Gear Shaving Basics – Part II

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In our last issue, we covered the basic principles of gear shaving and preparation of parts for shaving. In this issue, we will cover shaving methods, design principles and cutter mounting technique.

Shaving Methods

There are four basic methods for rotary shaving external spur and helical gears: axial or conventional, diagonal, tangential or underpass and plunge. The principle difference between the various methods is the direction of reciprocation (traverse) of the work through and under the tool.

***Axial or Conventional*:** Axial shaving (Fig. 1) is widely used in low and medium production operations. It is the most economical method for shaving wide face width gears. In this method, the traverse path is along the axis of the work gear. The number of strokes may vary with the amount of stock to be removed. The length of traverse is determined by the face width of the work. For best results, the length of traverse should be approximately 1/16" greater than the face width of the work, allowing minimum overtravel at each end of the work face. In axial shaving, in order to induce lead crown (Fig. 2), it is necessary to rock the machine table by use of the built-in crowning mechanism.

***Diagonal*:** In diagonal shaving, the traverse path is at an angle to the gear axis (Fig. 3). Diagonal shaving is used primarily in medium and high production operations. This method can reduce shaving times by as much as 50%.

In diagonal shaving, the sum of the traverse angle and the crossed axes angle is limited to approximately 55° unless differential type serrations are used; otherwise, the serrations will track. The relative face widths of the gear and the shaving cutter have an important relationship with the diagonal traverse angle. A wide face width work gear and a narrow shaving cutter restrict the diagonal traverse to a small angle. Increasing the cutter face width permits an increase in the diagonal angle. The gear teeth can be crowned by rocking the machine table, provided the sum of the traverse angle and cross axes angle does not exceed 55°.

When using high diagonal angles, it is preferable to grind a reverse crown (hollow) in the lead of the shaving tool. In most cases, the diagonal traverse angle will vary from 30° to 60° to obtain optimum conditions of cutting speed and work gear quality.

With diagonal traverse shaving, the center line of the crossed axes is not restricted to a single position on the cutter, as it is in conventional shaving, but is migrated across the cutter face, evening out the wear. Consequently, cutter life is extended. Although conventional shaving requires a number of table strokes, each with its increment of upfeed, diagonal shaving of finer pitch gears may be done in just two strokes with no upfeed and a fixed center distance between cutter and work. An automatic upfeed mechanism on the shaving machine materially enlarges the scope of diagonal shaving by also making it available for multi-stroke operations. This device feeds the work into the cutter in a series of small increments, instead of two large increments, further increasing cutter life. It also makes the process feasible for gears requiring more stock removal than can be handled on a two-stroke cycle. When upfeed is completely automatic, there can be no danger of an error in selecting feed rates. Inasmuch as the cycle starts and stops in a position of maximum backlash, loading and unloading can be very fast.

Tangential or Underpass: In the tangential (underpass) method of shaving (Fig. 4), the traverse path of the work is perpendicular to its axis. Tangential shaving is used primarily in high production operations and is ideally suited for shaving gears with restricting shoulders.

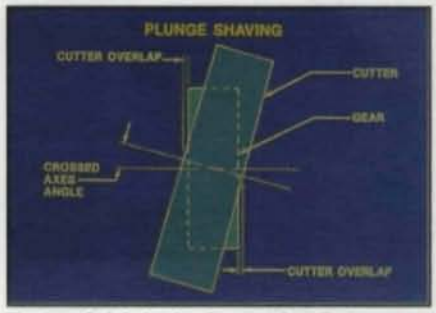

Fig. 1 — Axial shaving (conventional).

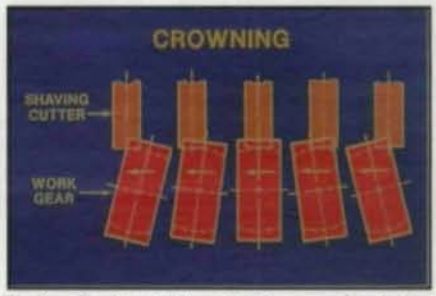

Fig. 2 — Rocking table action for crowning during conventional shaving.

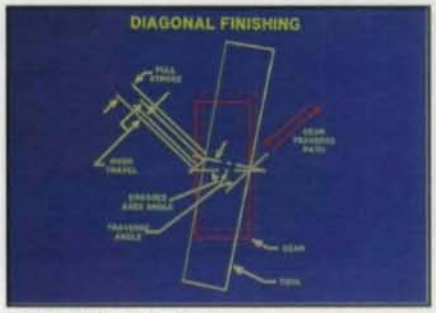

Fig. 3 — Diagonal shaving.

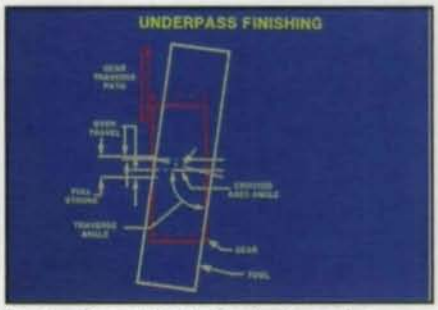

Fig. 4 — Tangential shaving (underpass).

When using this method, the serrations on the cutter must be of the differential type. Also, the face width of the cutter must be wider than that of the work gear.

Plunge: Plunge shaving (Fig. 5) is used in high production operations. In this method, the work gear is fed into the shaving cutter with no table reciproca-

tion. The shaving cutter must have differential type serrations or cutting action will be impaired. To obtain a crowned lead on the work, a reverse crown or hollow must be ground into the shaving cutter lead. In all cases of plunge shaving, the face width of the shaving tool must be greater than that of the work gear. The primary advantage of plunge shaving is its very short cycle time.

Shaving Internal Gears

Internal gears can be shaved on special machines on which the work drives the cutter or by internal cutter head attachments on external shavers.

Because of the crossed-axes relationship between the cutter and the work gear in internal shaving, the cutter requires a slight amount of crown in the teeth to avoid interference with the work gear teeth. Crowning of the teeth on gears over 3/4" wide is best achieved by a rocking action of the work head similar to the rocking table action used in external gear shaving.

When internal gears are 3/4" wide or less, or when interference limits the work reciprocation and crossed-axes angle, plunge shaving can be used. In this method, the cutter has differential serrations and is plunge fed upward into the work. If lead crown is desired on the work gear, a reverse crowned cutter is used.

The Shaving Cutter

Rotary shaving cutters are high precision, hardened and ground, high speed steel generating tools held to Class "A" and "AA" tolerances in all their principle elements. The gashes in the shaving cutter extend the full length of the tooth, terminating in a clearance space at the bottom. These clearance spaces provide unrestricted channels for a constant flow of coolant to promptly dispose of chips. They also permit a uniform depth of serration penetration and increase cutter life.

The shaving cutter is rotated at high speeds up to 400 and more surface feet per minute. Feed is fine, and the tool contact zone is restricted. Cutter life depends on several factors: operating speed, feed, material and hardness of the work gear, its required tolerances, type of coolant and the size ratio of cutter to work gear.

Design

Rotary gear shaving cutters are designed in much the same manner as other helical involute gears. The serrations on the tooth profiles, in conjunction with the crossing of the axes of the cutter and the work gear, make it a cutting tool. In designing rotary gear shaving cutters, the following points must be considered:

- Normal diametral pitch and normal pressure angle must be the same as those of the gears to be shaved.
- Helix angle is chosen to give a desired crossed-axes angle between the cutter and work. The crossed-axis is the difference between the helix angle of the shaving cutter and the work gear. The desired range is from 5–15°.
- The number of teeth is chosen to give the required pitch diameter, considering helix angle and diametral pitch. Hunting tooth conditions and machine capacity are also important factors.
- Tooth thickness of the cutter is selected to provide for optimum operating conditions throughout the life of the tool.
- The addendum is always calculated so the shaving cutter will finish the gear profile slightly below the lowest point of contact with the mating gear. The tooth thickness and the addendum of the cutter are not necessarily given to the theoretical pitch diameter.
- Cutter serrations are lands and gashes in the involute profile of the tool. They extend from the top to the bottom of the tooth, clearing into a relief hole at its base. The width or size is determined by the work gear to be shaved. Differential serrations with a control lead are produced on shaving cutters used for plunge shaving and diagonal with the traverse angle over 55°.
- The involute profile of the shaving cutter tooth is not always a true involute. Very often, it must be modified to produce the desired involute form or modifications in the profile of the gears being shaved.

Sharpening Shaving Cutters

The shaving cutter, like other tools, dulls with use. In sharpening, minimum stock is removed on the tooth faces. With normal dullness, the resharpening operation usually reduces the tooth thickness approximately 0.005". An excessively dull or damaged tool must be ground until all traces of dullness or damage are gone.

The number of sharpenings varies with pitch and available depth of its serrations. Usually a cutter can be sharpened until the depth of its serrations has been reduced to 0.006" – 0.012".

Shaving Machines

Rotary gear shaving machines are manufactured in various configurations. Gears smaller than one inch and as large as 200 inches require different approaches. Rotary gear shaving uses a shaving machine which has a motor-driven cutter and a reciprocating work table. The cutter head is adjustable to obtain the desired crossed axis relationship with the work. The work carried between centers is driven by the cutter. Machines ranging from mechanical ones having one CNC axis to those with a full five CNC axes are available.

During the shaving cycle, the work is reciprocated and fed incrementally into the cutter with each stroke of the table. The number of infeeds and strokes is dependent upon the method used and the amount of stock to be removed.

The Machine Setup

Mounting the Work Gear: The work gear should be shaved from the same locating points or surfaces used in the pre-shave operation. It should also be checked from these same surfaces. Locating faces must be clean, parallel and square with the gear bore. Gears with splined bores may be located from the major diameter, pitch diameter or minor diameter. When shaving form centers, the true center angle should be qualified, and the surfaces should be free of nicks, scale and burrs. Locating points of work arbors and fixtures should be held within a tolerance of .0002". The arbor should fit the gear hole snugly. Head and tailstock centers should run within .0002" for dependable results. Gears should be shaved from their own centers whenever possible. If this is not possible, rigid, hardened and ground arbors having large safety centers should be used (Fig. 6).

Integral tooling is another popular method of holding the workpiece, especially in high production. This consists of hardened and ground plugs instead of centers (Fig.7) mounted on the head and tailstock. These plugs are easily detached and replaced when necessary. They locate in the bore and against the face of the gear. It is therefore essential that the gear faces be square and bore tolerances held to assure a good slip fit on the plugs.

Mounting the Cutter

Great care is required in handling the shaving cutter. The slightest bump may nick a tooth. Until the cutter is placed on its spindle, it should lie flat and away from other objects. The cutter spindle and spacers should be thoroughly cleaned and the spindle checked before the cutter is mounted. The spindle should run within .0002" on the O.D. and .0001" on the flange, full indicator reading.

After mounting, the cutter face should be indicated to check mounting accuracy. Face runout should not exceed .0008" for a 12" diameter cutter, .0006" for a 9" diameter cutter or .0004" for a 7" cutter.

Feeds and Speeds

Shaving cutter spindle speeds will vary with the gear material hardness, finish and size of part. Normally, when using a 7-inch cutter on a 10-pitch gear having a 3-inch pitch diameter, spindle speed will be approximately 200 rpm, or using a 9-inch cutter, 160 rpm. This speed, figured on the pitch circle, is approximately 400 surface feet per minute, which in most cases produces good results.

The following are formulas for determining cutter and gear speeds (in rpms):

$$\text{Cutter rpm} = \frac{\text{Desired Surface fpm}}{\frac{\text{Cutter Diameter (in.)} \times \pi}{12}}$$

$$\text{Gear rpm} = \text{Cutter rpm} \times \frac{\text{No. of Teeth in Cutter}}{\text{No. of Teeth in Gear}}$$

For conventional shaving, about .010" per revolution of the gear is a good starting point and becomes a factor in the following formula:

$$\text{Table Feed Rate} = .010 \times \text{Gear rpm}$$

For diagonal shaving, an "effective feed rate" of approximately 0.040" per revolution of the gear is a good starting point. Effective feed rate is the speed at

which the point of crossed axes migrates across the face of the gear and the shaving cutter. The following is the formula for determining the table traverse rate (ipm) to produce an .040" effective feed rate:

$$\text{Table Traverse Rate (ipm)} = \frac{0.040 \times \text{Gear rpm}}{R_f}$$

where

$$R_f = \frac{\text{Sine Traverse Angle}}{\text{Tangent Crossed-Axes Angle}} + \text{Cosine of Traverse Angle}$$

These suggested feed rates may be varied depending on individual operating conditions. If higher production is desired, the table feed rate can be increased, but this may result in some sacrifice in quality of tooth finish. Where surface finish is very important, as with aviation and marine gears, table feeds are reduced below the amounts indicated. In some cases, notably large tractor applications, feeds considerably in excess of those indicated are used. ○

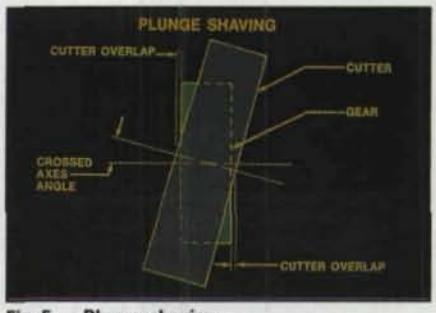

Fig. 5 — Plunge shaving.

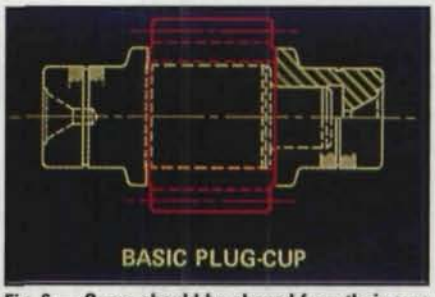

Fig. 6 — Gears should be shaved from their own centers, but if this is not possible, hardened and ground arbors having large safety centers should be used.

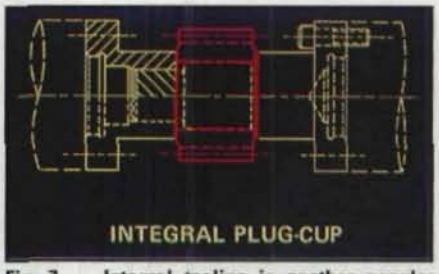

Fig. 7 — Integral tooling is another popular method of holding the workpiece.

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provides technical sales support at National Broach and leads training seminars for customers. He is also the author of a number of papers and articles on gear subjects.

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