Chamfering and Deburring External Parallel Axis Gears

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The chamfering and deburring operations on gear teeth have become more important as the automation of gear manufacturing lines in the automotive industry have steadily increased. Quieter gears require more accurate chamfers. This operation also translates into significant cost savings by avoiding costly rework operations. This article discusses the different types of chamfers on gear teeth and outlines manufacturing methods and guidelines to determine chamfer sizes and angles for the product and process engineer.

Why Chamfers?

Chamfers are needed in gears:

- To prevent nick and bump damage along the active tooth surface after the shaving or finishing operation;
- To prevent burrs and sharp edges which cause gear noise;
- To prevent the break-off of burrs and sharp edges during torque transfer when the gears have been assembled in boxes or transfer cases;
- For cosmetic reasons.

In the last few years, gear manufacturers have intensified their efforts to prevent or reduce nick and bump damage. Handling systems have ratchet conveyors, which prevent the gears from touching each other. Special baskets are used to protect the gears from accidental damage during heat treatment process. Operator training has stressed the careful handling of gears at every stage of production. In spite of all these steps, the problem still persists. The number of gears rejected because of nicks can range from 10–60% of a batch. Nicks modify lead or involute characteristics, causing meshing defects.

Chamfers significantly reduce noise while the gears mesh and effectively protect all vulnerable zones in the gear tooth.

Types of Chamfers

Four chamfers are shown in Fig. 1. Chamfer A is the tip chamfer along the lead produced by the preshave tool. B is the acute edge chamfer in cylindrical helical gears. C is the obtuse edge chamfer in cylindrical helical gears produced by cutting, grinding or rolling operations. D is the tip chamfer on end faces produced during the turning of blanks.

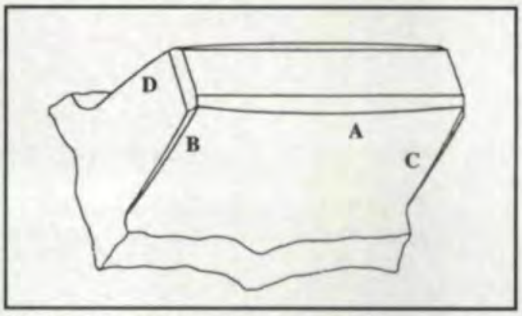

Fig. 1 — Types of chamfers on gear teeth.

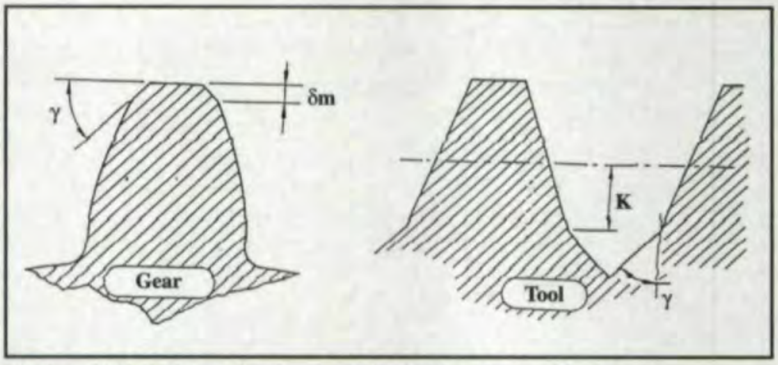

Fig. 2 — A) End of chamfer along lead; B) Basic rack of preshave tool.

The tip chamfer along the lead is generally executed while cutting the gear with either a hob or a shaper cutter which has a modified tooth profile called semi-topping. The size of the chamfer depends on the gear's diametral pitch (the module). Generally it is

$$\delta_m = 0.10\text{–}0.15 \text{ mm}$$
$$\gamma = 30\text{–}40°$$

See Fig. 2 for details.

It is difficult to maintain the size of the tip chamfer, since it is related to the tolerances of the outside diameters and gear tooth thickness. For example, gears with normal diametral pitches up

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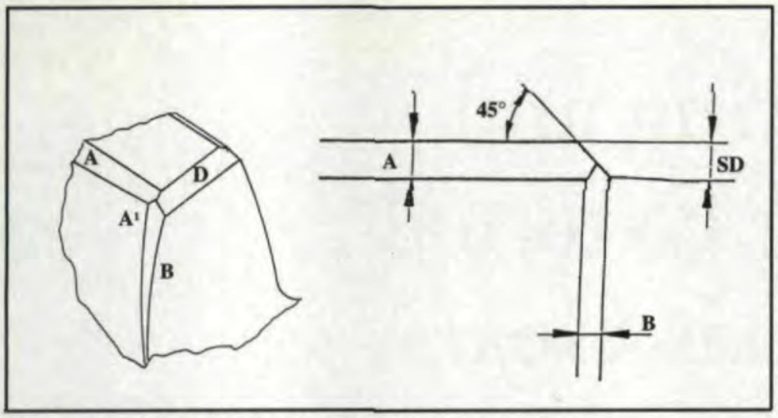

Fig. 3 — Gear tooth with edge chamfer and both tip chamfers.

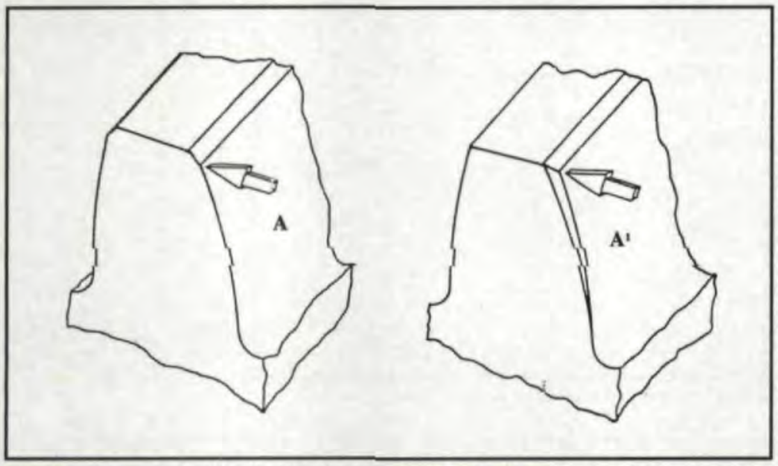

Fig. 4 — Gear tooth with tip chamfer and tip chamfer along lead and edge chamfer.

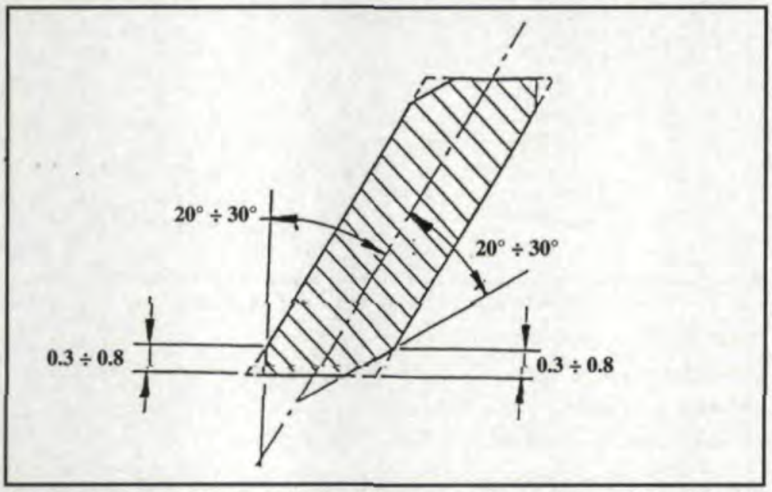

Fig. 5 — Chamfer angles must be set with exposed points as far away from the ends of the tooth as possible.

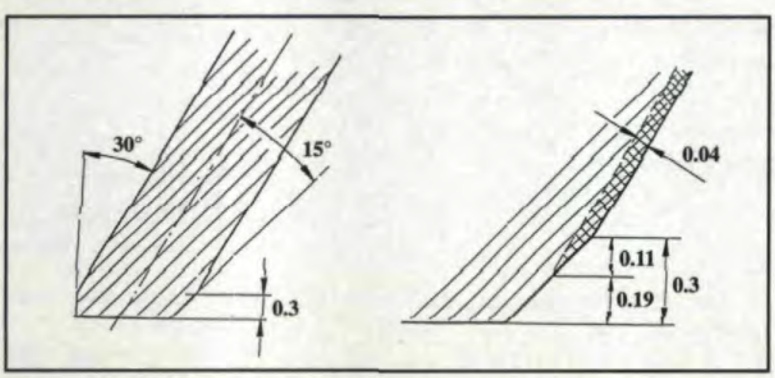

Fig. 6 — Shaving reduces the size of the chamfer to some extent.

to 8–10 (module 2.5–3.0) have an O.D. tolerance of roughly 0.008" (0.2 mm) and a variation of 0.004" per side (0.1 mm/side). The cutting tolerance on tooth thickness may be ± 0.0008" (0.02 mm), which affects the cutting tool position. The chamfer will have the following variation:

$$\delta_m = \frac{(0.0008)}{\tan \alpha_n}$$

where α_n = normal pressure angle

When $\alpha_n = 14°30'$, $\Delta\delta_m = 0.003"$ (0.077 mm).

When $\alpha_n = 20°$, $\Delta\delta_m = 0.002"$ (0.055 mm).

This variation is close to 50% of the nominal value of the chamfer size. This becomes much more significant when we are dealing with gears with a normal diametral pitch (NDP) of more than 20 (or module less than 1.25). The tolerances of the O.D. and the tooth thickness exceed the chamfer's nominal value. It then becomes necessary to cut the gears with "topping" tools, which simultaneously cut the teeth and the O.D.

Sometimes when it is necessary to use as much active profile as possible because tip chamfers reduce the working diameter and the line of action, gear designs do not allow tip chamfers. In some rare instances, only a few tenths of a millimeter make up the meshing continuity. Such constraints must be resolved during the early stage of a transmission design, and the designer must make accommodations for tip chamfer.

The chamfer "D" on end faces is required for assembly purposes and for smoother meshing. The chamfer "D," which is put on the gear during turning, can actually cause more nicks than it prevents. Usually the project engineer requires an end tip chamfer without paying too much attention to its size. From Fig. 3, it can be seen that as chamfer "D" is increased, chamfers "A" and "B" provide less protection. Therefore, it should be made as small as possible and never larger than the value

$$S_d = 0.5(a + b)$$

Another reason favoring reduction of the end tip chamfer to a minimum is the presence of hobbing and shaping burrs in this area. These burrs are not removed by the usual deburring tools and may be difficult to remove if they are large. Smaller burrs usually disappear during heat treatment or shot peening. If the chamfer "D" is large and has a heavy burr, sometimes it is necessary to employ an additional deburring tool.

From Fig. 4, it is clear that in the absence of an edge chamfer, point A is more exposed to nicking. With an edge chamfer, the most exposed point, A^1, is shifted towards the inside and is therefore less prone to nicks. The tip chamfer is rendered useless unless there is an edge chamfer. Edge chamfer dimensions do not have the constraints of tip chamfers, since they are made after the gear teeth are cut. Their dimensions are to some extent independent of gear tooth tolerances. Chamfer sizes range from 0.012" (0.3 mm) to 0.030" (0.8) mm. The angles need to be set so that the exposed points are as far away from the ends of the tooth as possible (see Fig. 5). As the helix angle increases, the chamfer angle (related to the tooth axis) decreases to less than 20°. For example, a 30° helix angle will lead to a 15° chamfer angle. There is some reduction in the chamfer size while shaving (Fig. 6). During this process, 0.0015" (0.04 mm) of stock is removed from each flank. If the original chamfer size was 0.012" (0.3 mm), the chamfer size after shaving would be

$$\delta_m = 0.3 - \frac{(0.04)\sin 45^\circ}{\sin 15^\circ} = 0.19 \text{ mm or } 0.0075"$$

Therefore, it is necessary to start with a larger size chamfer, maybe 0.024–0.030" (0.6–0.8 mm). The chamfer should be made without finishing with a step. Sometimes it is better to chamfer the root fillet even if this area is not susceptible to nicking. Fig. 7 shows the correct procedure for chamfering.

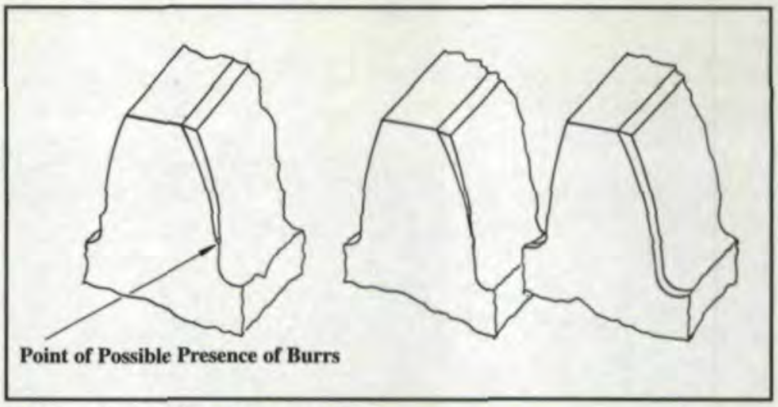

Fig. 7 — Correct chamfering procedure.

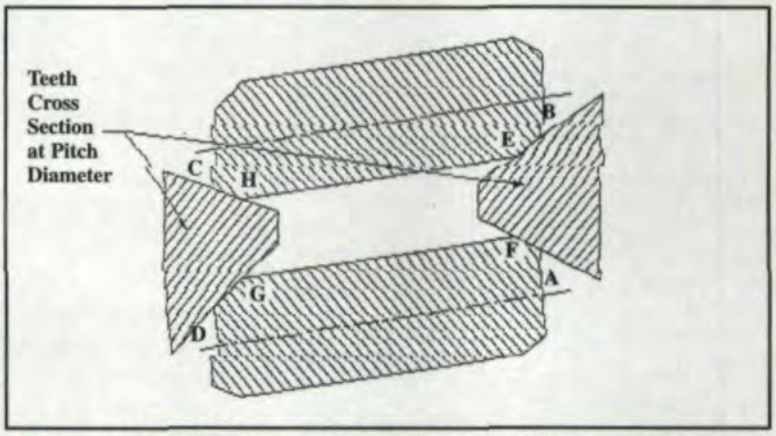

Fig. 8 — A cross section of gear and chamfering tool teeth in a rolling operation.

Production Methods

Edge chamfers can be produced by three different methods.

***A cutting operation*.** There are two cutting methods. The machine may be designed to have a milling cutter and a gear train of CNC equipment to generate an involute. The milling cutter can be held steady with only one circular speed along its axis. In this case, the chamfer is uniform and parallel to the involute. This method produces a good chamfer, and there is no need for any additional deburring operations. On the other hand, milling is a costly operation, and it is difficult to chamfer gears lying adjacent to a shoulder using this technique. Cycle times are long in this method because of indexing, and tool life is poor.

A second way to cut a chamfer is to use a gear train or CNC equipment to index in conjunction with a cutter. The cutter has a reciprocating motion timed with the indexing motion. This type of operation usually produces the chamfer along a straight line. The advantage of this method is that no further deburring operation is required. Among the disadvantages is the fact that this method creates an uneven chamfer extending through the whole root. Sometimes burrs are left on the gear in the root area. Chamfering gears adjacent to a shoulder is also difficult with this method. Again, cycle times are long, and tool life is poor. This approach also requires a lot of operator assistance to maintain a good setup.

***A grinding operation*.** In this method, a grinding wheel is used to produce the chamfers. The advantages are low cycle times and acceptable chamfers all around, but the grinding powder mixed with steel particles pollutes the atmosphere, creating Clean Air Act compliance problems and raising concerns about employee health and general environmental ethics. To counter the pollution effects, expensive filters and dust collectors are needed. Tiny burrs are created along the involute, and they need an extra cleaning operation like shot peen blast. A lot of operator assistance is required to maintain a good setup.

***A rolling operation using special chamfer tools*.** This operation involves driving a chamfer tool in mesh with the gear under pressure. The pressure will plastically deform the material, producing the chamfer. Most of the material deformed plastically will flow out of the sides A, B, C and D (see Fig. 8). Tiny portions, about 0.0008" (0.02 mm), will rise up as tiny ridges inside the involutes E, F, G and H, and a very small portion will rise out of the tip chamfer (D) (Fig.1) produced by a turning operation. Because of this, the operation must be followed by a finishing operation like shaving or grinding. It is not recommended for finished cut parts.

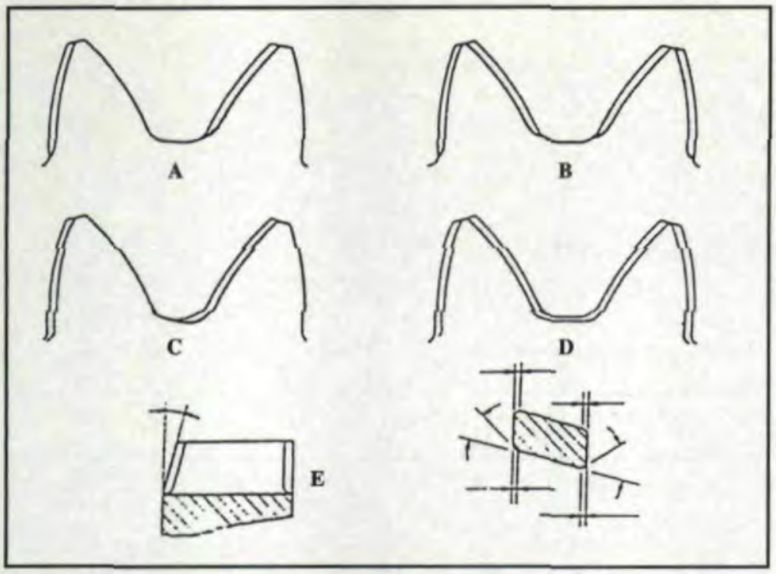

Fig. 9 — Types of edge chamfers.

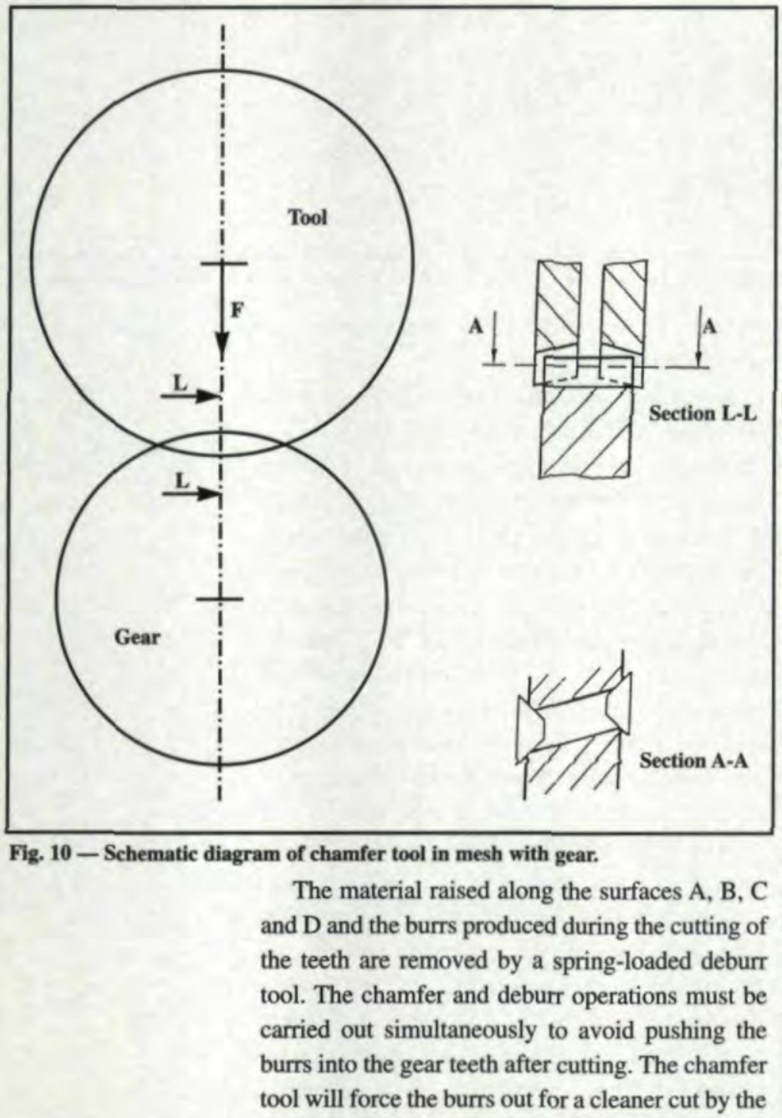

Fig. 10 — Schematic diagram of chamfer tool in mesh with gear.

The material raised along the surfaces A, B, C and D and the burrs produced during the cutting of the teeth are removed by a spring-loaded deburr tool. The chamfer and deburr operations must be carried out simultaneously to avoid pushing the burrs into the gear teeth after cutting. The chamfer tool will force the burrs out for a cleaner cut by the deburr tool. The material raised along the surface D can be minimized by designing the chamfer tool with an operating pressure angle that minimizes the sliding velocity toward the tip. A pair of burnishing tools can be added to the deburr tool group to remove the raised material along D.

The main advantage of this method is extremely long cutter life. It is quite common to chamfer more than 100,000 parts between resharpening. The machine cut cycle time is only 3–4 seconds, while the floor-to-floor cycle time varies from 7–15 seconds for pinion gears. Constant sizes of chamfer parallel to the involute and chamfering the root are possible. This method can chamfer/deburr any adjacent shoulder both on the gear side and the groove side.

Some stress points should be considered when producing edge chamfers by rolling. The plastic deformations of the material should produce residual stresses along the involute surface chamfer that would locally increase the surface stress limit and reduce the stress concentration factor, *thus enhancing the overall resistance of the chamfered gear.* It is essential to chamfer not only the acute angle called for on most drawings, but also the obtuse angle. This gives better protection from nicks and bumps and ensures homogeneous behavior of both the flanks of the gear under load because of the residual stress.

For simplest applications, the tool used on chamfering and deburring machines consists of a set of chamfering tools and a set of skiving tools to deburr lateral surfaces. Because of the force between the tool's springs and the gear's width once it enters into the tools, the two deburring tools will spread open. Chamfering and deburring tools run free on their own quills and self-center themselves on the center line of the gear, thus assuring symmetrical chamfers and complete removal of burrs.

The tool group on a one-head machine in the simplest form consists of one set of chamfer bevel gears and one set of cutter discs mounted together as a gang. The workpiece drives the complete tool group, since it is in mesh with the chamfering tool.

The various types of chamfers that can be achieved on either spur or helical gears cover the whole range usually required for any cylindrical gears. Examples of feasible chamfers include a) chamfering only on one flank without the root; b) chamfering both flanks without the root; c) chamfering one flank and part of the root; d) chamfering the complete profile; e) chamfering inclined faces (see Fig. 9).

Each problem can be evaluated individually and tooling engineered to suit specific applications. Cluster gears can be chamfered and deburred with machines having multiheads with two working stations. To work different gears on the same machine, the tools can be designed to keep a constant center distance between the workpiece and the tool in order to reduce the changeover time.

Chamfering Tools

Chamfering tools are engineered to generate the chamfer on the edges of the gear teeth. The chamfer is made by the rolling action of chamfering tools. In effect two bevel gears mate with the work gear only along the corner edges of its teeth. The force "F," provided by a pneumatic cylinder, represents the thrust necessary for rolling (see Fig. 10). Because of their bevel gear shape and balanced application (one pair of identical tools symmetrically coupled), opposed axial stresses are generated during rolling. As the tool group is free to move axially, it centers itself on the centerline of the gear width.

If the two tools are off center as in Fig. 11A, after the tool group is engaged, the gear will move axially until the forces are balanced. The final position is shown in Fig. 11B. This makes the chamfers symmetrical. These tools will work either spur or helical gears.

Fig. 12 describes a chamfering tool tooth. Besides being tapered, the teeth have an involute form enabling them to mesh with the gear and roll on its corners.

The angle of the tooth flanks of the chamfering tool depends on the gear helix angle and the angle of chamfers to be generated (Fig. 13).

$\beta 1$ and $\beta 2$ = chamfer angle required by part print drawing.

β = gear helix angle.

$\gamma 1$ and $\gamma 2$ = flank angle on the chamfering tool teeth.

$\gamma 1 = \beta + \beta 1$, and $\gamma 2 = \beta 2 - \beta$.

In order to have the chamfers correctly executed, the chamfering discs must be in such a position that the axes of the chamfer tools have the same helix angle as the gear (phasing along helix angle).

Special Cases

When a shoulder or radius is present on the side face of the gear, the chamfering operation cannot be completed all along the profile. The chamfer must end at least 0.012" (0.3 mm) before a step or a radius begins. In cases where the gear has an angled side face, it is necessary to engineer tools with properly modified pressure angles.

Chamfer Tool Resharpening

The chamfering tools are able to produce many thousands of pieces before resharpening. The chamfering tool teeth are not truly resharpened. Rather, the position of the chamfering disc is changed with respect to the gear so that afterward chamfers will be generated by a new area of the chamfer tool teeth that is not worn yet.

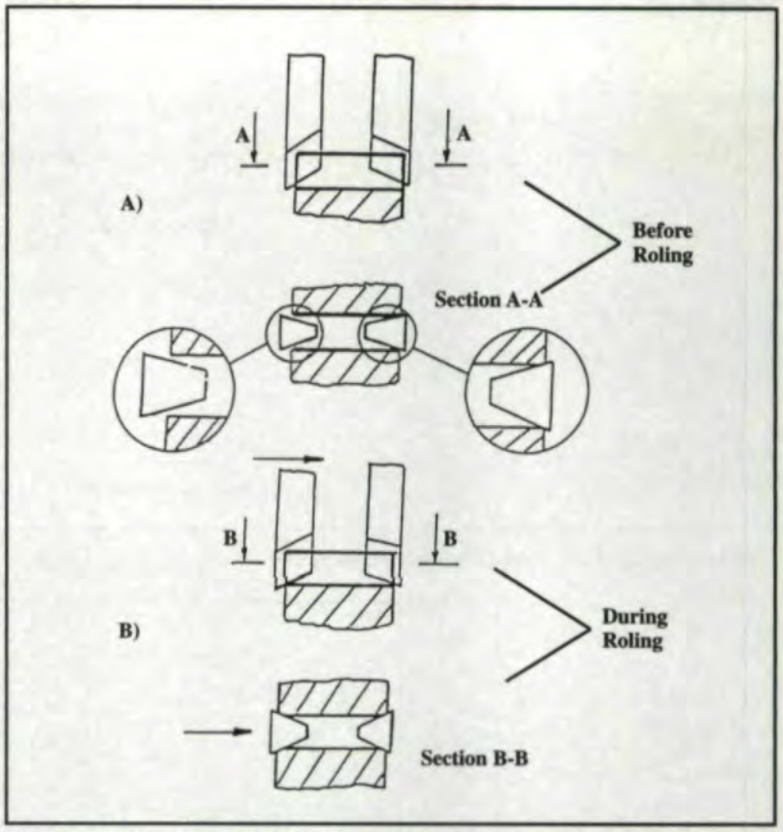

Fig. 11 — A) Nonsymmetrical chamfer tools; B) Symmetrical chamfer tools.

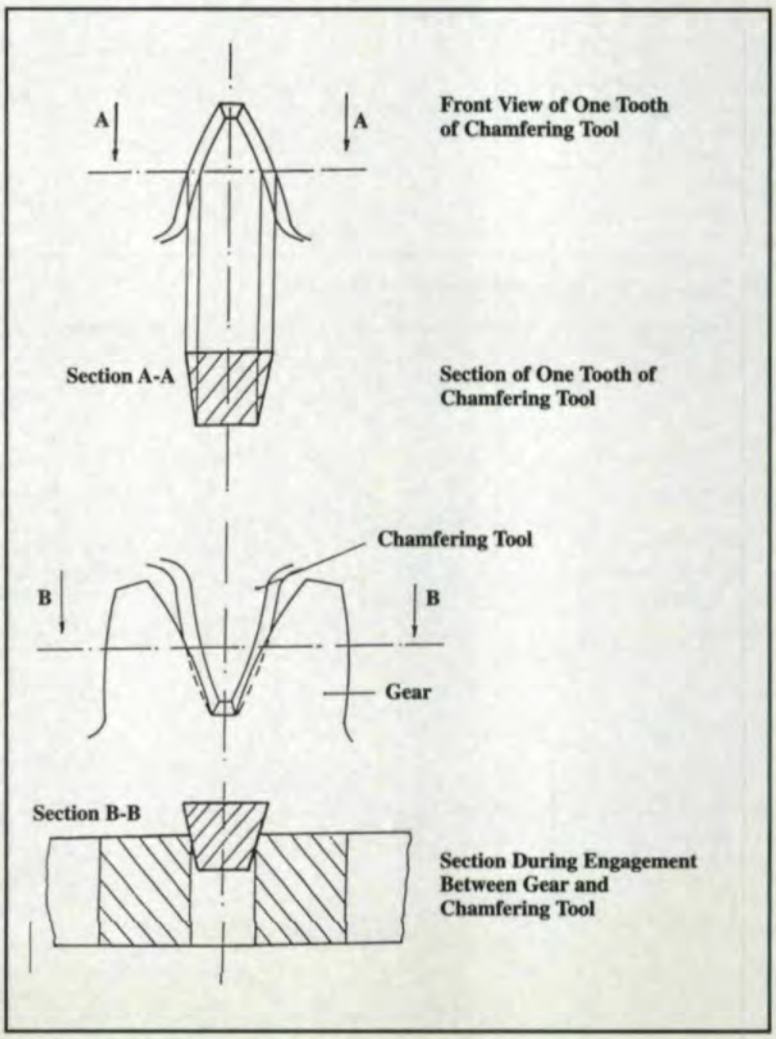

Fig. 12 — Gear tooth and chamfering tool tooth sections.

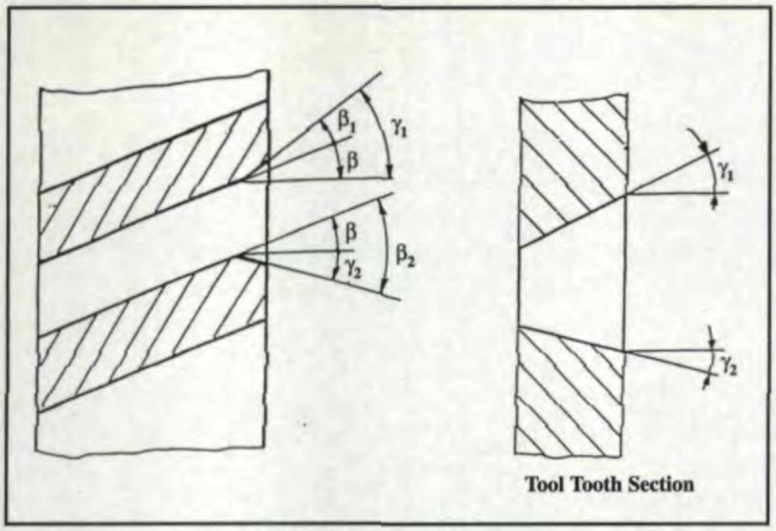

Fig. 13 — Section view of deburring tools in mesh with gear.

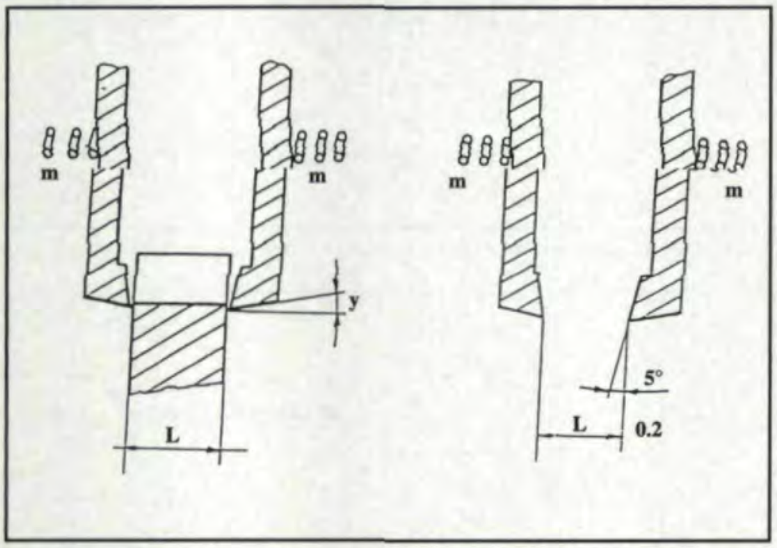

Fig. 14 — "R" type deburring tool in mesh with gear.

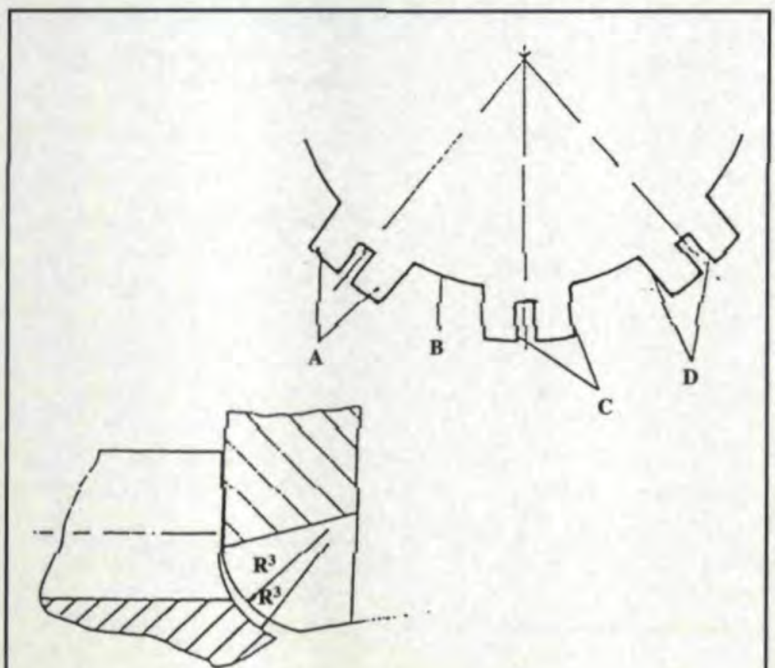

Fig. 15 — Cross sectional view of deburring tool.

Each chamfering disc can be utilized three or four times. When the chamfers no longer have a constant size from one gear tooth to another when the rolling stress rises, or when each single chamfer is no longer uniform along the profile, it is time to grind the chamfering discs in such a way that a new rolling area will contact with the edges of the gear teeth.

Deburr Tools

Deburring tools are large diameter discs whose external rims are ground to the rake angles necessary for cutting action. The distance between the two discs is not constant because they can move axially either under the action of the springs ("m" shown in Fig. 14) or as a consequence of the self-centering with the gear to be deburred.

In the rest position, the spring pressure on the deburring discs brings their separation distance to a minimal value, which is about 0.008" (0.2 mm) less than the minimum gear width. If the distance between the discs were fixed, the discs themselves would hit the outside diameter of the workpiece, chipping it when discs are plunge-fed towards the workpiece. To avoid this, the cutting edge of each disc is provided with a tapered lead-in whose size is large enough to avoid hitting the outside diameter of the gear to be deburred. The first contact must occur between the lead-in surface and the workpiece outside diameter.

The deburring discs are rotated by the workpiece itself, and the burrs are removed through a true skiving action on the gear lateral faces. Generally 100,000 pieces or more in some cases can be deburred before resharpening the tool. The tool life between resharpenings depends upon a number of factors. They are

- The hardness and machinability of workpiece material;
- The thickness of burrs and the size of the requested chamfer;
- The length of the deburred area (workpiece whole depth);
- The presence of steps, radii or shoulders, which may interfere with the tool cutting edge;
- The correct resharpening and assembly of the tool group.

Special Cases

For gears with shoulders or radii, special types of deburring tools are designed for a correct action of the deburring discs in order to avoid the interference. To deburr a gear with a radius (see Fig. 15), a special type of deburring tool known as an "R" type tool is used. Due to the spring loading action, the burrs are uniformly and cleanly skived off the surface by the tool following the profile of the gear. The same tool also performs the deburring of the straight portion. The radius form protuberances A are alternated with the cutting edges B, which work the straight portion of surface S like a standard deburring tool. Protuberances A remove burrs from the radii by means of the true cutting action of the cutting edges C or D according to the direction of rotation. Portion B skives the straight faces as far as .008" (0.2 mm) to 0.012" (0.3 mm) above radius R^3.

When the surface to be deburred is tapered, specially tapered deburring tools with many inclined slots are used to generate an adequate number of sharp cutting edges. During helical gear cutting with either a hob or with a shaper cutter, burrs are usually left on the acute edge (where the tool comes out of the gear). The relative traverse movement between the deburring tool and the gear must push the burr toward the tooth and not toward the space.

Deburring Tool Sharpening

Wear can be removed by grinding either surface E or surface H (see Fig. 16A). Stock size removed must be 0.008" (0.2 mm) or its multiples in the direction of the disc's axis. The disc thickness reduction is compensated for by shifting the spacers.

With no gear between the tools, the discs are in the conditions shown in Fig. 16B. The springs push the disc and the spacer against the shoulder flange. When the gear enters the discs, it forces the discs apart, thus moving the tool from the shoulder flange and creating a gap approximately 0.004" (0.1 mm) between flange and spacers (see Fig. 17). After resharpening the gap will not be the same. In order to return to the initial conditions, a space 0.008" (0.2 mm) thick will have to be shifted from position 1 to position 2 as shown in Fig. 18. After every resharpening, it is necessary to check the lead in chamfer size so that it lies outside of the gear when the tool contacts the gear. ○

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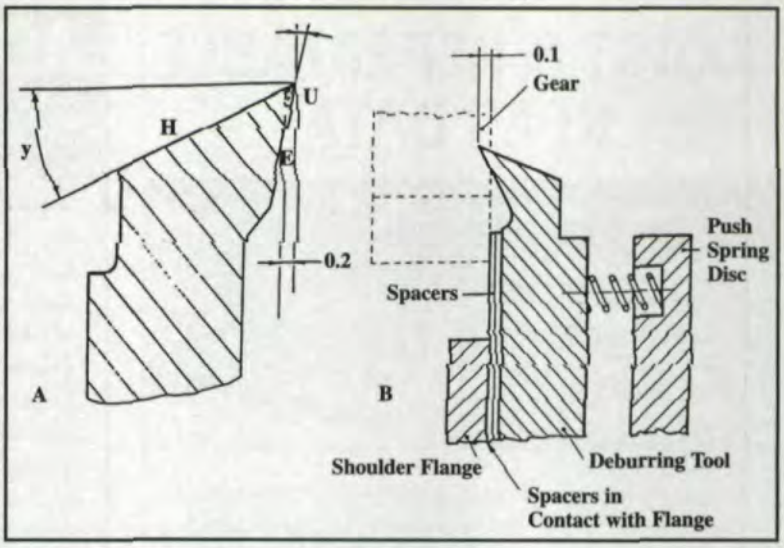

Fig. 16 — Principle of deburring tool operation.

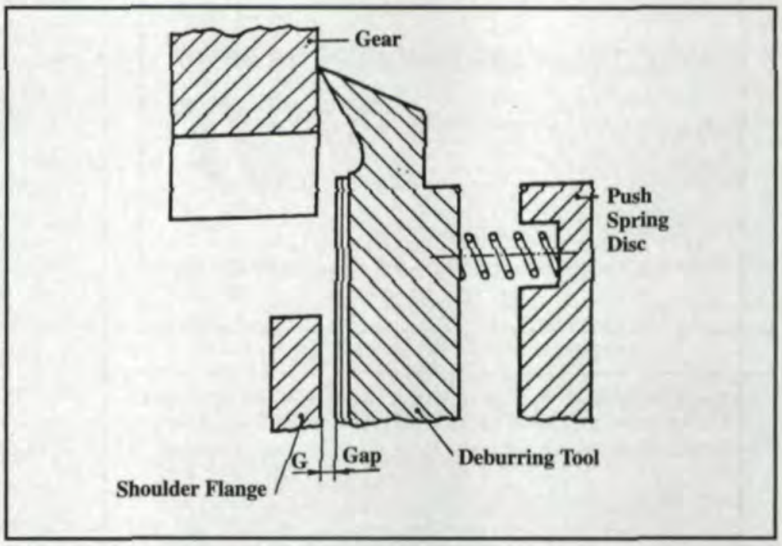

Fig. 17 — Cross sectional view of deburring tool with spacers and springs.

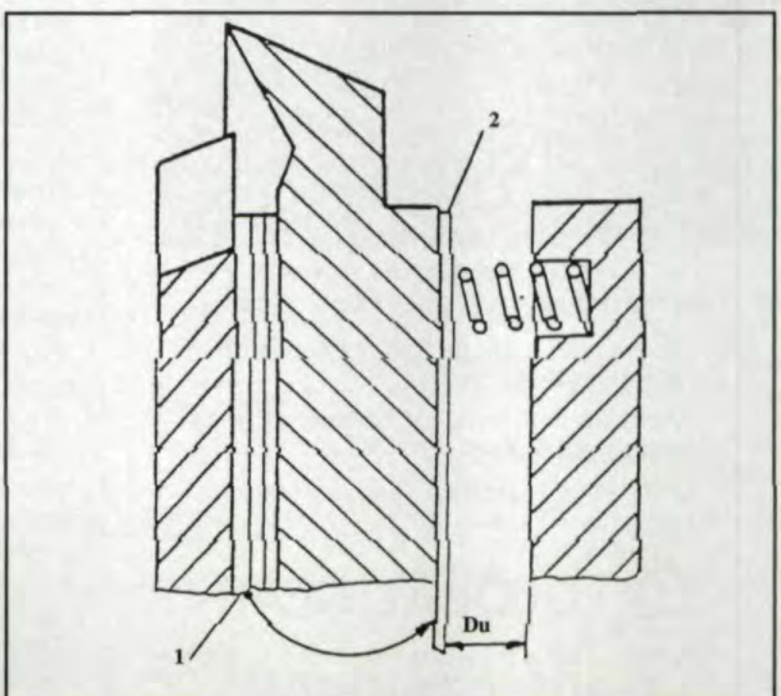

Fig. 18 — Position shift after resharpening.