Design Implications for Shaper Cutters

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A gear shaper cutter is actually a gear with relieved cutting edges and increased addendum for providing clearance in the root of the gear being cut. The maximum outside diameter of such a cutter is limited to the diameter at which the teeth become pointed. The minimum diameter occurs when the outside diameter of the cutter and the base circle are the same. These theoretical extremes, coupled with the side clearance, which is normally 2° for coarse pitch cutters and 1.5° for cutters approximately 24-pitch and finer, will determine the theoretical face width of a cutter.

At some point between the theoretical outside diameter extremes, there lies a desirable shaper cutter design. There are several factors that will limit the outside diameter, one being the necessity of ensuring that a reasonable amount of land remains on the tips of the cutter teeth. This amount ranges from a minimum of .100" on a 2-pitch cutter to .002" at 200 pitch. For example, a 6-pitch, 20° pressure angle cutter will have a minimum tip land of .060".

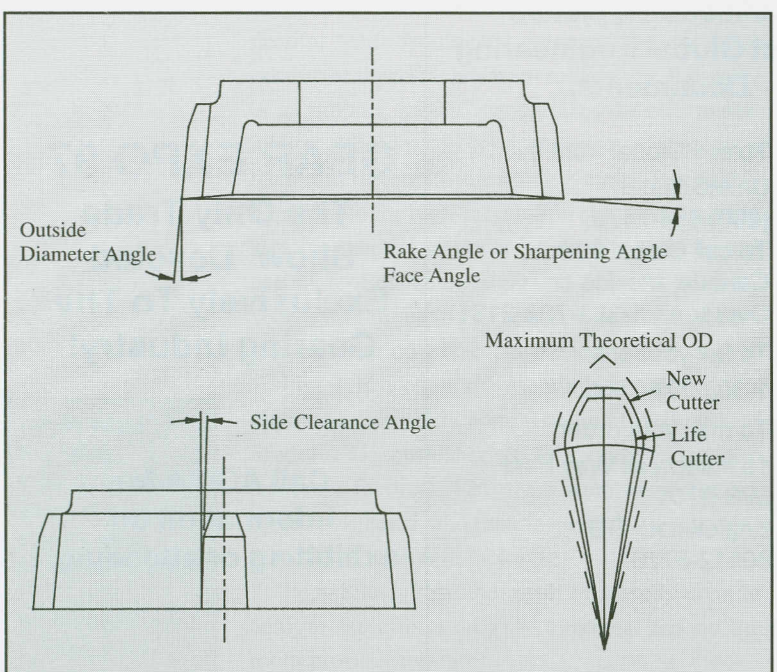

Fig. 1 — Cutter clearance angles and the sharpening angle.

All outside diameters of gear shaper cutters are ground to be tapered at the outside angle. This angle is so calculated as to produce a constant tooth thickness and depth of cut at the new and the approximate life positions of the cutter. The amount of this outside angle is dependent upon the operating pressure angle between the cutter and the work and the amount of the side clearance. These angles range from approximately 4° on a 30° pressure angle, 2° side clearance, up to 7.5°–8° on a 14.5° pressure angle and 2° side clearance (Fig. 1).

There are some cases where it is desirable to have a minor change in the involute from the Start of Active Profile (SAP) point to the outside diameter. This is quite common in finish cutting to alter bearing patterns, especially on heat treated parts, or to help improve profile in shaving operations. Most spur gear shaper cutters in the coarse pitch range are made with 2° side clearance angles and a 5° face angle. On this basis a 1° change in face angle will result in a .0013" change in profile on a 1-pitch rack. Other pitches are proportional; i.e., on a 6 DP gear, the change would be .0013/6" or .000217".

A higher face angle, say 8°, would result in a lower pressure angle or a plus involute of .00065" on a 6 DP gear. Conversely, a 2° face angle would result in a higher pressure angle or a minus involute of .00065" on the same 6 DP gear. Generally, face angles of less than 0° or above 10° are not recommended. An angle of 10° weakens the cutting tool edges and makes tools more prone to chipping. Relieving the tip approximately to the corner break at 0° face angle to improve cutter life is a common procedure on coarse pitch work (Fig. 2).

Fig. 2 shows the effect of changing the face to change the pressure angle produced. This will also change the amount of stock on the involute at the tip of the gear.

A Word of Caution: We have seen in Fig. 2 how changing the face angle can change the pressure angle. If one is not careful in sharpening the shaper cutter at the designated face angle, then an error in involute can be inadvertently imposed on the part being cut.

How to determine a new outside diameter and the new tooth thickness after a grind back or a design reduction is shown below.

$$\text{New } OD = OD - 2 * GB * \text{Tan}(ODA) \quad (1)$$

$$\text{New arc } T = PD * \left[\frac{\text{arc } T}{PD} - \frac{GB * \text{Tan}(SCA)}{BR} \right] \quad (2)$$

OD = Outside Diameter
GB = Grind Back
ODA = Outside Diameter Angle
arc$T$ = Arc Tooth Thickness at Pitch Diameter
PD = Pitch Diameter
SCA = Side Clearance Angle
BR = Base Radius

In Equation 2, the fraction of $\frac{GB * \text{Tan}(SCA)}{BR}$ is a small arc on the base diameter, as is $\frac{T}{PD}$.

Equation 2 is simply the arc length formula of $L = a * r$, where L is the arc length, a is the angle under the arc and r is the radius.

Fig. 3 shows the angles involved in finding the new tooth thickness after a grind back. Remember the formula for arc length: $L = a * r$

where:
L = Arc Length
a = Central Angle in Radians Described by the Arc
r = Radius to the Arc

Cutter manufacturers may define the side clearance angle either at the pitch diameter or the base diameter. If the SCA is defined at the pitch diameter, it may be converted to an angle on the base diameter.

Treating the SCA as a helix angle, we can use the proportion below to express the SCA at the base diameter.

$$\frac{\text{Tan}(SCA \text{ at } BD)}{BD} = \frac{\text{Tan}(SCA \text{ at } PD)}{PD} \quad (3)$$

$$\text{Tan}(SCA \text{ at } BD) = \frac{BD * \text{Tan}(SCA \text{ at } PD)}{PD} \quad (4)$$

The proportion in Equation 3 was derived from the formula for lead and the fact that the lead is constant and only the diameter and helix will change.

In cases where a cutter is designed to produce a specific part, the outside diameter of the cutter is determined so that the generated fillet or trochoid does not come above the start of active profile (SAP) or form diameter, based on the cutter having normal cornering (Fig. 4). The minimum diameter is designed to avoid excessive tip modification in the case of large gears or to avoid excessive undercut when cutting low pressure angle gears with small numbers of teeth (Fig. 5).

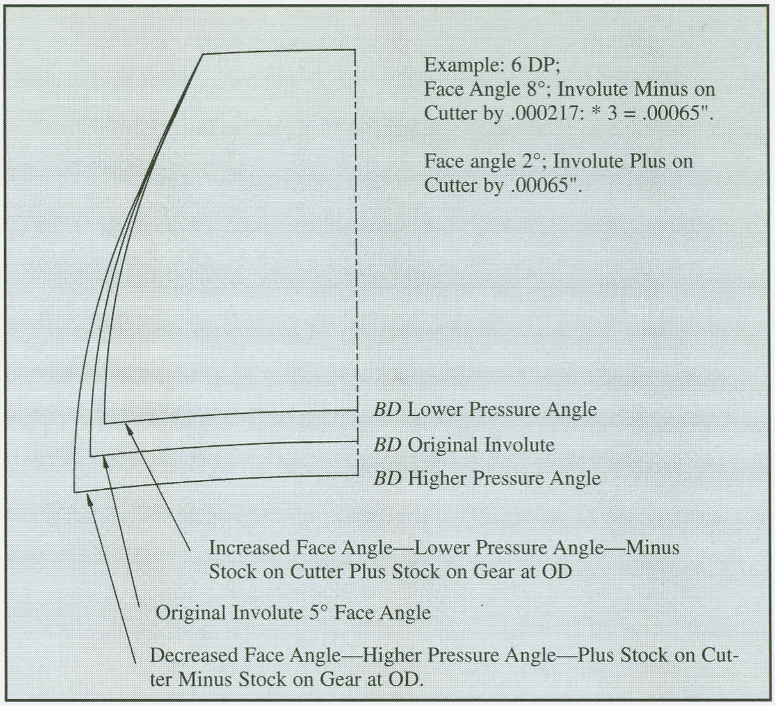

Fig. 2 — The effect of changing the face angle to change the pressure angle.

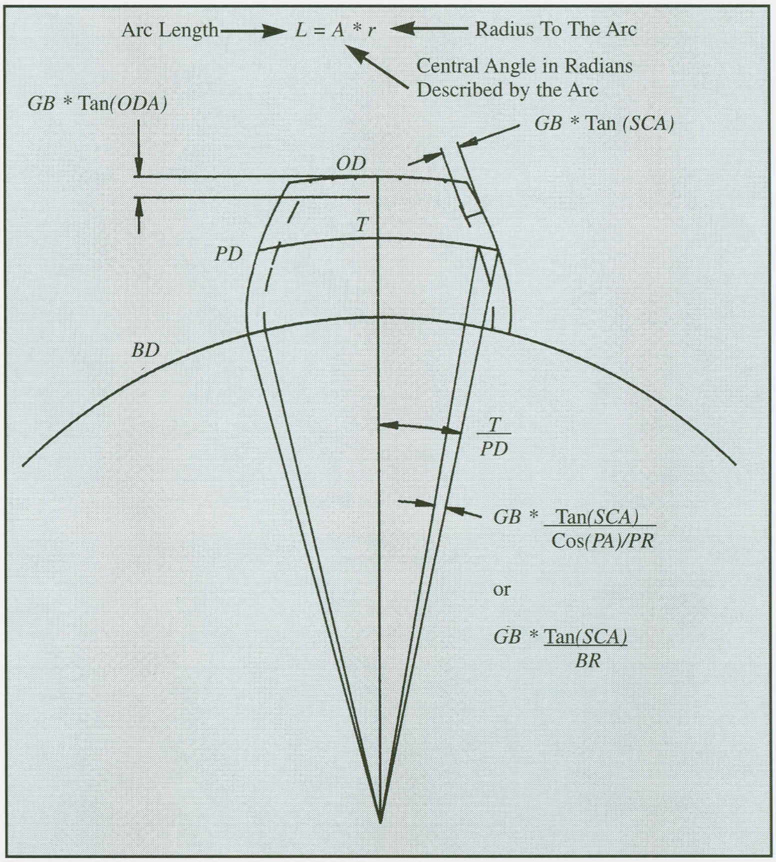

Fig. 3 — Angles involved in finding the new tooth thickness after a grind back.

Types of Shaper Cutters

Disc Cutter. These are the common pancake-type blanks with a minimum extended hub. Sizes normally run from 1" pitch diameter with a 1/2" hole up to 8" or 9" with 4" holes for use on larger capacity gear shapers. Most gear shaper cutters for modern gear shapers are equipped with unaligned driving keys to prevent cutters from

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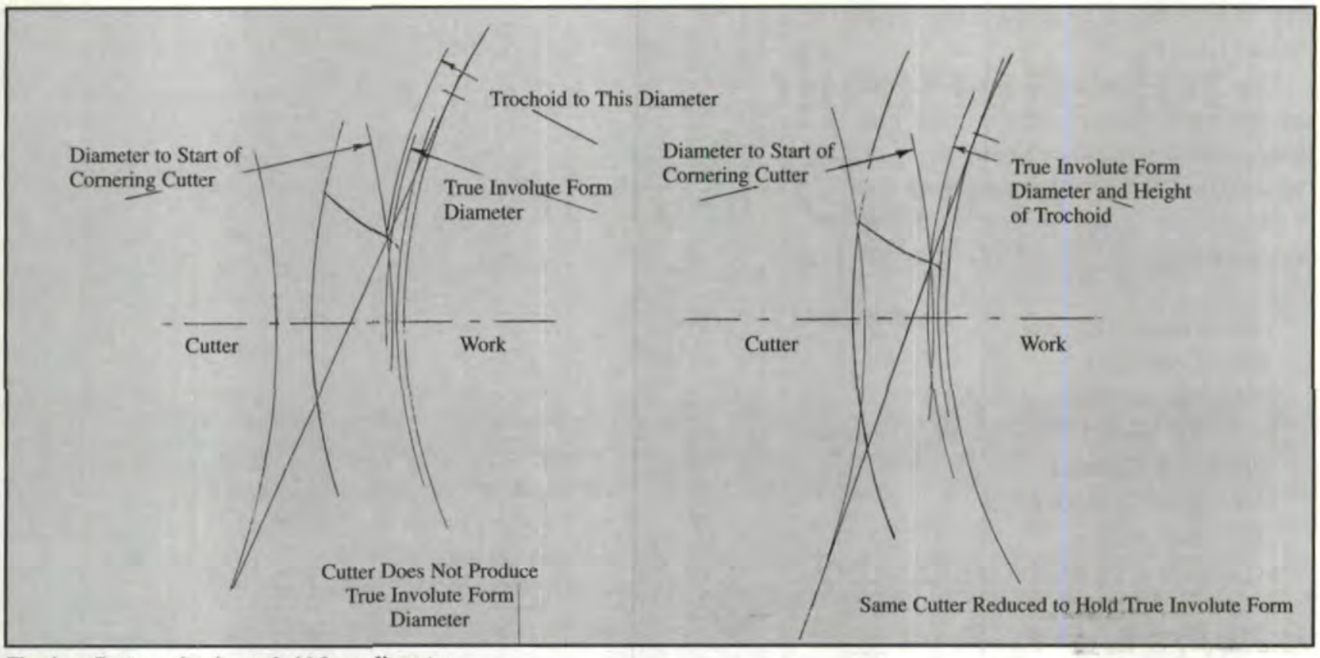

Fig. 4 — Cutter reduction to hold form diameter.

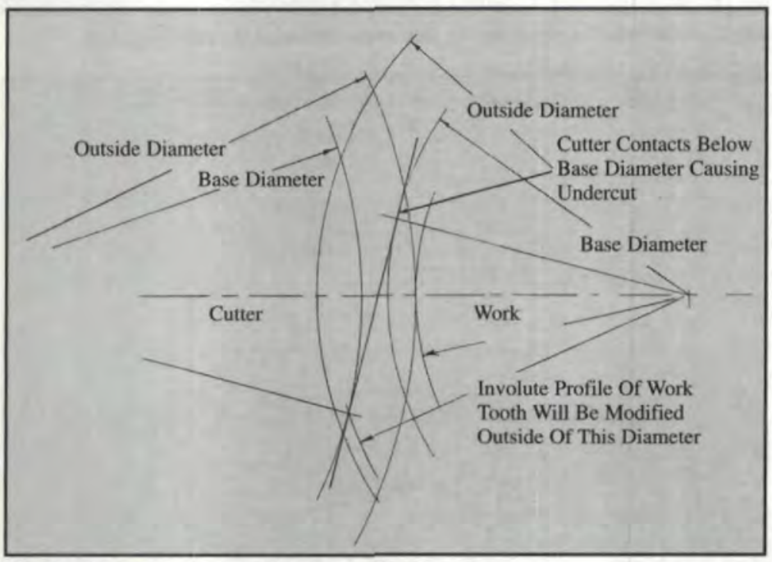

Fig. 5 — Example of tip modification and undercut.

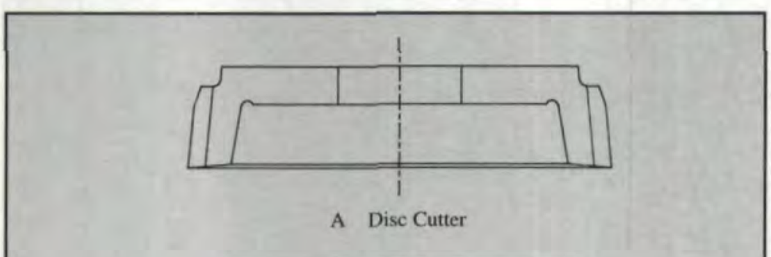

Fig. 6 — Typical blank designs.

slipping on the locating pilot under the higher feeds being used. Hole sizes are generally limited to 1/2", 3/4", 1", 1 1/4", 1 3/4" and 4". (See Fig. 6a).

Deep Counterbore Cutters. These are disc cutters with the addition of hubs to provide a deeper counterbore to permit recessing of the cutter holding nut or screw throughout the life of the cutter. Normally they are used for cutting internal gears or shoulder gears. To minimize the overall blank thickness of deep counterbore cutters, it is desirable to have available short-nosed adapters and screw-type clamping screws (Fig. 6b).

Taper Shank Cutters. These are normally used for cutting internal gears. They can be manufactured with as few as 4 teeth and a pitch diameter as small as .1875". The length of the shank must be sufficient to cut the face width of the part, plus over-travel, plus any recess over the top of the teeth, life of the cutter or any other thickness of the fixture hold-down plate that may be required. They are normally made in four taper sizes (Fig. 7a & b).

Solid Disposables. These cutters are generally used in high production applications where tool sharpening and machine adjustment are eliminated. These cutters are of optimum design; that is, the best possible design within the given gear parameters. A cutter adapter of the appropriate diameter will add more rigidity to the cutter. This type of shaper cutter can be used for both helical and spur applications (Fig. 6c).

Shaping Internal Gears

In cutting internal teeth, conditions relating to tooth profiles and tooth modifications occur which are similar to those already described for external gears. Obviously, there is no natural undercut produced on internal work. Tip modifications are more prevalent on internal work due to the wrap-around effect between the cutter and the work (Fig. 7).

Taper shank cutters are usually furnished when the required pitch diameter is approximately 2" or less. As previously mentioned, the length below the taper must be long enough to cut the face width of the part, but the resulting length below taper versus the barrel diameter of the cutter may produce a cutter that does not have sufficient bending strength. These cutters will deflect, causing tapered work, excessive rub and, in extreme cases, breakage. By adding flutes along the barrel (Fig. 8), the beam strength has been improved about 50%. There are some cases when, due to the small diameter and/or wide face width of the part to be cut, there is no choice but to make a cutter that exceeds accepted deflection limits.

Most modern gear shapers are equipped to make multiple cuts at a high rotary feed, greatly reducing the cutter force between cutter and work. The last cut is generally taken at a normal rotary feed, which gives the same finish and accuracy as conventional cutting. This method is quite common and will allow the cutting of splines that require long and slender cutters.

Cutter rub is almost always present to some degree when cutting internal gears. All gear shaping machines relieve either the cutter or the work on the return stroke to avoid scuffing the cutting edges during the return stroke and before starting the next cutting stroke. The amount of relief depends upon the make and type of machine. When cutting some internal parts, a wrapping effect of the internal part around the cutter results, causing the cutter to interfere or rub with the internal teeth when it is pulled back to give cutting edge relief. Fig. 9 illustrates one type of cutter rub called rough side rub or trailing side rub.

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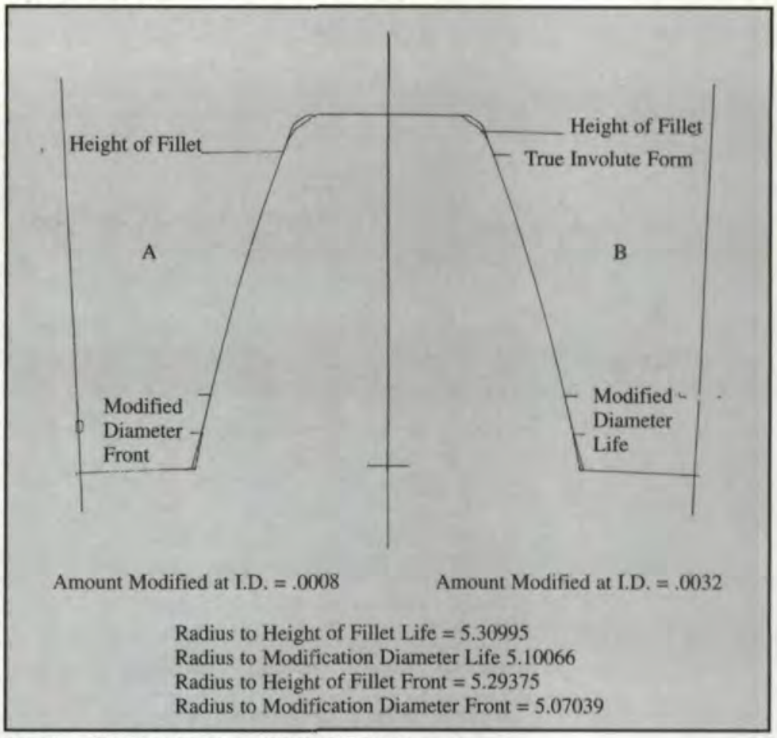

Fig. 7 — Tip Modification: 6/8 DP 20° PA internal gear.

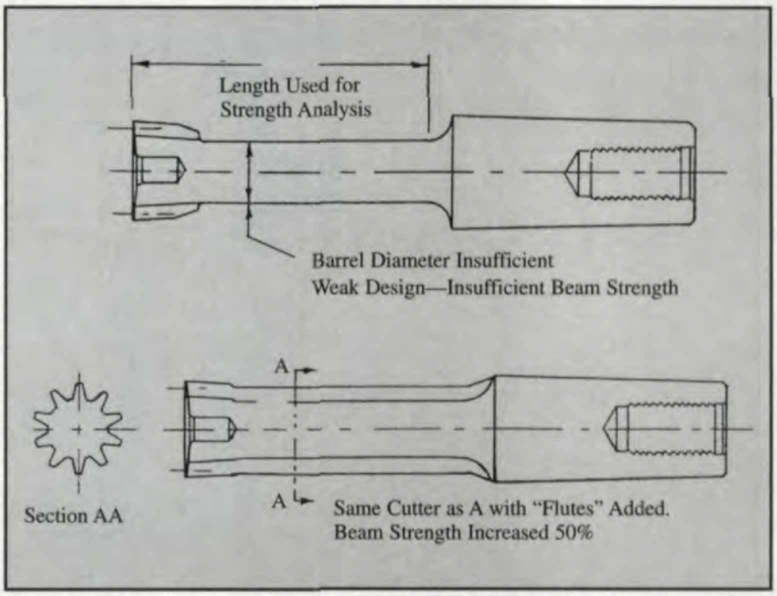

Fig. 8 — Effect of adding flutes to the barrel of a taper shank cutter.

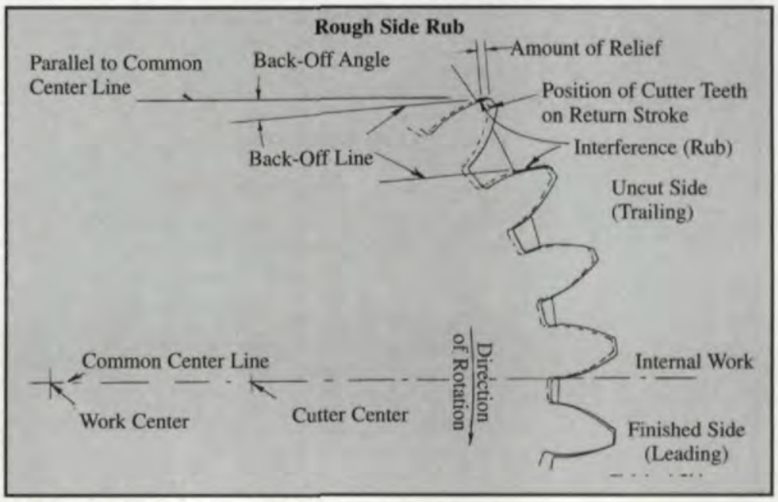

Fig. 9 — Rough or trailing side rub.