BACK TO BASICS...

The Process of Gear Shaving

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Gear shaving is a free-cutting gear finishing operation which removes small amounts of metal from the working surfaces of the gear teeth. Its purpose is to correct errors in index, helical angle, tooth profile and eccentricity. The process can also improve tooth surface finish and eliminate, by crowned tooth forms, the danger of tooth end load concentrations in service. Shaving provides for form modifications that reduce gear noise. These modifications can also increase the 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 equal economy.

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

The form of the shaving cutters can be re-ground to make crown and profile allowance for different heat treatment movements due to varying heats of steel. The gear shaving machine can also be reset to make allowance for lead change in heat treatment.

The gear shaving process can be performed at a high production rate. Machines are available to shave external spur or helical gears up to 180" in diameter. Other machines are also available for internal spur or helical gears.

For best results of shaving, the hardness of the gear should not exceed 30-32 Rc scale. When stock removal is kept to the recommended limits, and gears are properly qualified, the shaving process will finish gear teeth in the 7 to 10 pitch range to the following accuracies: involute profile .0002; tooth-to-tooth spacing .0003; lead or parallelism .0002. In any event, it should be remembered that gear shaving can remove 65 to 80% of the errors in the hobbed or shaped gear. *It will make a good gear better. The quality of the shaved gear is dependent to a large degree upon having good hobbed or shaped gear teeth.*

Basic Principles of Gear Shaving

The rotary gear shaving process uses a gashed rotary cutter, (Fig. 1), in the form of a helical gear having a helix angle different from that of the gear to be shaved.

When the cutter and work gear are thus rotated in close mesh, the edge of each gash, as it moves over the surface

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of a work gear tooth, shaves a fine hair-like chip, somewhat like that produced by a diamond boring tool.

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 utilized in a shaving machine, (Fig. 2), which has a motor-driven cutter head and a reciprocating work table. The cutter head is adjustable to obtain the desired crossed axes 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 up-fed an increment into the cutter with each stroke of the table. This shaving cycle (axial) is one of several methods.

The Crossed Axes Principle

To visualize the crossed axes principle, consider two parallel cylinders of the same length and 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 degress, their common contact plane remains

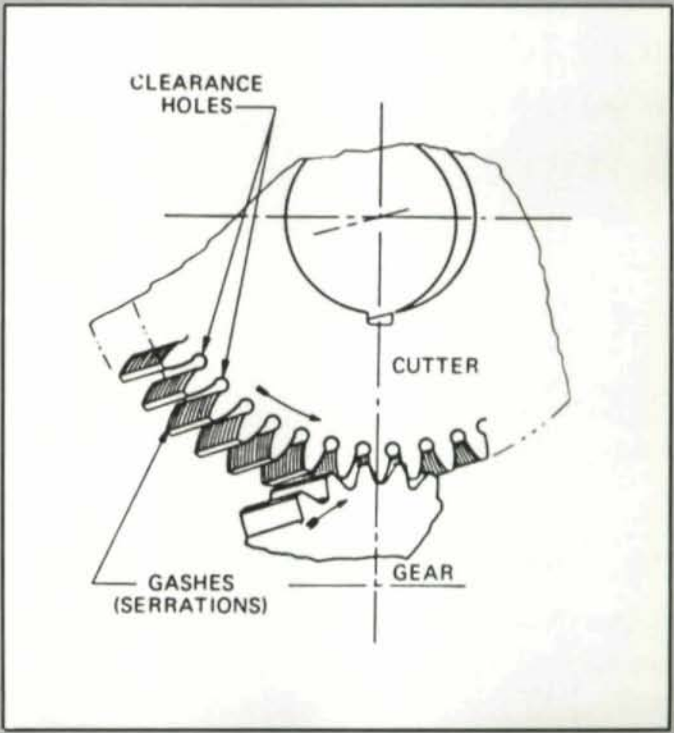


Fig. 1 – Work gear in crossed axes mesh with rotary shaving cutter mounted above.

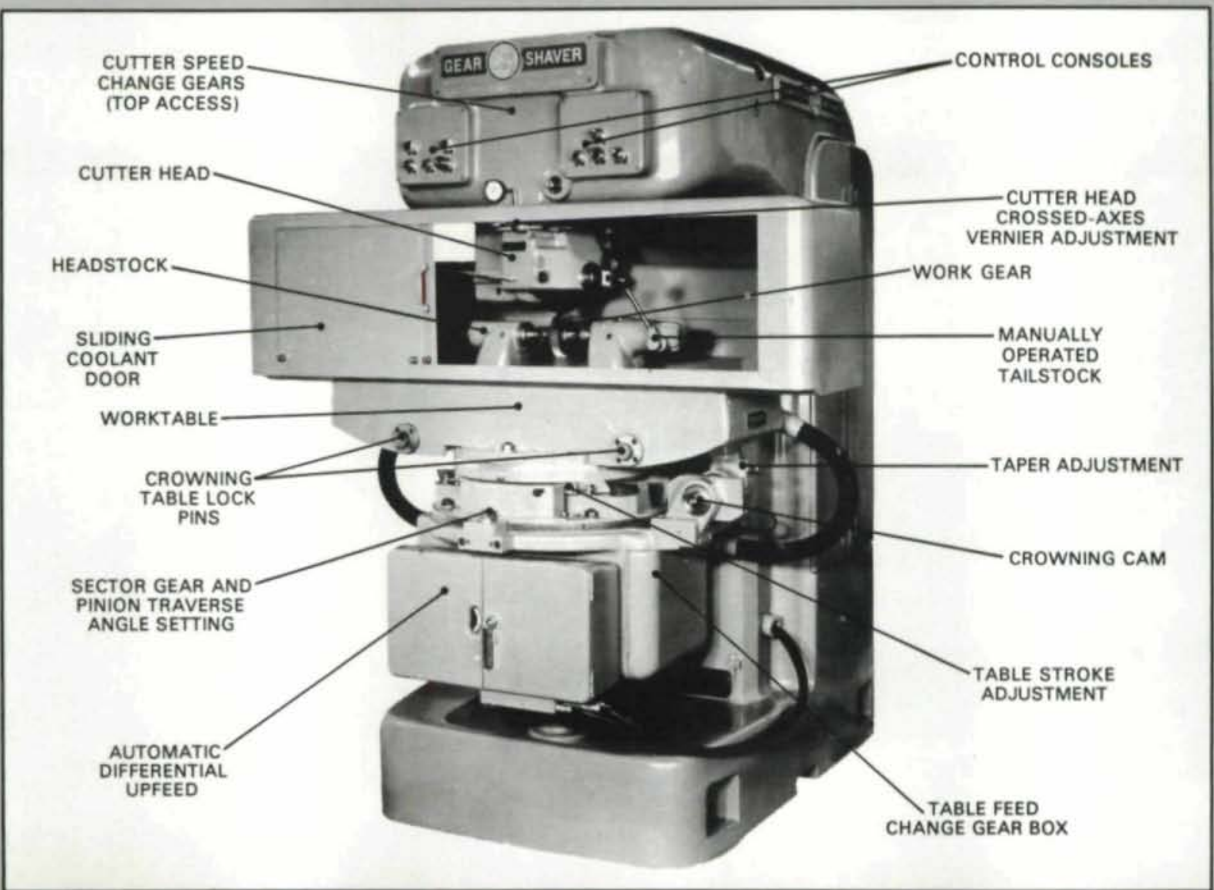


Fig. 2 – Operating components of a knee-and-column type shaving machine.

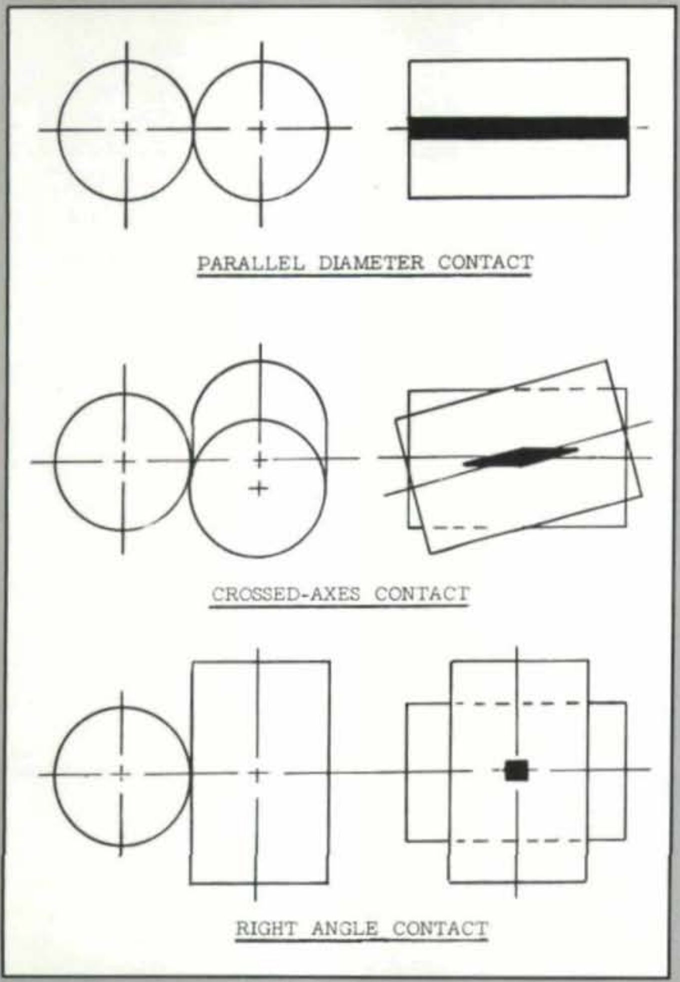


Fig. 3 – How the contact between cylinders changes as the angle between their axes is varied.

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 pressure required for cutting is small.

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 of their helical angles.

Crossing of the axes produces reasonable uniform diagonal sliding action from the tip of the teeth to the root. This not only compensates for the non-uniform action typical of gears in mesh on parallel axes, but also provides the necessary shearing action for metal removal.

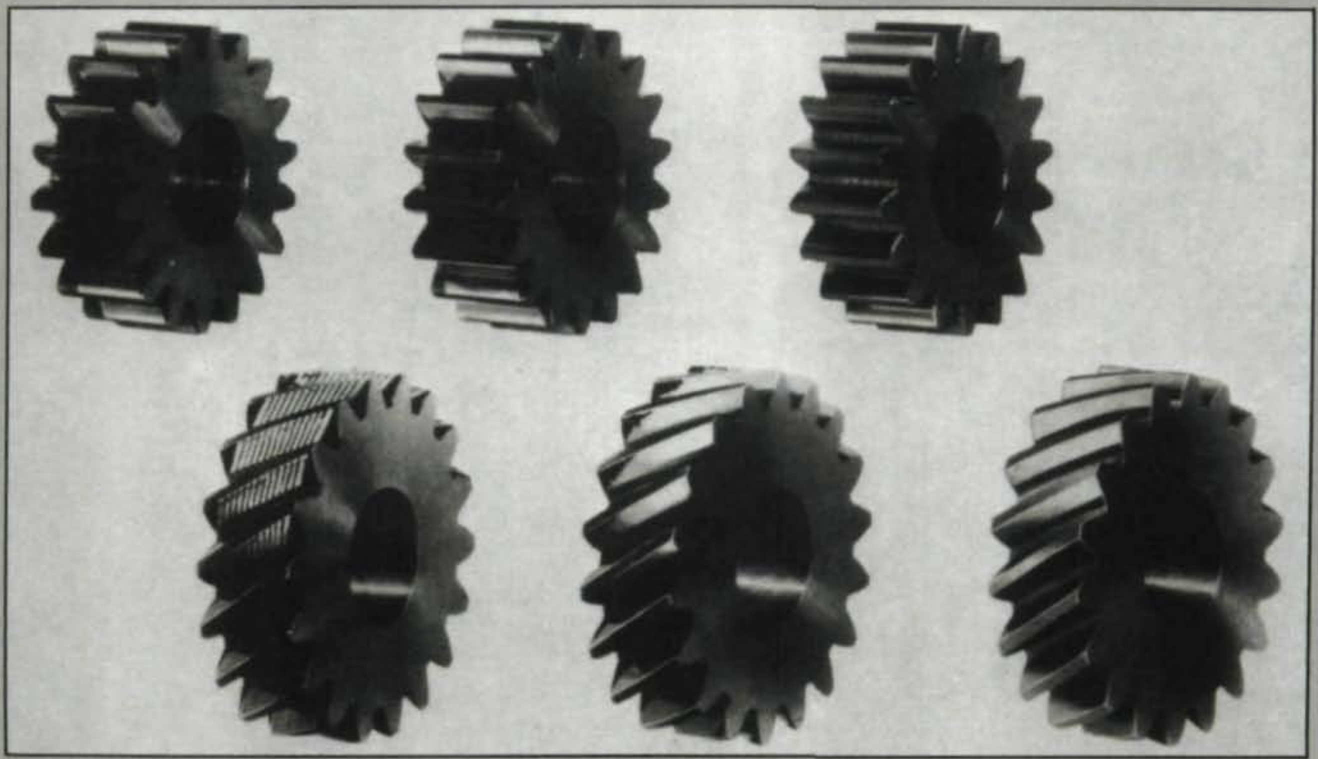
Relation Between Cutting and Guiding Action

Increasing the angle between the cutter and work gear 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. At zero angle, there is no cutting.

The spur and helical gears at the left in (Fig. 4), were shaved without table reciprocation. They show the band of cutter contact less than gear face width; and also a deeper cut in the middle of the gear than on either side.

The gears in the center of (Fig. 4), were shaved with only about 1/4 in. table reciprocation. The profiles of these teeth are perfect over the distance of reciprocation, but they fade out at each end. The chordal thickness along this 1/4 in. length is less than that at the ends.

Fig. 4 – The cut developed with varying amounts of cutter reciprocation in shaving spur gears, top, and helical gears, bottom.



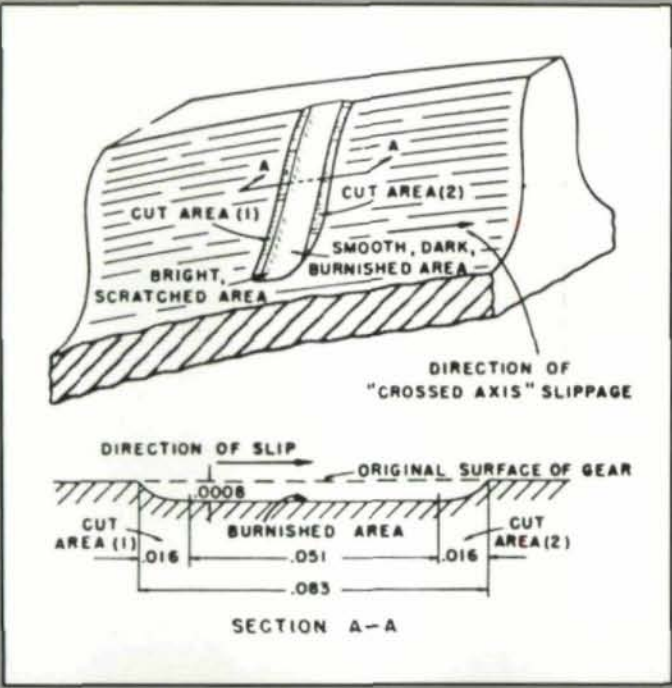


Fig. 5—Gear shaving is a combination of both cutting and burnishing.

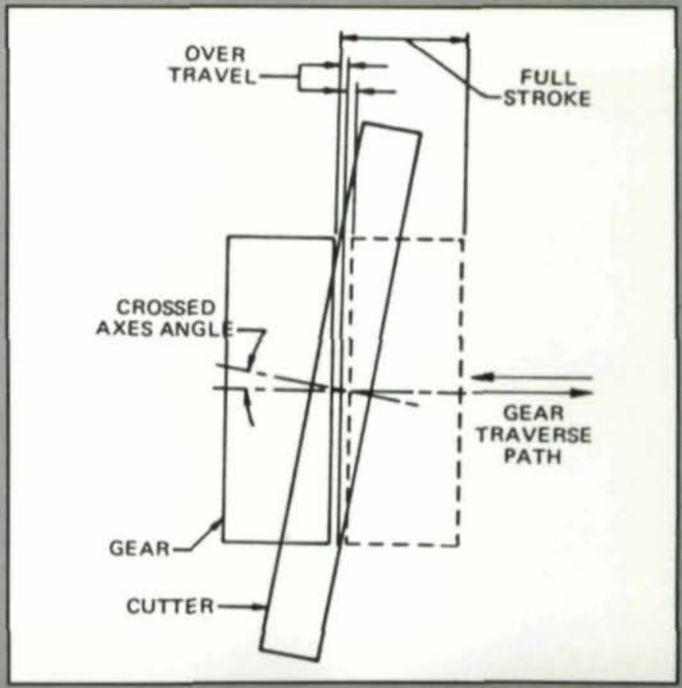


Fig. 6—Axial shaving (conventional)

Gears at the right in (Fig. 4), were shaved with full reciprocation and, therefore, have been finished to the full depth over the entire face. Tooth thickness may be decreased by increasing the up-feed of work toward the cutter.

Shaving cutters are high precision, hardened and ground, high speed steel generating tools, held to Class A or AA tolerances in all principle elements. The gashes in the shaving cutter extend the full length of the profile, termination in the clearance space or oil hole at the bottom. These clearance spaces provide unrestricted channels for a constant flow of coolant to promptly dispose of chips. They also permit uniform depth of serration penetration and increased life of the cutter. 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 size ratio of the cutter to work. Rotary shaving cutters are available in tooth size ranges from 120 diametral pitch to 1 diametral pitch, with outside diameters up to 16", and widths up to 4⅞ in.

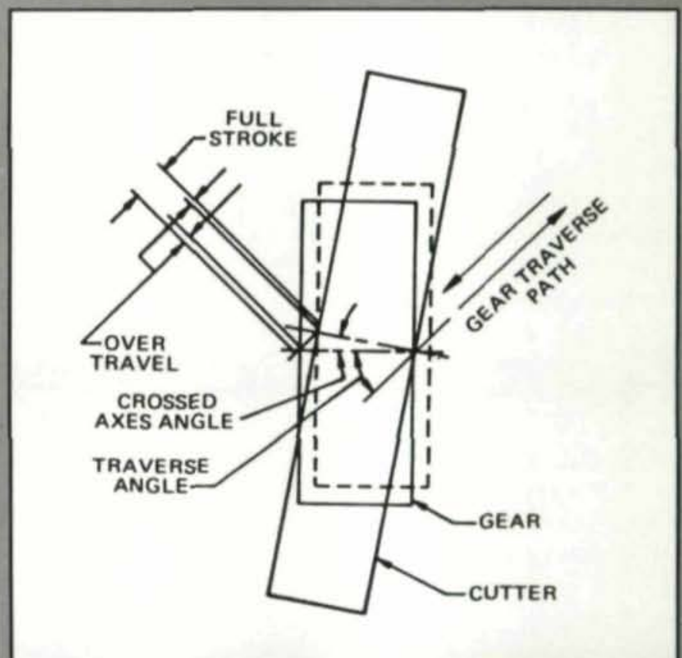


Fig. 7—Diagonal shaving

Shaving Methods

There are four basic methods of gear shaving:

1) Axial or conventional method
2) Diagonal method
3) Tangential or underpass method
4) Plunge

Axial shaving (Fig. 6) 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 centerline of crossed axes is passed through the entire face of the gear. The number of strokes may vary due to the amount of stock to be removed. In axial shaving, in order to crown the work gear teeth, it is necessary to rock the machine table by use of the built-in crowning mechanism.

Diagonal shaving (Fig. 7) is used primarily in medium and high production operations. By use of this method, shaving times are reduced 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 special differential type serrations are used; otherwise, the serrations will track. Relative face width of the gear and the shaving cutter has an important relationship with the diagonal traverse angle. A wide face work gear and a narrow shaving cutter restrict

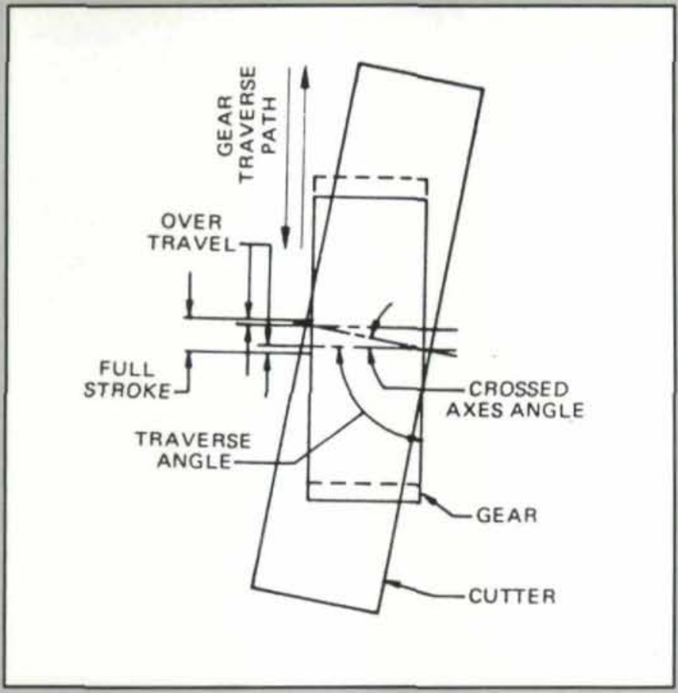


Fig. 8 – Tangential shaving (underpass)

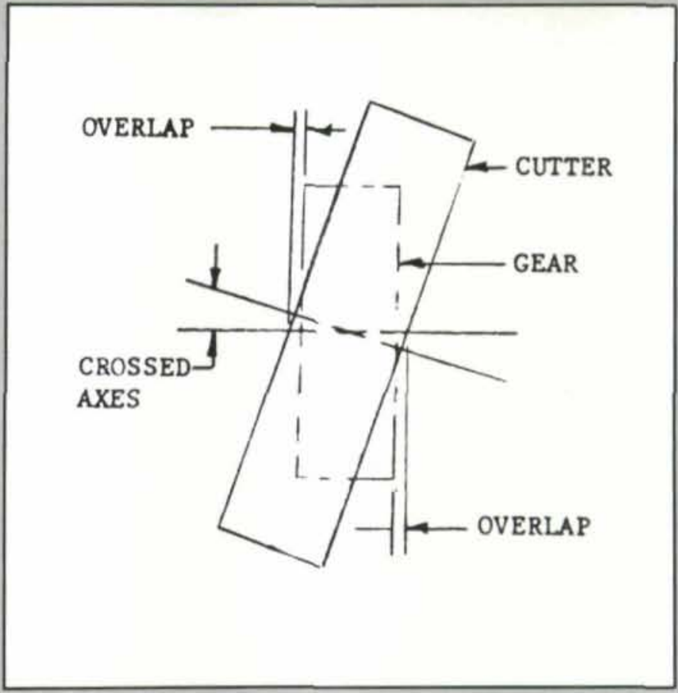


Fig. 9 – Plunge shaving

the diagonal traverse to a small angle. Increasing the cutter face width permits an increase in the diagonal angle. Crowning the gear teeth can be accomplished by rocking the machine table providing the sum of the traverse angle and crossed 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 cutter.

In tangential (underpass) shaving (Fig. 8), 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. This method of shaving has restriction. First, the serration on the cutter must be of a special differential type. Second, the face width of the cutter must be larger than that of the work gear.

Diagonal shaving has some built-in advantages over axial shaving. In most cases, it is much faster than axial. In many cases, up to 50% faster. With diagonal traverse, the cutting is not restricted to a small zone of the cutter as it is in axial shaving, but is migrated across the cutter face. Consequently, cutter life is extended.

Plunge shaving (Fig. 9) is used in high production operations. In this method, the work gear is fed into the shaving cutter with no table traverse. The shaving cutter must have special differential type serrations or tracking will occur. To obtain a crowned lead on the work, it is necessary to grind into the shaving cutter lead a reverse crown or hollow. In all cases of plunge shaving, the face width of the tool must be greater than that of the work. The advantage of plunge shaving is very short cycle times. The disadvantage is lower tool life due to the speed stock being removed.

Mounting the Work Gear

The work gear should be shaved from the same locating points or surfaces used in the preshaving operation. Locating faces should be clean, parallel and square with the gear hole. Gears with splined holes may be located from the major diameter, side of the splined teeth or minor diameter. When shaved from the centers, the true center angle should be qualified and surfaces should be free of nicks, scale and burrs.

Locating points on the work arbors and fixtures should be held within a tolerance of 0.0002 in. The arbor should fit the gear hone snugly. Head and tailstock centers should run within 0.0002 in.

For the most dependable results, gears should be shaved from their own centers whenever possible. If this is not possible, rigid, hardened and ground arbors (Fig. 10), having large safety centers would be used. Locating faces should be the same as those used in hobbing or shaper cutting.

Integral tooling is another method which is becoming popular, especially in high production shops. This consists of hardened and ground plugs instead of centers, on the head and tailstocks. These plugs are easily detached and replaced when necessary. They locate in the bore and against the faces of the work gear.

Coolants

It is very important to use the proper cutting oil or coolant for gear shaving, the basic essential of which will be found in the following:

For steels, use a sulphur base oil having a sulphur content of 3 to 3.5%.

For bronze, cast iron and aluminum use a mixture of eight parts of kerosene and one part of light machine oil. Some types of quenching and honing oils are also satisfactory.

For plastics, use a water-soluble oil mixture of approx-

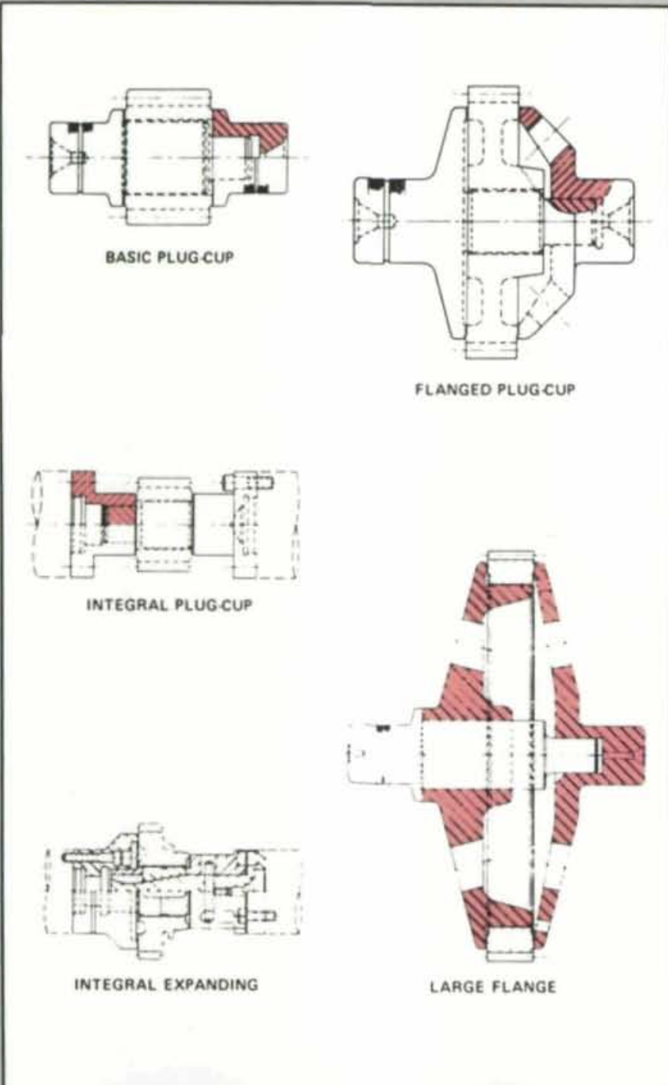


Fig. 10—Typical gear shaving arbors for external gears.

imately one part oil and twenty parts water.

The type of coolant and the degree of its contamination directly affect cutter service life and the finish of the shaving tooth surfaces. Avoid the use of a cutting oil that is too thin as this will cause chip scratch on the gear teeth faces. Chip baskets should be cleaned periodically if a supplementary filter is not used.

The cutting oil should have a viscosity of about 135 S.S.U. at 100°F. A magnetic chip separator in the coolant circuit will help reduce contamination.

Feeds and Speeds

The following are formulas for determining shaving cutter and work gear speeds (rpm):

$$\text{Cutter Rpm} = \frac{\text{Desired surface Ft. Per Minute}}{\frac{\text{Cutter Diameter (In.)} \times \pi}{12}}$$

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

For conventional shaving, about 0.010 in. per revolution of gear is considered a good starting point and becomes a factor in the following formula:

$$\text{Table Feed (ipm)} = 0.010 \times \text{Gear Rpm}$$

For diagonal shaving, an "Effective Feed Rate" of approximately 0.040 in. per revolution of gear is considered 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 cutter. The following is the formula for determining the table travese rate (ipm) to produce 0.040 in. effective feed rate:

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

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

The maximum theoretical diagonal traverse angle is determined by:

$$\text{Tangent Max. Traverse Angle} = \frac{\text{Cutter Face Width} \times \text{Sine Crossed Axes Angle}}{\text{Gear Face} - (\text{Cutter Face} \times \text{Cosine Crossed Axes Angle})}$$

Supplementary 1

Approximate Stroke for Tangential and Diagonal Shaving for Machine with Upfeed

$$\frac{\sqrt{\left[\frac{.0005}{\tan \emptyset_n} + C\right]^2 - C^2}}{\sin \partial} + \frac{.5\,F \sin X}{\sin (X + \partial)} = \text{FRONT STROKE}$$

Rear Stroke Same As Front Stroke

For Machine Without Upfeed

$$\frac{\sqrt{\left[\frac{.0005 + .5\,S}{\tan \emptyset_n} + C\right]^2 - C^2}}{\sin \partial} + \frac{.5\,F \sin X}{\sin (X + \partial)} = \text{FRONT STROKE}$$

Rear Stroke Same As Above (with upfeed)

$$C = \frac{\text{(Approx.) Pitch Dia. Cutter} + \text{Pitch Dia. Gear}}{2}$$

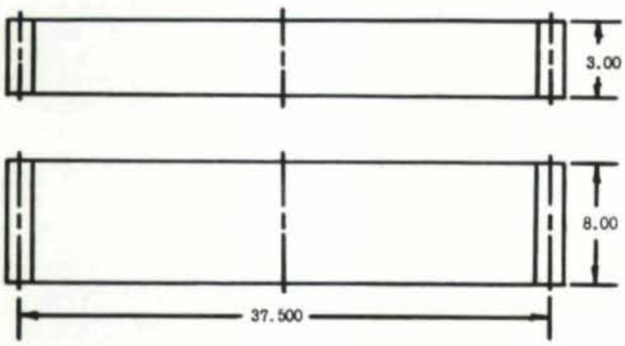
∂ = Diagonal Traverse Angle
X = Cross Axis Angle
$\emptyset_n$ = Normal Pressure Angle
F = Gear Face Width
S = Shaving Stock on Gear Tooth Thickness (Approx.)

Supplementary 2

(continued on next page)

4 DP 20° PA 150 TEETH 30° HELIX OR SPUR

MATERIAL: 8620 180-220 BHN.



AXIAL SHAVING

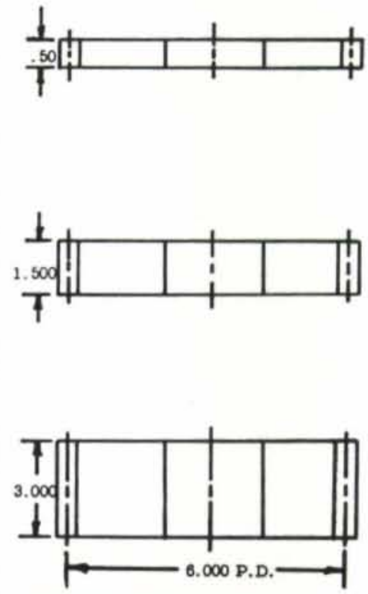
3" FACE	41.7 Min.
8" FACE	108.5 Min.

SHAVING CUTTER - 12" DIA x 1" FACE

Supplementary 3

10 DP 20° PA 60 TEETH SPUR

MATERIAL: 8620 180-220 BHN.



.500 FACE WIDTH GEAR

METHOD	MIN.	C. FACE
AXIAL	1.10	1.000
DIAGONAL	1.05	1.000
TANGENTIAL	.84	1.000
PLUNGE	.50	1.000

1.500 FACE WIDTH GEAR

METHOD	MIN:	C: FACE
AXIAL	2.87	1.000
DIAGONAL	1.47	1.250
TANGENTIAL	1.05	1.750
PLUNGE	.75	1.750

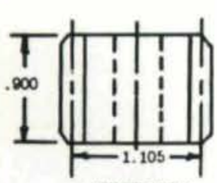
3.000 FACE WIDTH GEAR

METHOD	MIN.	C. FACE
AXIAL	5.52	1.000
DIAGONAL	2.10	2.750
TANGENTIAL	1.68	3.250
PLUNGE	1.50	3.250

Supplementary 4

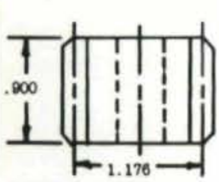
19 DP 20° PA 21 TEETH SPUR and 20° HELIX

MATERIAL: 8620 180-220 BHN.



SPUR GEAR

METHOD	TIME	C: FACE
AXIAL	47 SEC.	.750
DIAGONAL	18 SEC.	1.000
TANGENTIAL	14 SEC.	1.150
PLUNGE	10 SEC.	1.150



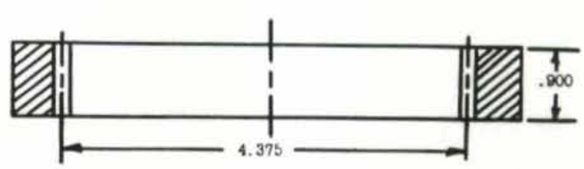
20° HELICAL GEAR

METHOD	TIME	C. FACE
AXIAL	47 SEC.	.750
DIAGONAL	18 SEC.	1.000
TANGENTIAL	14SEC.	1.150
PLUNGE	10 SEC.	1.150

Supplementary 5

16 DP 20° PA 70 TEETH SPUR and 20° HELIX

MATERIAL: 8620 180-220 BHN.



AXIAL SHAVING

SPUR	1.37 Min.
20° HELIX	1.37 Min.

SHAVING CUTTER - 3" DIA. x .750 FACE

Supplementary 6

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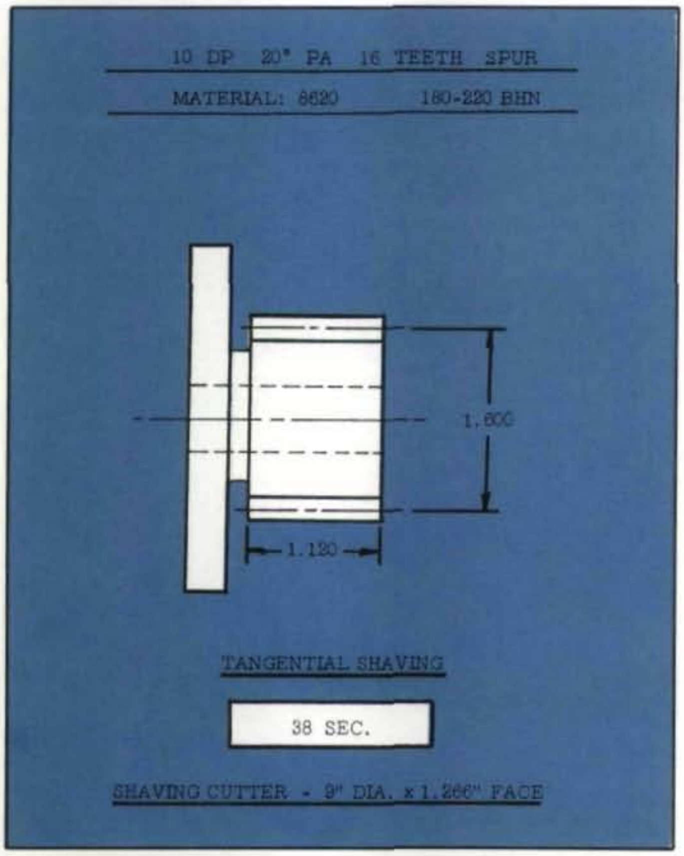
THE PROCESS OF GEAR SHAVING . . .
(continued from page 46)



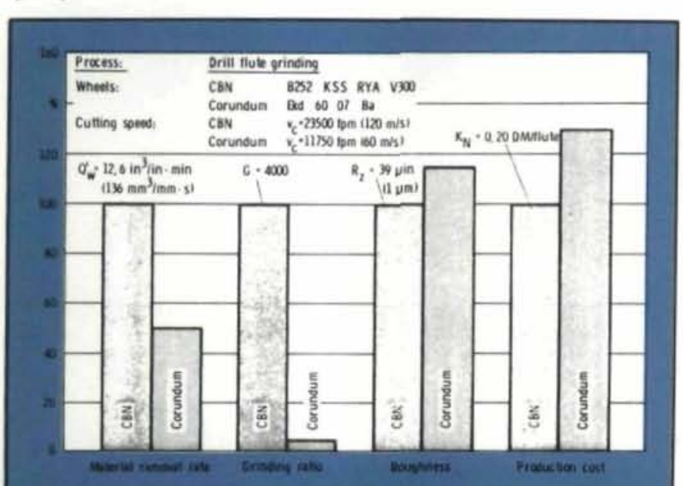
Supplementary 7

E-5 ON READER REPLY CARD

LOWER GRINDING COST . . .
(continued from page 21)

the trueing costs (not included here) these constitute the production costs per flute. This shows that corundum grinding is about 30% more expensive than CBN grinding. The superioity of CBN is likely to increase still further, assuming a rise in the labor and machine costs which determine production costs. Moreover, further developments may be expected in the relatively young CBN technology, on the basis of ongoing progress in fundamental knowledge.

Fig. 17 – CBN grinds more economically than corundum and gives better quality



Summary

One of the main problems in the application of CBN wheels is the correct economical and technological design of the dressing process, i.e. trueing and sharpening. This paper presents methods for optimizing the dressing process, and in particular, the sharpening process. A process model for sharpening with a corundum sharpening stick is presented. The chip space of the grinding wheel is described as a function of wheel specification, setting parameters and duration of the sharpening process. The model for description of sharpening results can be used directly in practical application, since it includes only variables that can be regarded as known when the process design is made.

The technological advantages offered by the use of CBN must be offset against the main disadvantage of high grinding wheel cost. As the tool costs per workpiece are mainly influenced by wheel wear, the result of the present investigations show possibilities of improving wear behavior by adaptation of the grinding wheel specification. Possible measures might be the selection of suitable grit size, the use of a harder bond and an increase in grit concentration. An increase in grit concentration makes the grinding wheel more expensive, but in return it gives a clear improvement in the length of service life.

The machine concepts were also discussed as the prerequisite for economic application of this process. The following must be particularly stressed: high rigidity of the machine, high cutting speeds and drive powers and automated trueing and sharpening systems.

If the process is properly designed, it is at present possible to reduce the production costs per drill flute by approximately 30% as compared with corundum grinding.

E-1 ON READER REPLY CARD

EFFECT OF SHOT PEENING . . .
(continued from page 36)

10. TOWNSEND, D. P.; COY, J. J.; and ZARETSKY, E. V.: "Experimental and Analytical Load Life Relation for AISI 9310 Steel Spur Gears." Journal of Mechanical Design, Trans. ASME, Vol. 100, No. 1, Jan. 1978, pp. 54-60.
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E-4 ON READER REPLY CARD