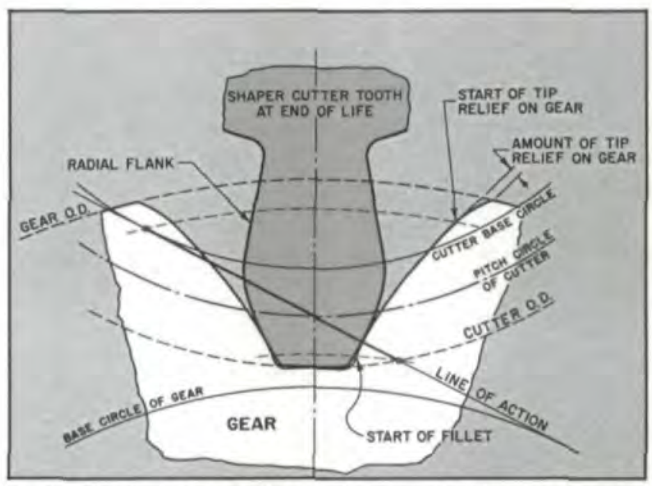

Fig. 14 – The effect of a radial flank on the form cut by trimming away part of the involute at the gear tip.

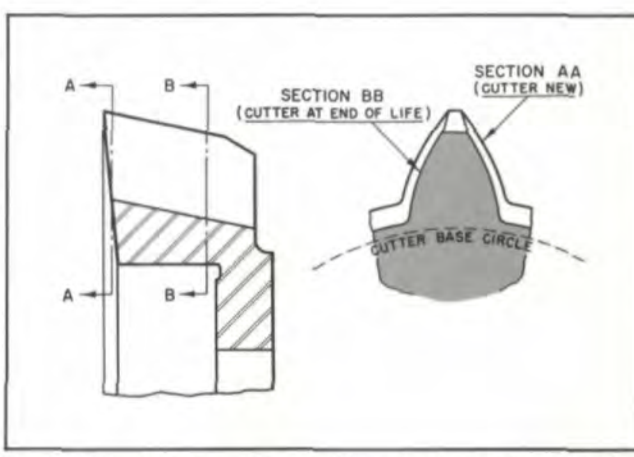

Fig. 15 – This sketch shows the case of the cutter base circle and involute lying above the cutter root diameter throughout the cutter's life. This is a preferred configuration.

ter to produce an alteration on the gear profile can fall into several categories.

Gear Tip Relief. Gear tip relief as shown in Fig. 16 can be produced by a cutter in three ways. The first method is by a constant approach built into the flank of the cutter that will cut a uniform tip relief throughout the cutter life. This is a controlled preferred method and is illustrated in Fig. 17.

The second is by using a straight flank tangent to the involute just above the base circle. This modification produces a variable amount of tip relief during cutter life. See Fig. 18.

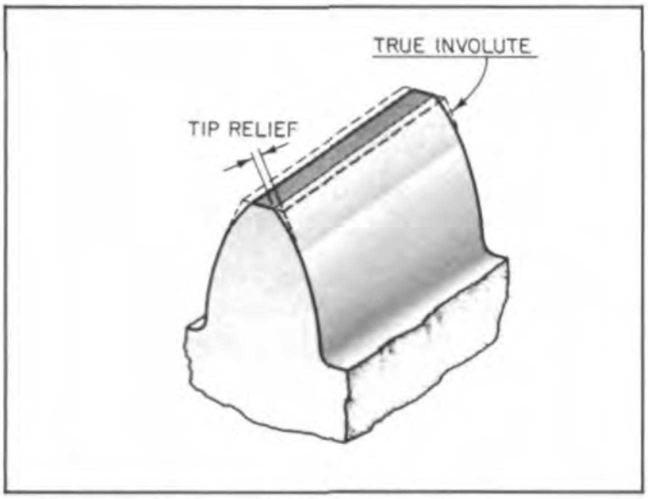

Fig. 16 – Isometric view of a gear tooth with a tip relief.

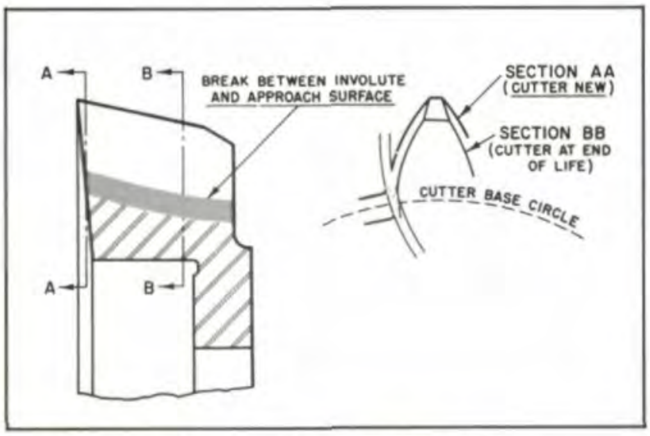

Fig. 17 – Diagram of a cutter with a "constant approach".

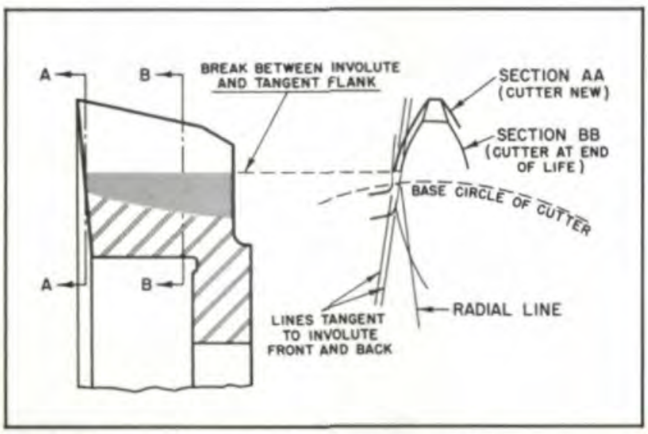

Fig. 18 – Diagram of a cutter with a "tangent approach".

The third is by using a radial flank tangent to the form at the base circle, which may produce no tip relief when the cutter is new and then gradually more as the cutter is sharpened back. See Fig. 19.

The latter two modifications are applied with a flat wheel generating grinder doing one flank at a time. The third way is not really used as a method of producing a specified relief, but can occur naturally because of the construction of some shaper cutters, especially those with low numbers of teeth and/or low pressure angles.

Gear Tip Chamfer. Whenever it is necessary to produce a tip chamfer on the gear being cut, such as is shown in Fig. 20, a semi-topping tooth form is used. A ramp is added to the cutter root flank and is located so a reasonably uniform chamfer is produced throughout the cutter life. See Fig. 21.

Gear Flank Undercut. When further processing is done on a gear after shaping, such as shaving, grinding, skiving, or cold rolling, the gear is prepared by undercutting the flank in-

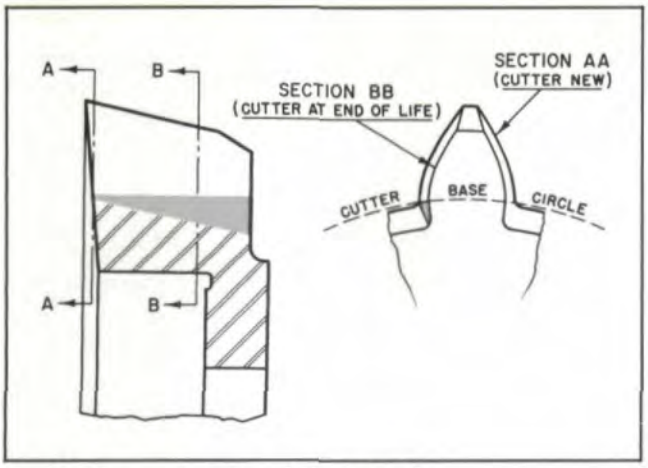

Fig. 19 – Diagram of a cutter with a radial flank.

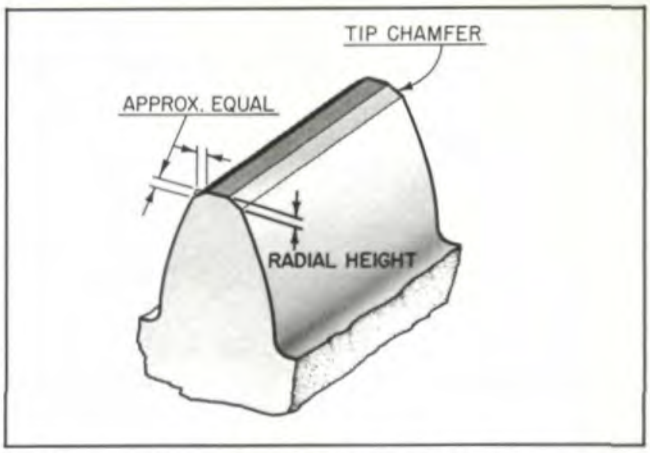

Fig. 20 – Isometric view of a gear tooth with a tip chamfer.

volute near the gear root. This is accomplished by the use of a protuberance on the cutter form. See Fig. 22.

Topping. Occasionally it is necessary to shape a gear, cutting the outside diameter at the same time that the gear is cut. Such a topping cutter is restricted to spur cutters and helical cutters with a circular sharpening.

Full Fillet Root. The tip of the cutter tooth generates the root fillet on the gear teeth. If the gear fillet is to be a full radius, then the cutter tip radius also will be full. For gears without a full radius a smaller corner radius or, in some cases, a small corner chamfer is used on the cutter tip.

Cutting Internal Gears

One of the very important applications of shaper cutters is the generation of internal spur and helical gears. Some extra considerations have to be given to the rather confining conditions of having the work part surrounding or enveloping the cutter.

The normal practice is to use as large a cutter as possible and still avoid the special geometry problems of internal gear cutting. Table 1 presents a listing of both a maximum and a minimum number of teeth suggested for the cutter for three different tooth form systems. Generally if a cutter is picked

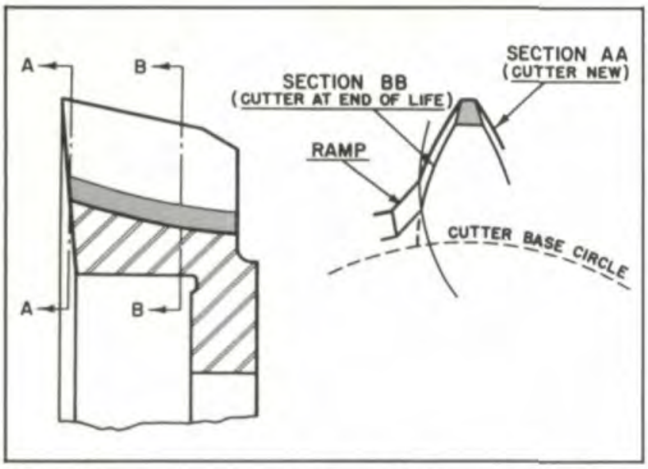

Fig. 21 – Diagram of a semi-topping cutter with a ramp which cuts the tip chamfer.

Table I
Size Guide for Selection of Shaper Cutters
For Internal Gears
All values in number of teeth

Internal Gear	20° Stub			20° Full Depth			25° Full Depth		
	Max. for Cutter	Max. in Pinion	Min. for Cutter	Max. for Cutter	Max. in Pinion	Min. for Cutter	Max. for Cutter	Max. in Pinion	Min. for Cutter
22	10	14	10	–	–	–	10	16	10
24	11	16	11	10	14	10	11	18	10
26	12	18	11	10	16	10	12	20	10
28	13	20	12	11	18	11	13	22	11
30	14	22	13	12	20	12	14	24	11
32	16	24	14	14	22	13	16	26	12
36	19	28	16	16	26	15	19	30	13
40	22	32	18	19	30	16	22	34	14
44	25	36	19	22	34	18	25	38	15
48	28	40	21	25	38	20	28	42	16
52	32	44	22	28	42	21	32	46	17
60	38	52	24	35	50	23	38	54	18
70	47	62	26	43	60	26	47	64	19
80	56	72	28	51	70	28	56	74	20

within the limits for the number of teeth being cut, it will be suitable. If there is any departure from standard proportions or if long or short addendums are used, the chart can only act as a guide.

There are four specific problem areas to be investigated.

Feed Fouling. Fig. 23 shows an example of a cutter that in effect overhangs part of the finish gear profile, and as it is fed radially into the part, it will machine away that part of a tooth flank. If this occurs, it generally means the cutter used had too many teeth. It was too big.

Rubbing Interference. Fig. 24 is an illustrated case of the cutter outline overlapping the cut teeth when the cutter is retracted for the return stroke. This would drag the cutter back, rubbing on the gear teeth. Cutter and part damage is likely. One solution is to first try a change in the relieving direction to see if a retraction path can be found to clear the interference. Another is to consider using a cutter with fewer teeth.

Flank Trimming. Fig. 25 shows a case of flank trimming on the addendum of the gear being cut during generation. In actuality a tip relief is produced, and if it is not acceptable on the product, it means the cutter may be too small or even undersize. It generally is corrected by using a larger number of cutter teeth or increasing cutter diameter.

Tip Fouling. Fig. 26 shows a geometrical phenomenon that also is unique to internal gears. As the cutter tip passes through a cycle of entering, generating, and leaving a tooth space, if its path crosses the corner of the gear tooth, it will machine away the interfering area. All the gear teeth are affected by this action if it occurs. In this case the cutter is too

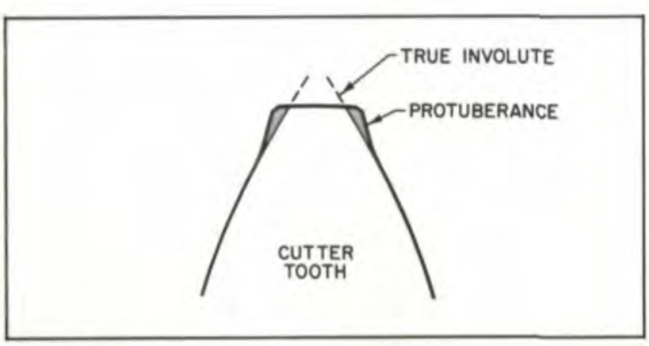

Fig. 22 – Gear shaper cutter tooth with protuberance.

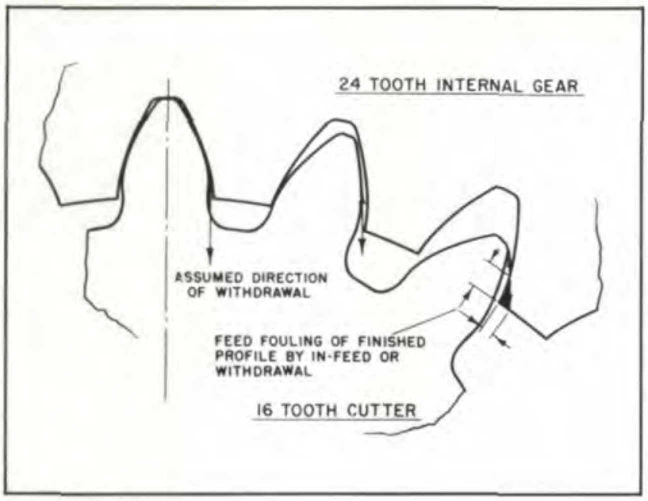

Fig. 23 – Feed Fouling.

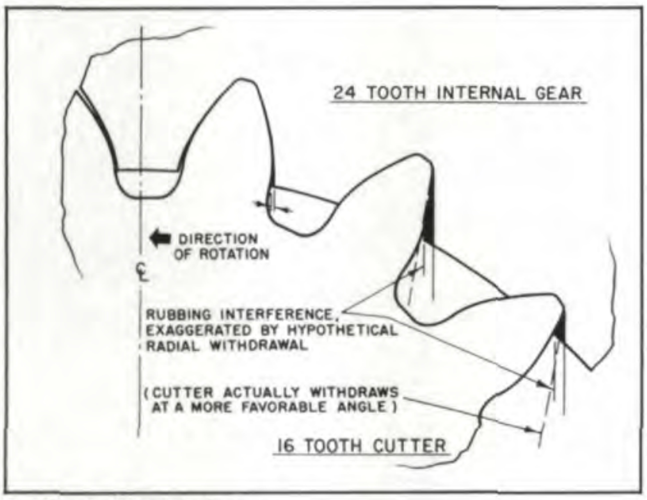

Fig. 24 – Rubbing Interference.

large, and a smaller number of teeth should be considered.

If for an urgent job, a cutter must be selected from an available stock list, and it violates the suggested tooth numbers, it is best to pick a lower cutter tooth number. There are less damaging problems with a smaller cutter.

In the above four cases, as well as the case of the influence of cutter oversize or undersize on the part/cutter relationship, the investigation of internal cutter design is a perfect problem

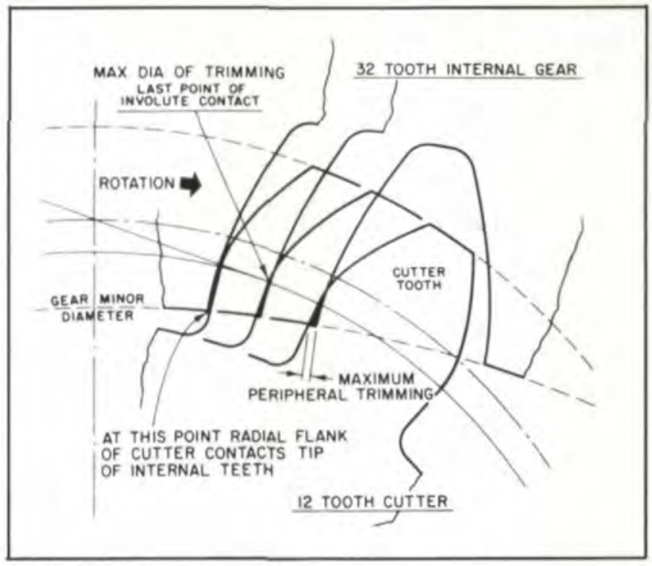

Fig. 25 – Flank Trimming.

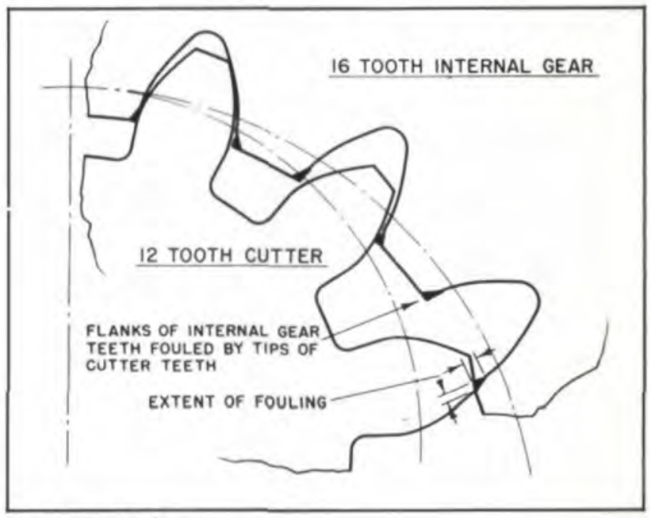

Fig. 26 – Tip Fouling.

for computer aided design. To be sure a cutter will work properly an analysis or mathematical model must be made. This assures all critical specifications, including gear root fillet, requirements are met.

Acknowledgement: *Presented at the SME Gear Processing and Manufacturing Clinic, November 1-3, 1988. Reprinted with permission of the Society of Manufacturing Engineers.*