Computer Aided Design For Gear Shaper Cutters

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Computer programs have been developed to completely design spur and helical gear shaper cutters starting from the specifications of the gear to be cut and the type of gear shaper to be used. The programs generate the working drawing of the cutter and, through the use of a precision plotter, generate enlarged scaled layouts of the gear as produced by that cutter and any other layouts needed for its manufacture.

The gear data which should appear on the gear drawing to insure that a cutter correct for the part can be designed are shown.

Part information should include the following items:

1. Number of teeth.
2. Diametral pitch or module. (If helical, specify normal or transverse.)
3. Pressure angle (normal or transverse).
4. Outside or inside diameter. (Include limit if topping.)
5. Tooth thickness (normal or transverse at some given diameter or dimension over or between specified pins).
6. Helix angle and hand.
7. Depth of cut. (Specify root diameter and tolerance.)
8. Material and hardness at time of cutting.
9. Lowest point of contact. (Specified as true involute form diameter. Mating part and center distance information will answer this requirement.)
10. Root fillet radius specification.
11. Stock allowance for preshave, pregrind, or roughing operations (amount and position of undercut if required).
12. Amount of chamfer measured radially with limit angle of chamfer if necessary.
13. AGMA quality number.
14. Type and serial number of machine.

A computer program works through an optimizing process to produce the best cutter design possible for the part in question. A good program considers the many constraints and variables involved and investigates many designs before it arrives at the optimum one. Because of these many variables, it is not possible to write a direct formula or algorithm that will result in a cutter that will meet all of the requirements. For this reason many designs may be investigated. The following is a step by step description of how such programs are arranged.

Fig. 1 illustrates the three basic cutter blanks that will be discussed here: disk, deep counterbore for internals and parts with interfering shoulders, and taper shank (usually for internals).

The type of blank is an input parameter with the blank dimensions, thickness, face width, life, etc. being supplied by program libraries of standard dimensions for the pitch and cutter size involved. If special blank dimensions are required, they can be substituted for the standard ones. The basic size of the cutter (number of teeth) will be computed to fit the machine being used if this is known, or it may be input by the number of teeth or pitch diameter wanted on the cutter.

In addition to cutter blank dimensions, all other information required for the

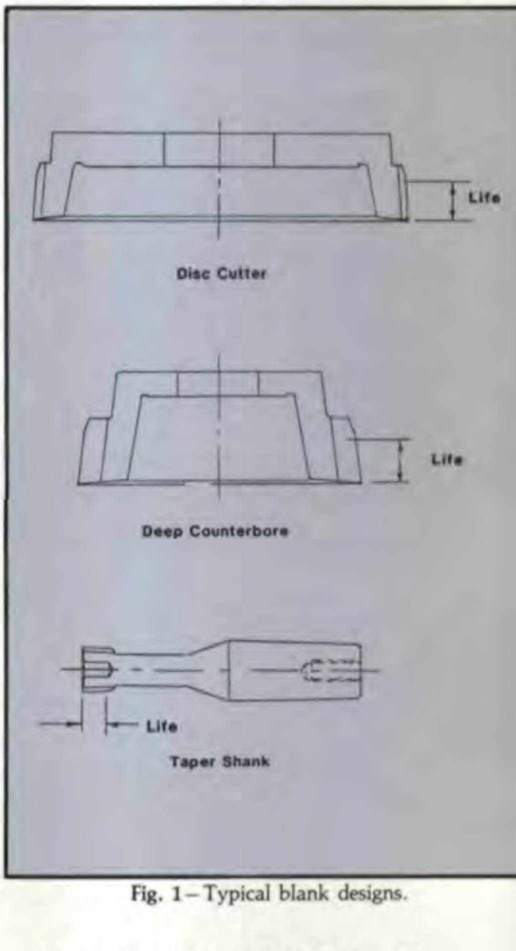

Fig. 1 – Typical blank designs.

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design, such as, clearance angles, tolerances, material, etc. is supplied by the program libraries and need not be entered as input parameters, unless special, non-standard values are required.

Once the cutter size (pitch diameter) has been fixed by one of these methods, the program computes the cutter tooth dimensions for the given part and then checks all of the following points, ascertaining that it produces the part specifications and meets the following good cutter design criteria:

1. Does the cutter have sufficient tip land?
2. Will the true involute form (TIF) diameter be held?
3. Will the cutter have a suitable size radius on the tip corners?
4. Will the cutter modify the tips of the work teeth?
5. Will the undercut produced by protuberance be positioned correctly?
6. Will chamfer produced be to specifications?
7. Will too much rough side rub be present on cutters for internal work? Will cutter have finish rub? Will it trim the tips of the work teeth?
8. Is the cutter barrel strong enough on taper shank cutters? Does it need flutes?
9. Will flank rub be present on internal or external work?

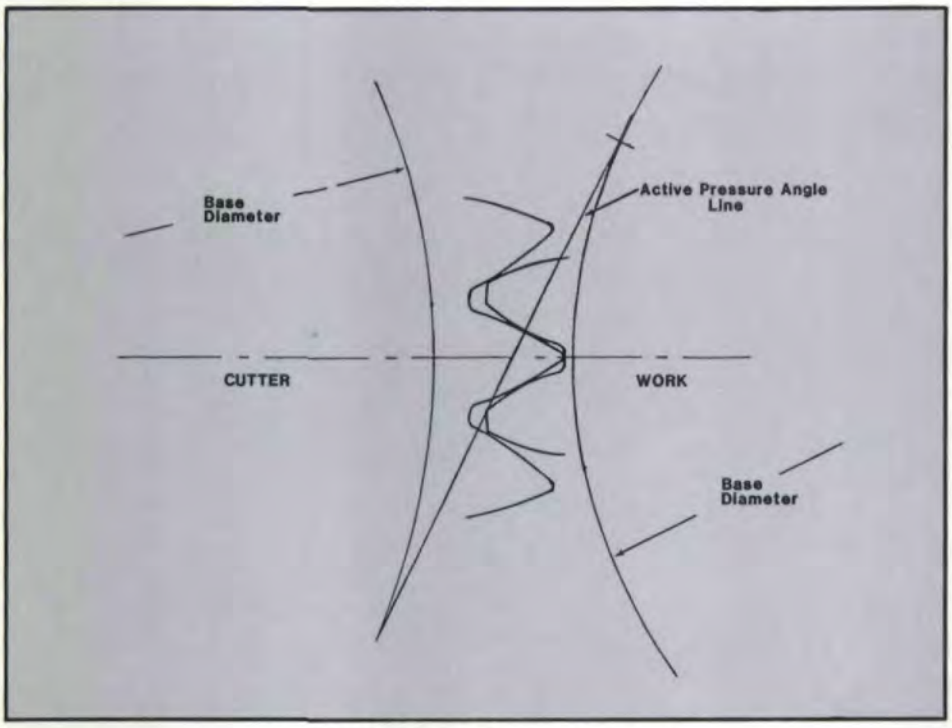


Fig. 2 – Enlarged cutter – too little tip land.

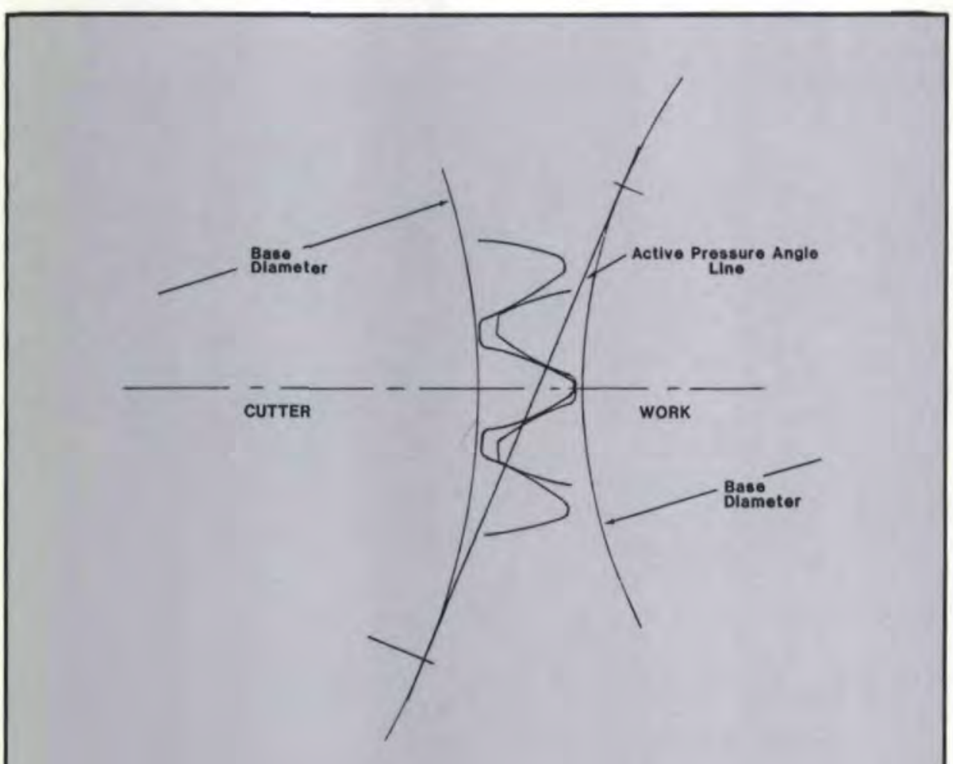


Fig. 3 – Reduced cutter – sufficient tip land.

Items 1, 2, 3, 4, 5 and 7 are dependent on the active pressure angle (APA) between the cutter and work, so the program must determine by trial and error the best starting APA to produce best results when the cutter is new and throughout its life. The APA of a cutter changes as it is sharpened back, so we must investigate what happens through its whole life. The APA discussed here originates from a cutter that operates at the transverse pressure angle of the work. When the cutter size (center distance) is increased from this point, the APA increases on external work and decreases when the size (center distance) is decreased. The active pressure angle change is in the opposite direction on internals, but the effect of enlarging or reducing the cutter is similar to external work with respect to cutter land and the true involute form (TIF) produced. This article will use the term "enlargement" or "reduction" of the cutter to indicate that the APA is being changed to satisfy requirements. The following examples will indicate situations that dictate this type of change.

Each time the cutter size (enlargement or reduction) is changed to improve or satisfy one of the above conditions, the new design is completely computed. Each feature is then checked to be sure that some other design requirement has not been violated.

Fig. 2 shows a cutter with too little land on the tips of the teeth. Fig. 3 is the same cutter reduced to a point where satisfactory land is attained. This is an external part; therefore, the APA is reduced with cutter size. Standards for the minimum allowable land for good cutter life are stored in the program library and are dependant on pitch and pressure angle of the part.

Fig. 4 illustrates how cutter enlargement affects the TIF produced. A reduced cutter will lower the trochoid height produced, resulting in a design that will hold the required TIF.

Fig. 5 shows a condition where the involute at the tip of the work tooth will be modified because of contact below the base diameter of the cutter. Shown on this same figure is the condition of cutter contact below the base circle of the work, resulting in "undercut", which takes away some of the involute near the base diameter of the work.

Undercut is most likely to happen on pinions of 20 teeth or less, while tip modification is more common on large gears and internal gears. Enlarging the cutter will improve or eliminate both the undercut or modification conditions.

From the foregoing, it can be seen that some situations require cutter enlargement, while others require reduction of the same cutter to remedy the problem. Obviously we cannot do both, so a compromise must be made by the program. The final design will always be one that at least has minimum land and produces the specified true involute form.

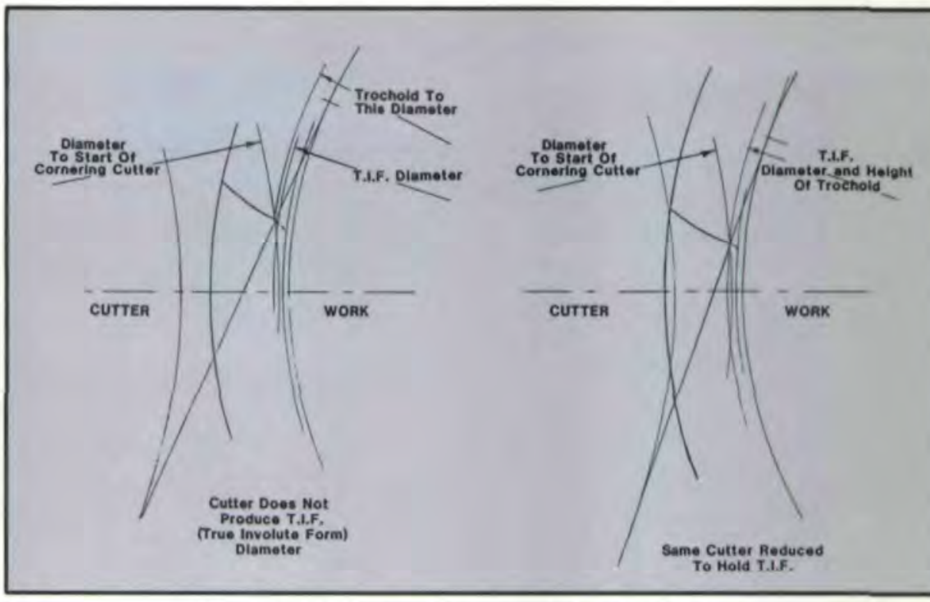


Fig. 4 – Effect of cutter enlargement on true involute form.

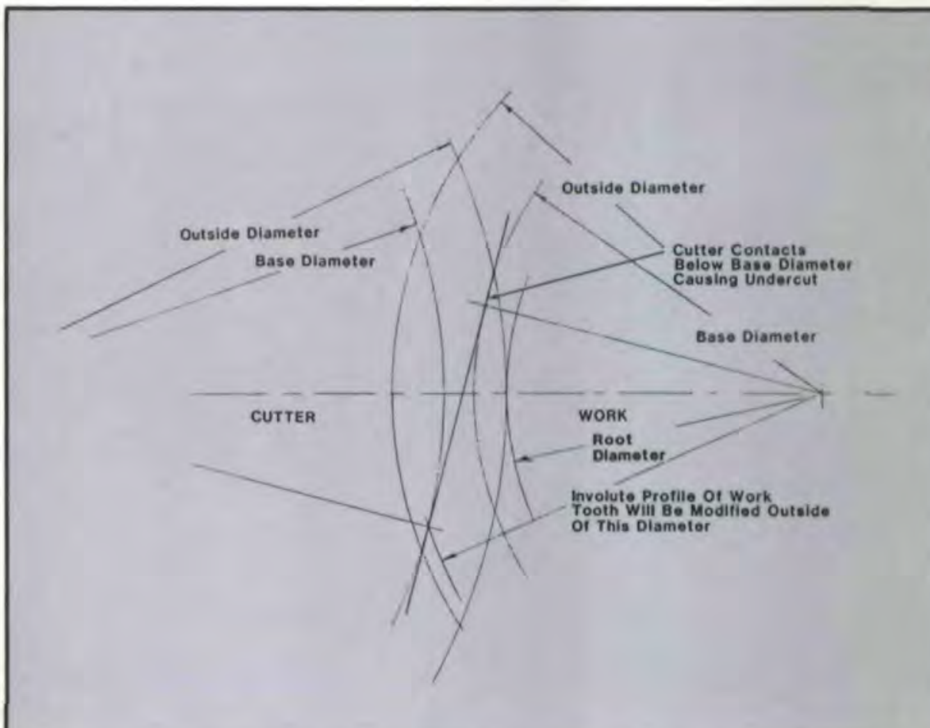


Fig. 5 – Example of tip modification and undercut.

Cutter Rub (Internal Gears)

This condition 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. This relief is generally accomplished by separating the cutter and work by approximately .010" (.25mm) to .032" (.81mm), depending 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. Three types of rub can occur and are described as follows:

Rough Side Rub. This interference, as shown in Fig. 6, is caused by the hooking action of the cutter teeth relative to the work profile as they enter on the uncut side of the work near the inside diameter. At this time, no generating action has taken place. Spaces produced are an image of the cutter teeth, requiring the cutter to be pulled back at an angle away from the hook side to provide relief on the return stroke. The dotted lines show the position of the cutting edges after the relieving motion has taken place. In the example shown, cutter rub exists even though the cutter was relieved on an angle known as the backoff angle. The amount of backoff angle is limited, as will be shown later. The conventional angle is normally about 5°, which is sometimes increased to as much as 10-12° to correct extreme rough side rub conditions. A small amount of rough side rub [less than .002" (.05mm)] can be tolerated and is usually present when cutting small internals. Excessive rough side rub will show up as an excessive burr on the face of the gear and the inside diameter from the trailing side of the cutter teeth. This problem causes excessive wear and/or load on the trailing side near the tips of the cutter teeth, resulting in a deterioration of tool life. Aside from an increase in the backoff angle, with limitations as shown later, the only way to reduce this condition is to decrease the

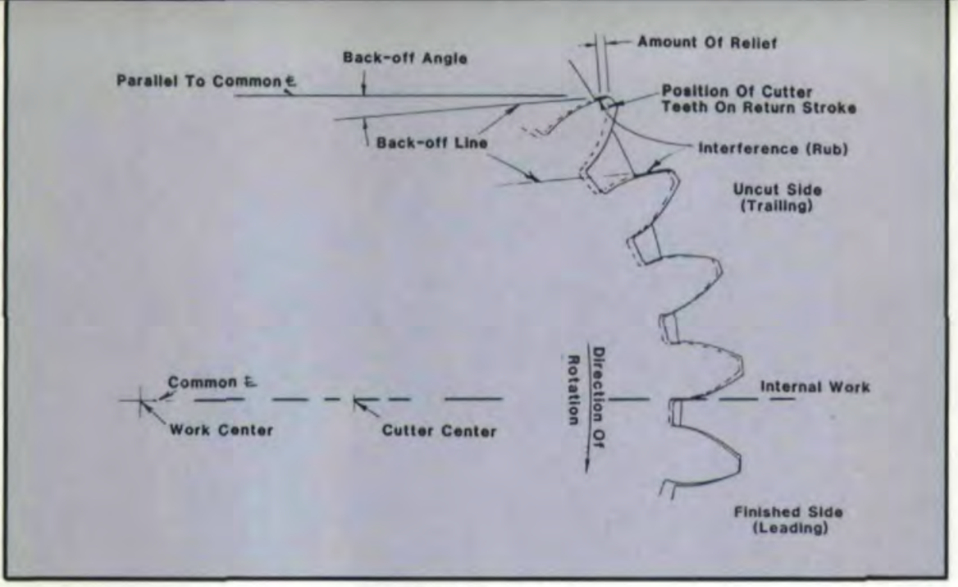


Fig. 6 – Rough side rub.

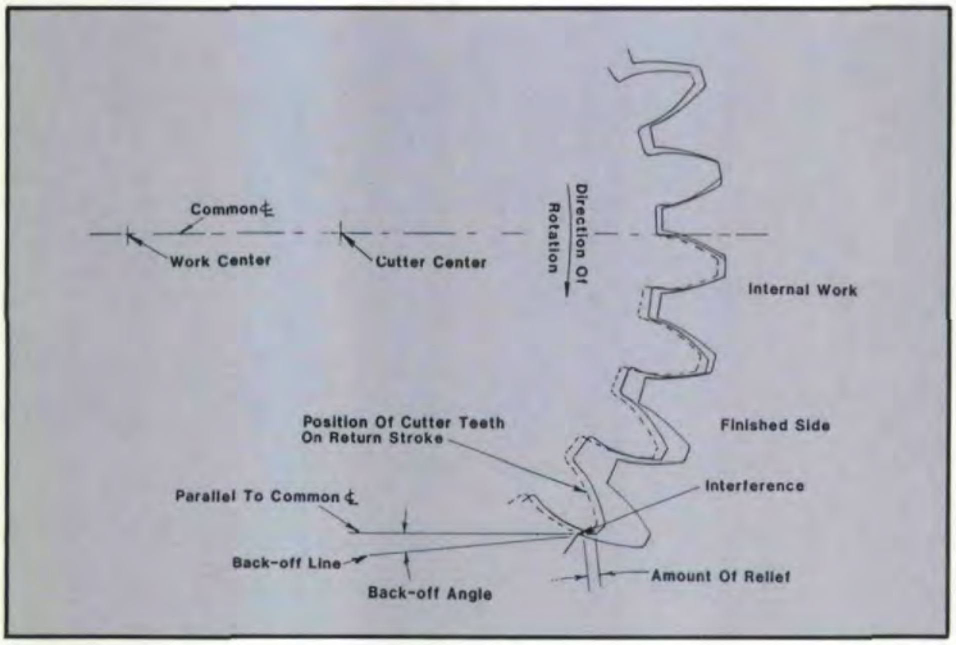


Fig. 7 – Finish side rub.

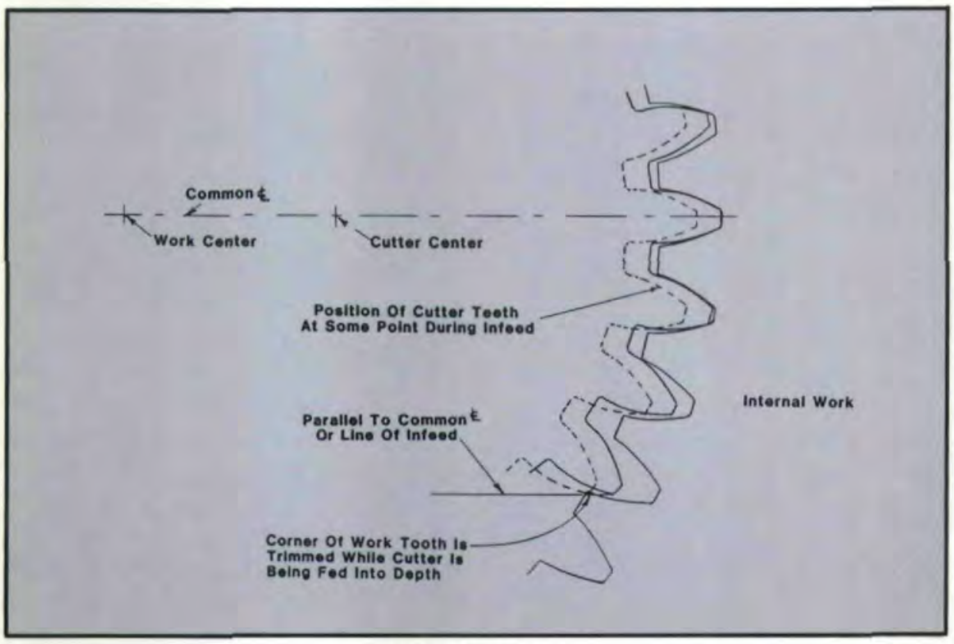


Fig. 8 – Infeed trim.

amount of backoff, usually to not less than .010" (.25mm), reduce the number of teeth in the cutter, increase the inside diameter of the part or use multiple cuts as described later.

Finish Side Rub. As shown in Fig. 7, finish side rub occurs when the cutter size is large relative to the work size, and it appears on a fully finished side of the work teeth. Finish rub will show up in the form of an excessive burr left at the inside diameter of the work teeth on the leading edges. The cutter will show excessive wear near the tips of the teeth on the corresponding side. The direction of backoff angle is almost always taken as shown and is dictated by the requirements of the rough side. Decreasing this angle would improve the finish side rub, but this usually cannot be done for the previously mentioned reasons. An increase in the operating pressure angle by reducing the cutter diameter and/or reducing the number of teeth in the cutter will decrease the amount of finish rub. This type of program will not allow any amount of finish rub to be present on the final design.

Infeed Rub. This is rub on the leading side of the teeth caused by the same conditions as finish side rub and occurring only while the cutter is feeding into depth. For this reason, the burr left at the inside diameter while infeed rub takes place will be cut away when the cutter reaches full depth and cannot be seen on the finished part. Excessive infeed rub will show up as abnormal wear on the leading side of the cutter teeth. The same remedies listed previously for improving finish side rub hold true for infeed rub. The multiple cut method, described later, will also reduce or eliminate infeed rub.

Infeed Trim. As shown in Fig. 8, infeed trim can exist regardless of the amount of backoff and occurs when the number of teeth in the cutter is too large in relation to the number of teeth in work. The angle of backoff can affect this trimming condition if it is accomplished by offsetting the cutting head upright (which is common on some of the newer types of gear shapers) and not by the swiveling method. Infeed trim will show up on the finished part as a modification or trimming at the inside diameter of one or more work teeth. This trimming is done by a cutting action, as opposed to rub, and thus does not harm the cutting tool. This condition can be reduced or eliminated by increasing the operating pressure angle of the cutter and work by decreasing the outside diameter of the cutter or by decreasing the number of teeth in the cutter.

Maximum Cutter Sizes (Internal Gears)

Fig. 9 shows the relationship between recommended teeth numbers in cutters and work pieces for the more common pressure angles. The data given here is to be used as a guideline in the selection of a cutter that will not produce excessive rough side rub, infeed rub or any amount of finish side rub or infeed trim. When the number of teeth in the work is less than the cross bars on the chart indicate for the pressure angle involved, the inside diameter should be increased by shortening the addendum. On such parts or on marginal ones, the amount of rub present should be checked by the computer program before cutting. Variations occurring from machine to machine in the amount and angle of backoff also make a precutting check desirable. Of course, internal parts of fewer teeth than shown on this chart can be cut successfully, but they should be treated as individual cases. The majority of parts in this category must be cut on machines with reduced backoff. The program stores the equivalent of this chart, which is used as a starting point to determine the number of teeth in a cutter for an internal part. If the starting number of teeth results in excessive rub, this number will be reduced by the program until the rub is eliminated.

Flank Rub (External or Internal Gears)

This type of rub can occur on the portion of the cutter tooth below its base circle on the trailing side of the cutter and will show up as excessive wear at this point. Fig. 10 illustrates this condition on an internal gear. If the previous cut leaves stock no greater than that shown by the dotted line, flank rub will not be present. For this reason, a common method for eliminating flank rub is to take multiple cuts or use the multipass method described later. The amount to feed in for each pass is determined by computer. Anything that can be done to increase the distance from the cutter base diameter to the outside diameter, such as, cutter enlargement or an increase in the number of teeth, will help eliminate this condition.

Multiple Cut Or Multipass Cutting Method

Most modern gear shapers are equipped to take multiple cuts (3 or 4 cuts in the normal manner) or to use the multipass (high rotary feed at low infeed rates) to provide a way of eliminating or reducing rough side rub and infeed rub on internals. These techniques also eliminate flank rub on both internal and external parts. Fig. 10 shows how multiple cuts can eliminate flank rub on an internal if the previous cut stock is as shown by the dotted line. This process can also be used to eliminate rough side

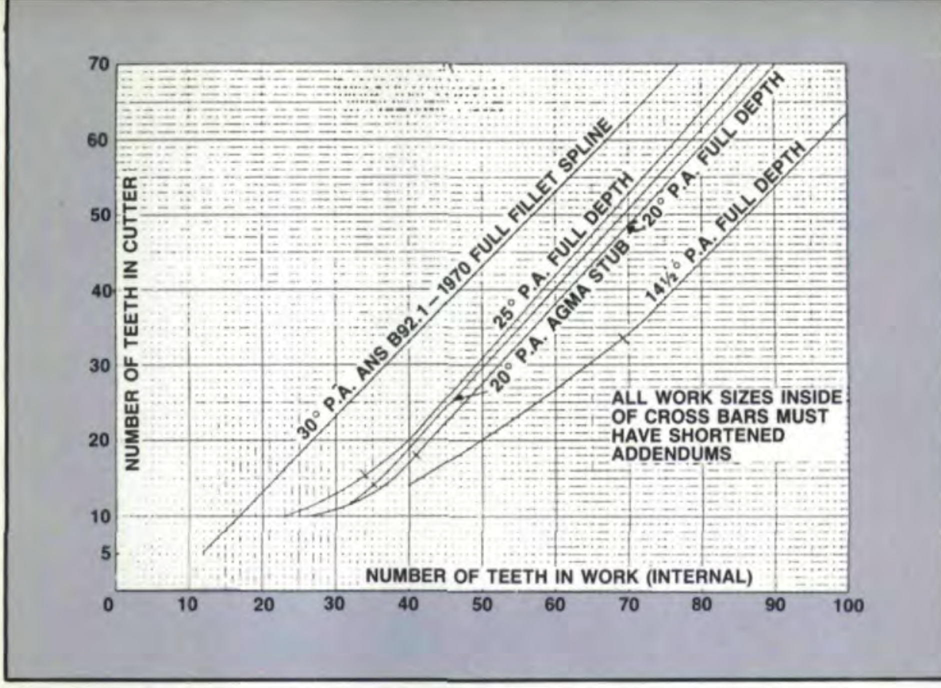


Fig. 9 – Relationship between recommended teeth numbers in cutters and work pieces for common pressure angles.

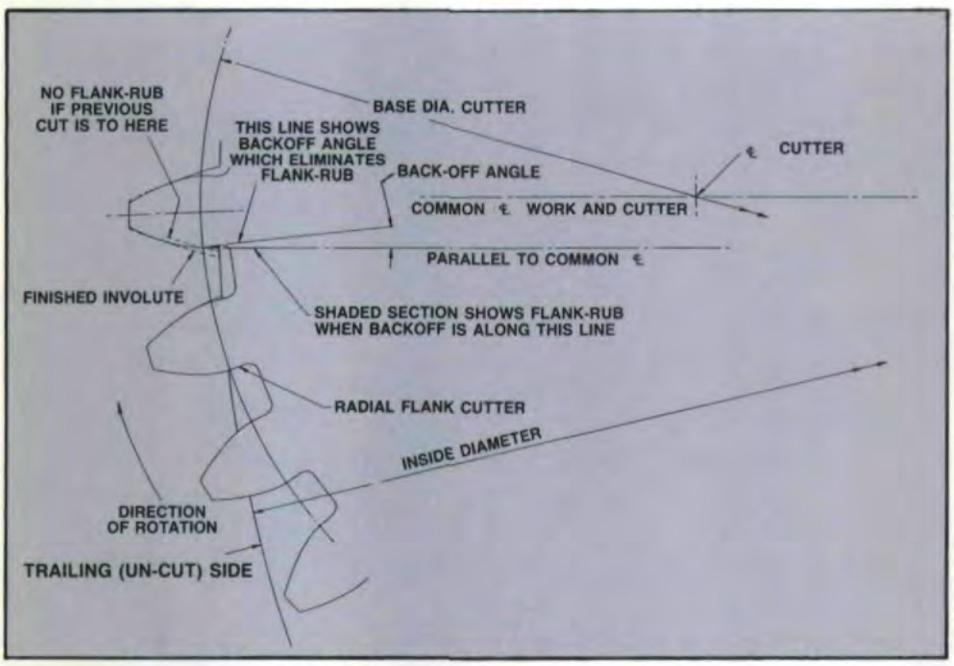


Fig. 10 – Flank rub diagram – internal work.

rub on internal gears. Fig. 11 shows that if the stock where rub takes place is removed by a previous cut, it will no longer rub. In this example, possibly more than one cut had to be taken to get to the "previous" depth, to attain that depth without rub. The amount of infeed between cuts for both flank rub and rough side rub elimination is determined by the computer program.

Another important feature of the multiple cut/multipass feature is to allow the use of a taper shank cutter larger than normal when cutting small internal splines. Because of reduced rub, a cutter with one or two teeth more may be used, resulting in a cutter with a stronger barrel which will be less apt to deflect.

Cutter Deflection of Small Taper Shank Cutters

The long slim cutters necessary for small diameter, wide face width, internal splines require special attention. A good program computes the relative beam strength of the barrel of the cutter, and if it comes below a previously determined minimum, it should change the cutter to a fluted barrel design. Fig. 12 illustrates the difference in the fluted and nonfluted design.

Finished Cutter Design

When the final optimized design has been determined using the methods outlined above, computer and plotter create a fully detailed working drawing as shown on Fig. 13. In addition to this, any enlarged layouts required for the fabrication of the cutter are plotted along

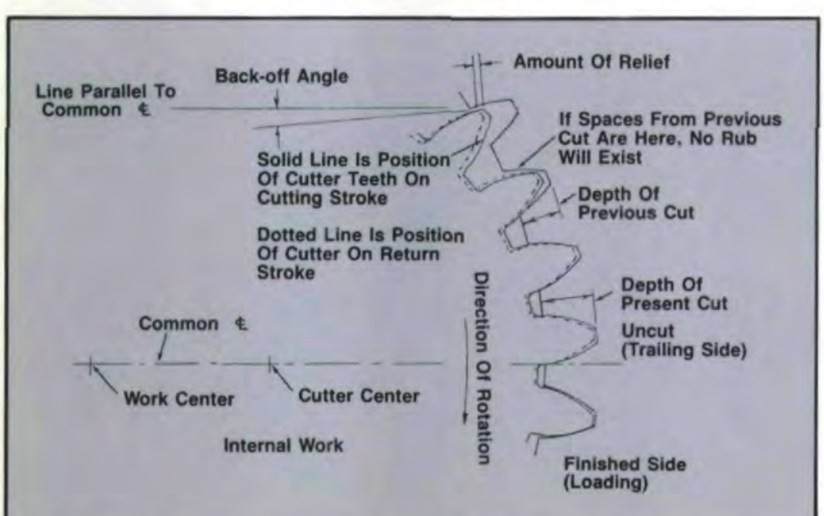


Fig. 11 – Multiple cut or multipass method of eliminating rub.

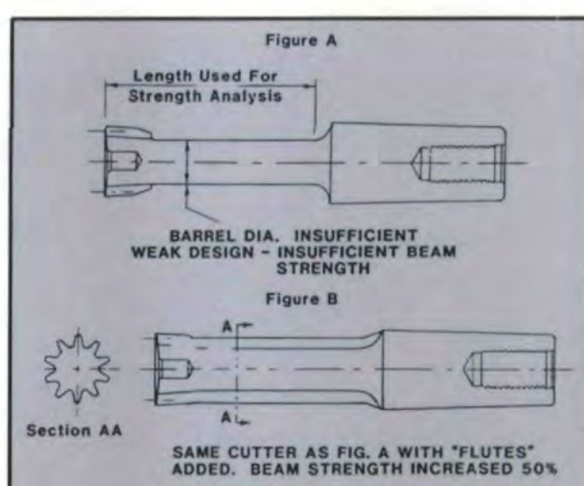
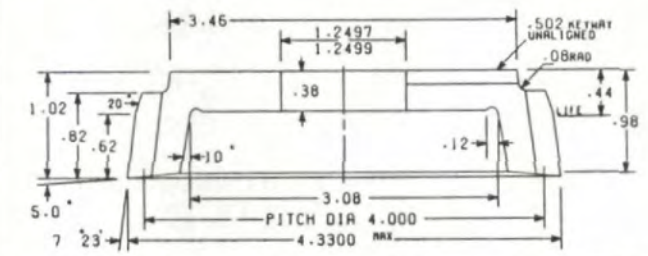


Fig. 12 – Improvement of beam strength by use of fluted barrel design.

EXAMPLE	CUSTOMER SPRINGFIELD, VT				PART NO.	CUST TOOL NO
SCALE 1.00 TO 1	WORK PRODUCED	O.D. 1.7000	NO TEETH 15.00	WD .2248	TIF DIA	NOR ARCTOOTH THICK. .1569



NOR PITCH		DIAMETRAL PITCH	10	HELIX ANGLE		NO TEETH	40.0000
NOR PRESS ANG		DIA PRESS ANG	14.5000	LEAD		PITCH DIA.	4.0000
SCA UH	° '	SCA DH	1°55'	BASE DIA. UH		BASE DIA. DH	3.8692
FLAT CORNERS	.015/.020	INV. REM. BY COR.	.68	BASE RAD. UH		BASE RAD DH	1.93460
		OFFSET ANG DH	10.37	MIN ANG INV UH		INVOLUTE TOL.	.00020
		LINEAR OFFSET DH	.3502	MIN ANG INV DH	17.40	CP (MAX)	.00030
FLANK FROM OFFSET UH		FLANK FROM OFFSET DH		J DIM	.1213	CP (T-T)	.00025
POINTS FLANK UH		POINTS FLANK DH		TAU (DESIGN OD)	.04982	CONE (RUNOUT)	.0009
T (NOR)		T (DIA PROJ)	.1660	CHORDAL H	.1385	DESIGN OD	4.3200

MIN GRIND DEPTH .245

B		
A		
	REVISIONS	DATE
MATERIAL	ROCKWELL C	POST TREATMENT
ASP-23	64.5-66	NONE
SPUR DISC	SHAPER CUTTER	FINISHING
DRAWN IMP		DATE 09/30/86

PRECISION DRIVE, P.O. BOX 351,
SPRINGFIELD, VT., 05156-0851 U.S.A.

Fig. 13 – Sample working drawing.

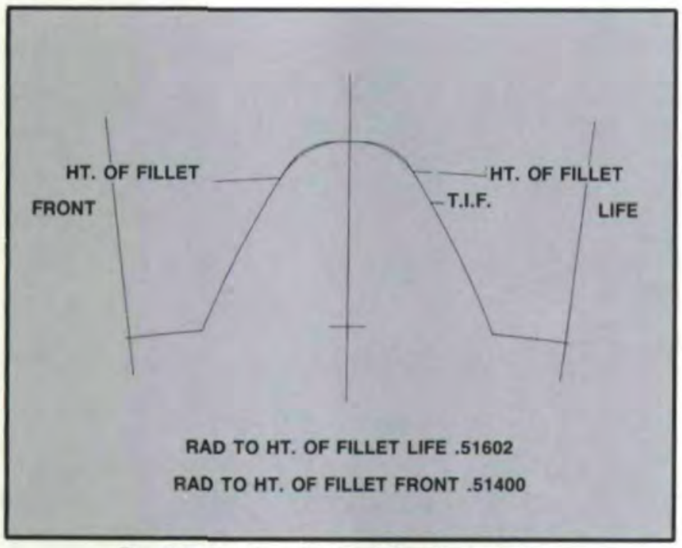


Fig. 14 – American National Standards Institute (ANSI) standard full fillet internal spline, 1.0 module, 30° p.a.

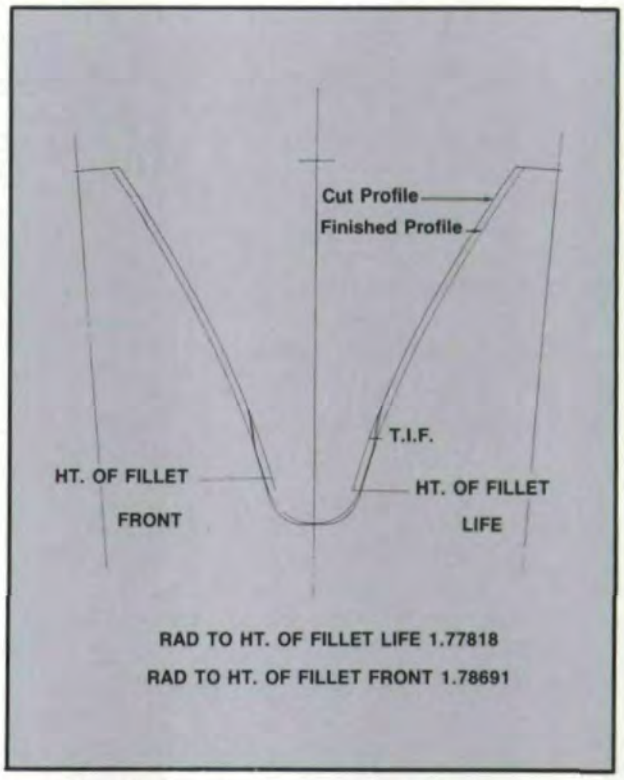


Fig. 15 – Example of undercut for preshaving or pregrinding, 10 d.p., 25° p.a.

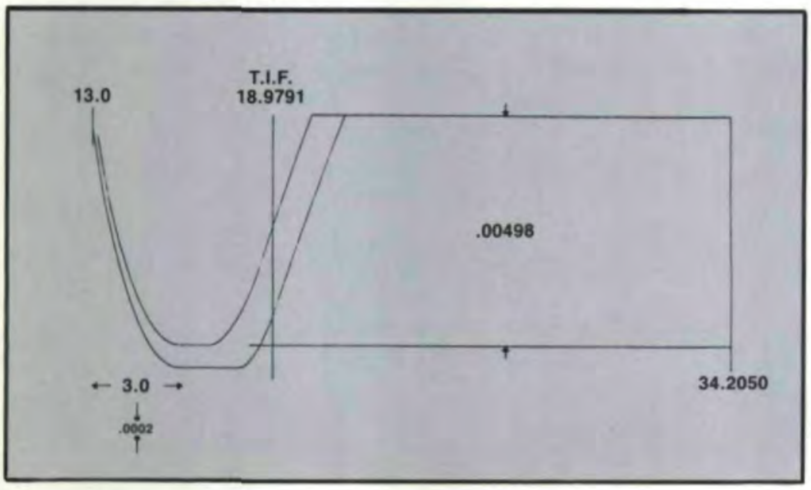


Fig. 16 – (left) Plotted involute chart of part shown in Fig. 15. Note stock left at TIF diameter.

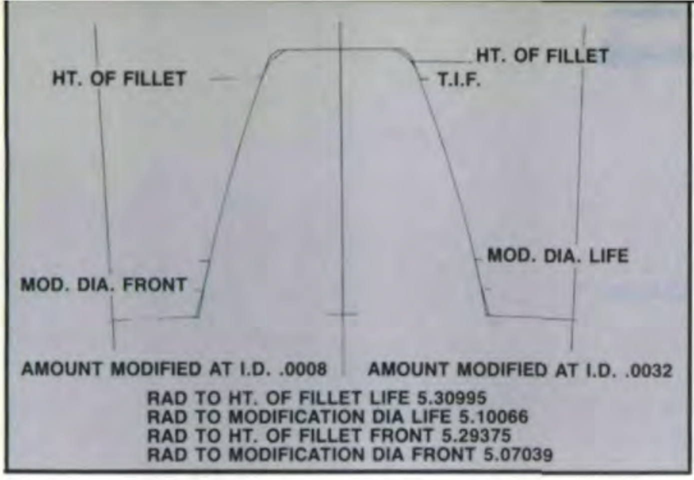


Fig. 17 – Tip modification – 6/8 d.p., 20° p.a. internal gear. See also Fig. 5.

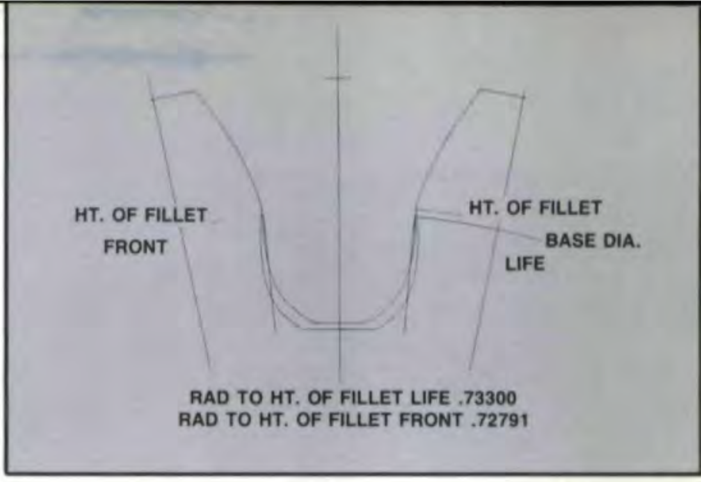


Fig. 18 – Extreme undercut, 10 d.p., 14½° p.a. pinion.

with a greatly enlarged layout from 10 to 100 x size of the work tooth profile. Examples of these work layouts are shown in Figs 14-18.

NOTE: These layouts show two values of fillet height and modification diameters, one for "front" (new cutter), and one for the life position. This change is due to the reduction of the outside diameter of the cutter as it is sharpened back, resulting in a change in the active pressure angle (APA), thus changing the fillet and modification diameters.

The computer programs also compute and print other important information for the designer and user, including the variation in depth of cut throughout the life of the cutter, variation in chamfer produced by a chamfering cutter and variation in the outside diameter produced by a topping cutter.

Each final cutter design, along with all of the input gear data, is stored in a data base on the computer system and is available to any computer aided manufacturing (CAM) programs used in the fabrication of the cutter.

Conclusion

The development of this type of software greatly enhances the ability to rapidly design a gear shaper cutter to do the best job possible. The many critical points that must be checked are done so without fail, with appropriate action in each case. The precise plotted layouts of the work are invaluable in communicating the exact profile that will be produced on the workpiece.

Acknowledgement:

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