Gear Shaving Basics – Part I

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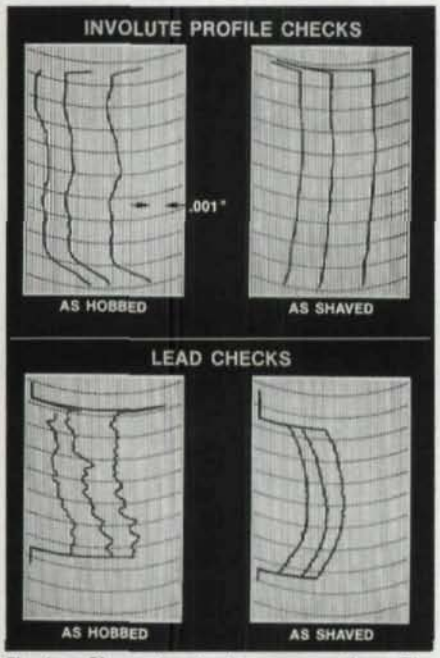

Fig. 1 — Charts showing improvement in profile and lead, 5.7 NPD, 20°, NPA, 3.85" P.D., crowned shaved with stock removal of 0.011" over pins.

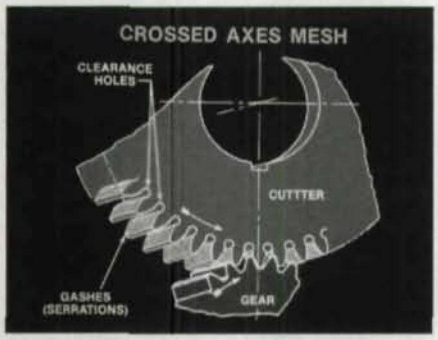

Fig. 2 — Work gear in crossed-axes mesh with rotary shaving cutter mounted above.

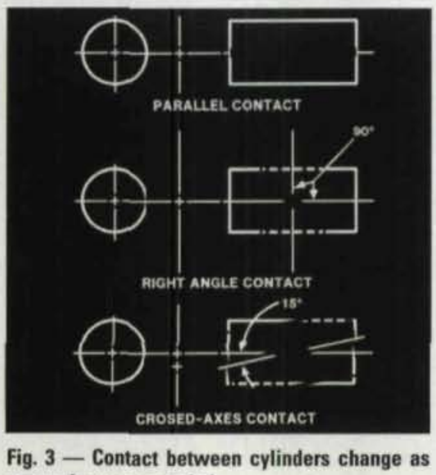

Fig. 3 — Contact between cylinders change as crossed axes are varied.

Gear shaving is a free cutting gear finishing operation which removes small amounts of metal from the working surfaces of gear teeth. Its purpose is to correct errors in index, helix angle, tooth profile and eccentricity (Fig. 1). The process also improves tooth surface finish and eliminates by means of crowned tooth forms the danger of tooth end load concentrations in service. Shaving provides for profile modifications that reduce gear noise, increase a gear's load carrying capacity, its factor of safety and its service life. Gear finishing (shaving) is not to be confused with gear cutting (roughing). They are essentially different. Any machine designed primarily for one cannot be expected to do both with equal effectiveness or with equal economy.

Gear shaving is the logical remedy for the inaccuracies inherent in gear cutting. It is equally effective as a control for those troublesome distortions caused by heat treatment.

The form of the shaving cutter can be reground to make profile allowance for different heat treat movements caused by varying heats of steel. The shaving machine can also be reset to make allowance for lead change in heat treatment.

Rotary gear shaving is a production process that utilizes a high speed, hardened and ground, ultra-precision steel shaving cutter. The cutter is made in the form of a helical gear. It has gashes in the flanks of the teeth which act as the cutting edges.

The cutter is meshed with the work gear in a crossed-axes relationship (Fig. 2) and rotated in both directions during the work cycle while the center distance is reduced in small increments. Simultaneously the work is traversed back and forth across the width of the cutter. The traverse path can either be parallel or diagonal to the work gear axis, depending on the type of work gear, the production rate and finish requirements. The gear shaving process can be performed at high production rates. It removes material in the form of fine hair-like chips.

Machines are available to shave external spur and helical gears up to 200" in diameter. Other machines are also available for shaving internal spur and helical gears. For best results with shaving, the hardness of the gear teeth should not exceed 30 Rockwell C scale. If stock removal is kept to recommended limits, and the gears are properly qualified, the shaving process will finish gear teeth in the 7 to 20 pitch range to the following accuracies: involute profile, 0.0002"; tooth-to-tooth spacing, 0.0003" and lead or parallelism, 0.0002".

In any event, it should be remembered that gear shaving can remove 65–80% of the errors in a hobbed or shaped gear. It will make a good gear better. The final quality of the shaved gear is dependent to a large degree upon having good hobbed or shaped gear teeth.

Excellent surface finish is achieved with gear shaving. A value of approximately 25° is the normal finish obtained with production gear shaving, although much finer finishes are possible by slowing the process. In some cases, shaving cutters will finish up to 80,000 gears before they need sharpening. They may generally be sharpened from four to ten times.

To a gear designer, the shaving process offers attractive advantages in the ability to modify the tooth form. If a crowned tooth form or a tapered tooth form are desired to avoid end bearing conditions, these can be easily provided by shaving.

If modifications are desired in the involute profile, these can be made by suitable modifications in the ground cutter tooth form. If heat treatment distortions can be kept to a minimum, the most inexpensive way to produce an accurate, quiet, high-performance gear is to specify hobbing followed by gear shaving. The shaving process uses a variety of standardized production equipment ranging from hand loading to fully automatic loading and unloading.

Basic Principles

The rotary gear shaving process is based on fundamental principles. This process uses a gashed rotary cutter in the form of a helical gear having a helix angle different from that of the gear to be shaved. The axes of the cutter and the gear are crossed at a predetermined angle during the shaving operation. When the cutter and the work gear are rotated in close mesh, the edge of each cutter gash shaves a fine hair-like chip as it moves over the surface of a work gear tooth. The finer the cut, the less the pressure required between tool and work, eliminating the tendency to cold-work the surface metal of the work gear teeth.

This process is performed in a shaving machine, which has a motor-driven cutter head and a reciprocating work table. The cutter head is adjustable to obtain the desired crossed axis relationship with the work. The work carried between live centers is driven by the cutter. During the shaving cycle, the work is reciprocated parallel to its axis across the face of the cutter and upfed an increment into the cutter with each stroke of the table. This conventional shaving cycle is one of several methods.

The Crossed-Axis Principle

To visualize the crossed-axis principle, consider two parallel cylinders of the same diameter (Fig. 3). When brought together under pressure, their common contact surface is a rectangle having the length of a cylinder and width which varies with contact pressure and cylinder diameter.

When one of these cylinders is swung around so that the angle between its axis and that of the other cylinder is increased up to 90°, their common plane remains a parallelogram, but its area steadily decreases as the axial angle increases. The same conditions prevail when instead of the two plain cylinders, a shaving cutter and a work gear are meshed together. When the angle between their axes is from 10° to 15°, tooth surface contact is reduced, and the pressure required for cutting is small. As the work gear is moved away axially from the point of intersection of the axes, backlash develops. Conversely, as it is returned to the point of axial intersection, backlash decreases until the two members engage in tight mesh with the teeth of the cutter wedging between those of the work gear. Thus, each succeeding cutting edge sinks deeper into the work gear tooth until the point of axial intersection is reached.

For shaving, the cutter and work gear axes are crossed at an angle usually in the range of 10° to 15° or approximately equal to the difference in their angles.

Crossing the axes produces reasonably uniform diagonal sliding action from the tip of the teeth to the root. This not only compensates for the nonuniform involute action typical of gears in mesh on parallel axes, but provides the necessary shearing action for stock removal.

Relationship Between Cutting & Guiding Action

Increasing the angle between the cutter and work axes increases cutting action, but, as this reduces the width of the contact zone, guiding action is sacrificed. Conversely, guiding action can be increased by reducing the angle of crossed axes, but at the expense of cutting action.

Preparation Prior to Shaving

The first consideration in manufacturing a gear is to select the locating surfaces and use them throughout the process sequence. Close relationship between the locating surface and the face of the gear itself must be held. Otherwise, when the teeth are cut and finished with tooling that necessarily contacts the gear faces, the teeth will be in an improper relationship with the locating or related surface on which the gear operates. Gears that locate on round diameters or spline teeth must fit the work arbors closely or these critical hole-to-face relationships will be destroyed.

Typical manufacturing tolerances for gear blanks prior to cutting of the teeth are shown in Table 1.

Once the gear blank has been manufactured, it is necessary to cut the gear teeth. The most common methods today for rough-cutting gear teeth are hobbing and shaper cutting. Of primary concern to the shaving cutter manufacturer is the fillet produced by the roughing operation. The tips of the shaving cutter teeth must not contact the gear root fillet during the shaving operation. If such contact does occur, excessive wear of the cutter results, and the accuracy of the involute profile is affected.

The shaving cutter just finishes the gear tooth below its active profile. Thus, the height of the fillet should not exceed the lowest point of contact between the shaving cutter teeth and the teeth on the work gear.

Protuberance type hobs and shaper cutters are often used prior to shaving to produce a slight undercut or relief near the base of the gear tooth. This method assures a smooth blending of the shaved tooth profile and the unshaved tooth fillet, as well as reducing shaving cutter tooth tip wear (Fig. 4). The amount of undercut produced by the protuberance type tool should be made for the thin end of the tooth. The position of the undercut should be such that its upper margin meets the involute profile at a point below its contact diameter.

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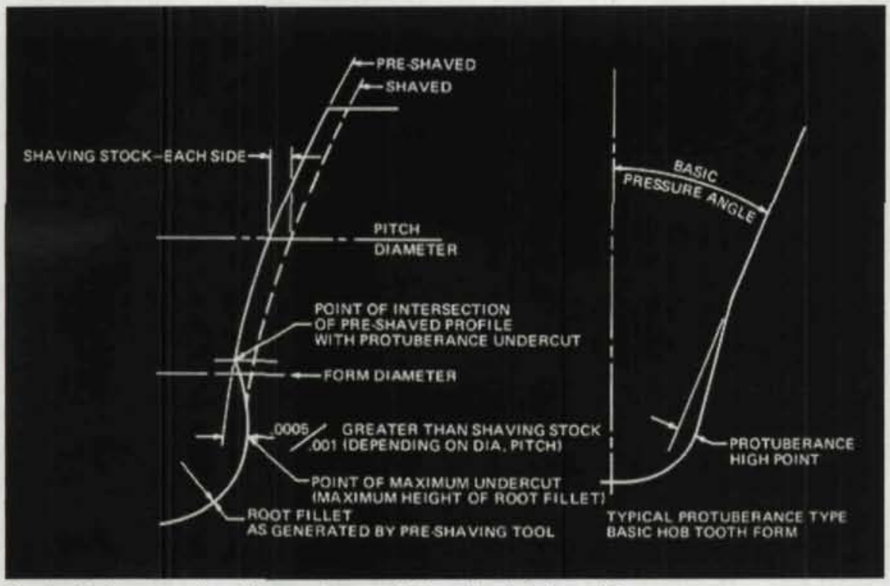

Fig. 4 — Undercut produced by protuberance hob and basic hob tooth form.

TABLE 1 – TYPICAL GEAR BLANK TOLERANCE

Blank Dia. In.	Face Runout In.	Hole Size In.	Hole Tape In./In.	Hole Roundness In.-Max.	O.D. In.-Max.	O.D. Runout In.
Up to 1 1-in *Thick*	0.0003–0.0005	0.0003–0.0006	0.0002–0.0003	0.0002–0.0003	0.003	0.003
1–4, up to 1 in. Thick	0.0004–0.0008	0.0005–0.001	0.0002–0.0003	0.0003–0.0005	0.005	0.005
4 to 8	0.0006–0.0012	0.0008–0.0012	0.0002–0.0003	0.0004–0.0006	0.005	0.007
8 to 12	0.001–0.002	0.001–0.0015	0.0002–0.0003	0.0005–0.0007	0.005	0.008

TABLE 2 – RECOMMENDED SHAVING STOCK AND UNDERCUT FOR PRESHAVED GEARS.

Normal Diametral Pitch	Shaving Stock (In. per Side of Tooth)	Total Undercut (In. per Side of Tooth)
2–4	0.0015–0.0020	0.0025–0.0030
5–6	0.0012–0.0018	0.0023–0.0028
7–10	0.0010–0.0015	0.0015–0.0020
11–14	0.0008–0.0013	0.0012–0.0017
16–18	0.0005–0.0010	–
20–48	0.0003–0.0008	–
52–72	0.0001–0.0003	–

Shaving Stock

The amount of stock removed during the shaving process is a key to its successful application. Sufficient stock should be removed to permit correction of errors in the preshaved teeth. However, if too much stock is removed, cutter life and part accuracy are effectively reduced.

Table 2 shows the recommended amounts of stock to be removed during the shaving operations and the corresponding amount of undercut required. ○

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The second half of this article, covering shaving methods and design, will appear in our Jan/Feb, 1998, issue.

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for many years was the Chief Tool Engineer at National Broach & Machine. He is the author of numerous papers and presentations on gear subjects. He is now retired.

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