Gear Finishing by Shaving, Rolling & Honing - Part II

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The first part of this article, which has been excerpted from *Dudley's Gear Handbook*, 2nd ed., covers rotary gear shaving and appeared in our March/April issue.

Gear Roll-Finishing

Gear roll-finishing is a fast and economical means of finishing the gear teeth of helical gears. Helical overlap is required in order to insure the smooth flow of material across the entire gear face.

Due to the speed at which gears are finished, this process is usually restricted to mass production facilities, such as in the auto industry. It is not unusual for a set of rolling dies to produce over 1 million pinions before being reconditioned. Rolling dies can normally be reconditioned between three and five times before their end of life.

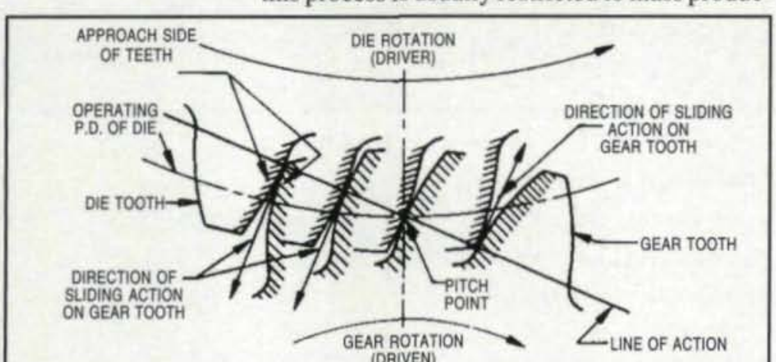

Fig. 1 - Contact action between one tooth of a work piece and the approach side of a rolling die tooth.

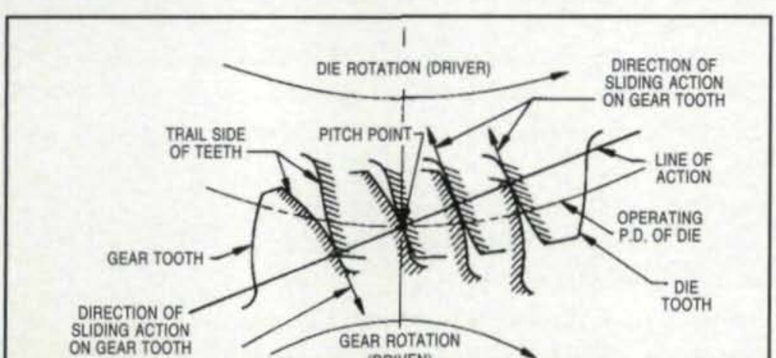

Fig. 2 - Contact action between the tooth of a work piece and the trail side of a rolling die tooth.

Gear rolling is a finishing operation requiring the teeth to be rough-cut by hobbing or shaper cutting.

In this discussion of gear roll-finishing, particular attention is called to the special tooth nomenclature resulting from the interaction between the rolling die teeth and the gear teeth. To eliminate confusion, the side of a gear tooth that is in contact with the "approach" side of a rolling die tooth is also considered to be the approach side. The same holds true for the "trail" side. Thus, the side of the gear tooth that is in contact with the trail side of a rolling die is also considered to be the trail side.

Gear roll-finishing is much different from gear shaving in that a flow of material is involved, rather than a removal of material. A study of gear tooth action is required to analyze the material flow in the rolling process. In Fig. 1 it can be seen that as a gear rolling die tooth engages the approach side of a work piece tooth, sliding action occurs along the line of action in the arc of approach in a direction from the top of the gear tooth toward the pitch point where instantaneous rolling action is achieved. As soon as the contact leaves the pitch point, sliding action occurs again, but in the opposite direction toward the pitch point in the arc of recession.

What is more interesting, however, is that the contact between the die and work gear teeth on the trail side produces exactly the opposite direction of sliding to that on the approach side (Fig. 2). The result of these changing directions of sliding is that material is being compressed toward the pitch point on the approach side and extended away from the pitch point on the trail side (Fig. 3).

This action causes a greater quantity of material to be displaced on the trail side than on the approach side by a ratio of about 3:1. On the approach side, the tendency is to trap the material rather than permit it to flow toward the top and root of the teeth as on the trail side. Thus, completely different from what occurs in a metal removal process such as gear shaving, the amount of material to be flowed during the rolling process, as well as the hardness of that material, have a significant effect on the accuracy of the produced form.

For successful roll-finishing, it appears that an undercut is desirable near the root section, such as with conventional preshave tooth forms. Since most production gears are also provided with a tip chamfer, the material will tend to be pulled up into the chamfer on the trail side and down away from the chamfer on the approach side.

As a result, some adjustment in hobbed tooth tip chamfer depths and angle are required to balance out the opposed metal flow conditions on each tip side. These chamfer depths and angles have to be held to close tolerances. If too much stock is left for gear roll-finishing, or if the gear material tends to be too hard (above approximately 20 Rc), several conditions may result. The sliding action on the approach side of the tooth may cause a "seaming" of material that builds up in the area of the pitch point. On the trail side, the flow of excess material may result in a burr on the tip of the gear tooth and a "slivering" of material into the root area. Fig. 4 shows the condition of a roll-finished gear tooth when too much stock is flowed or high-hardness conditions are encountered.

In Fig. 5 photomicrographs show the conditions encountered when stock removal is excessive, material is excessive, and material hardness is too high. A seam is evident in the approach side of the tooth at the left in the area of the operating pitch diameter. The trail side photomicrograph at the right in Fig. 5 shows slivering in the root portion with about 0.1 mm (0.004") of lapped-over metal, and about 0.05- mm (0.002-in) deep surface cold working of the material.

In contrast, photomicrographs in Fig. 6 show the excellent tooth structure that can be achieved with roll-finishing if stock reduction is held to a minimum and material is not too hard. No evi-

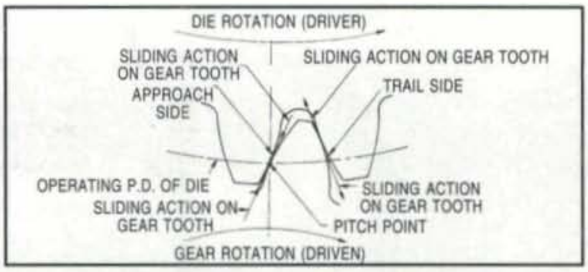

Fig. 3 - Differing flow directions induced by each side of a die tooth with gear roll-finishing.

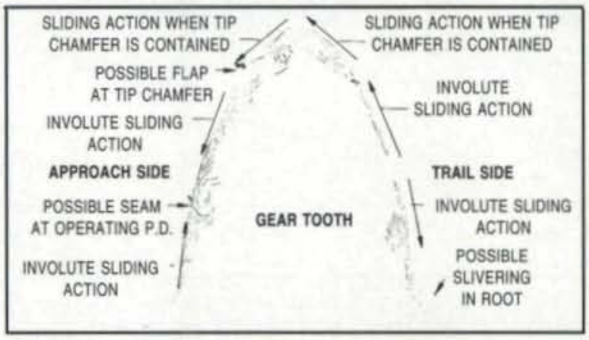

Fig. 4 - Tooth flow pattern that results when too much stock is left for roll-finishing, or when material hardness is excessive.

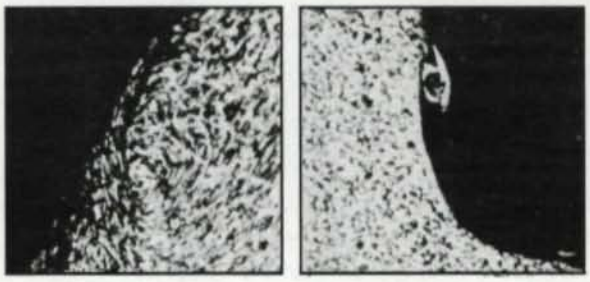

Fig. 5 - Photomicrographs of a gear tooth with high hardness. The approach side, left, has a seam in the area of the pitch diameter. The trail side, right, shows where excessive stock has caused cold working and a sliver near the root.

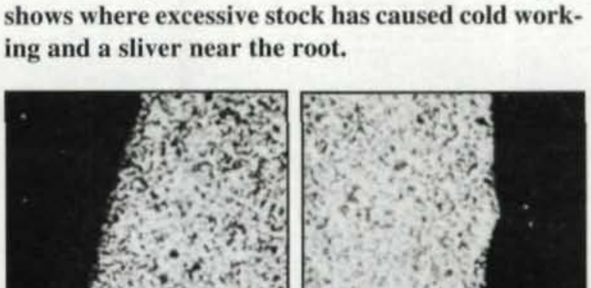

Fig. 6 - Photomicrographs of a gear tooth that has been properly roll-finished. The approach side, left, has no seaming. The trail side, right, shows no slivering or cold working.

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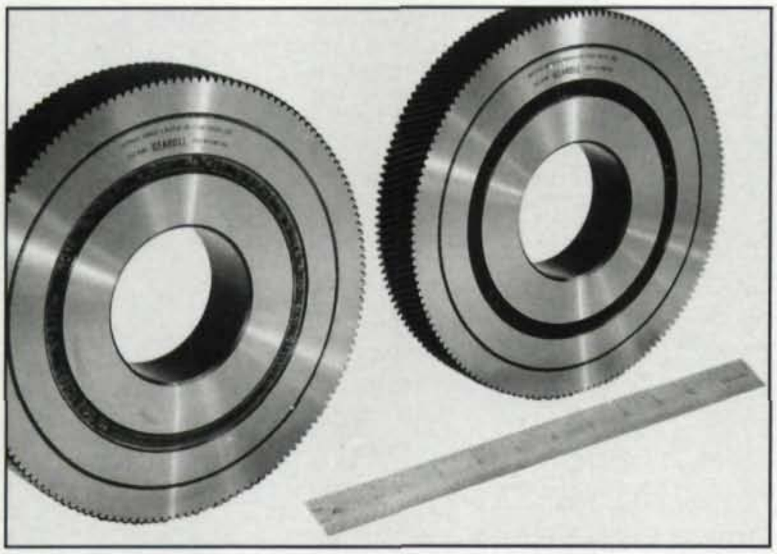

Fig. 7 - Gear roll dies.

Table I - Standard tolerances for rolling dies	
Die Specification	**Tolerance - In.**
Involute Profile (True Involute Form) - Active Length, tiv	
Through 0.177" working depth	0.00015
0.178 through 0.395" working depth	0.00020
Lead - (Uniformity-tiv Per Inch of Face)	0.0003
Parallelism - (Opposite Sides of Same Tooth Alike Within)	0.0002
Helix Angle - (Deviation From True Angle-Per Inch of Face)	0.0005
Tooth Spacing - (Adjacent Teeth at Pitch Diameter)	0.00015
Circular Pitch - (Variation-tiv)	0.0002
Spacing Accumulation - (Over Three Consecutive Teeth)	0.00025
Runout - (tiv at Pitch Diameter)	0.0004
Face Runout - (tiv Below Teeth)	0.0002
Tooth Thickness	Minus 0.0010
Hole diameter	Plus 0.0002

Note: Dies can be made in pairs alike within 0.0005" measured over pins if necessary.

dence of cold working or seaming is seen in the approach side at the left. In the trail side at the right in Fig. 6, no evidence of slivering or cold working is seen.

The amount of stock reduction with roll-forming should be held to about one-half that normally associated with shaving if seaming and slivering are to be avoided. The burr condition on the tip of the trail side of the tooth can be improved by close control of the angle and location of the protective tooth chamfer generated by the hob in the course of the tooth-generating operation.

Gear Rolling Dies - Since roll-finishing involves material flow rather than metal removal, it should be expected that the tooth form on the die would not be faithfully reproduced on the work piece tooth due to minute material springback and material flow conditions.

Even with gear shaving, it has been found necessary to modify the shaving cutter teeth profiles somewhat to produce a desired form on the work gear teeth. Experience to date has shown that a different type of tooth form modification is required for gear roll dies than for gear shaving cutters. The correct amount of gear rolling die tooth form modification is determined, as with gear shaving cutters, from an extensive development program. Less rigid gear roll-finishing machines usually require greater and varying die form modifications.

Gear roll dies (Fig. 7) are made from special

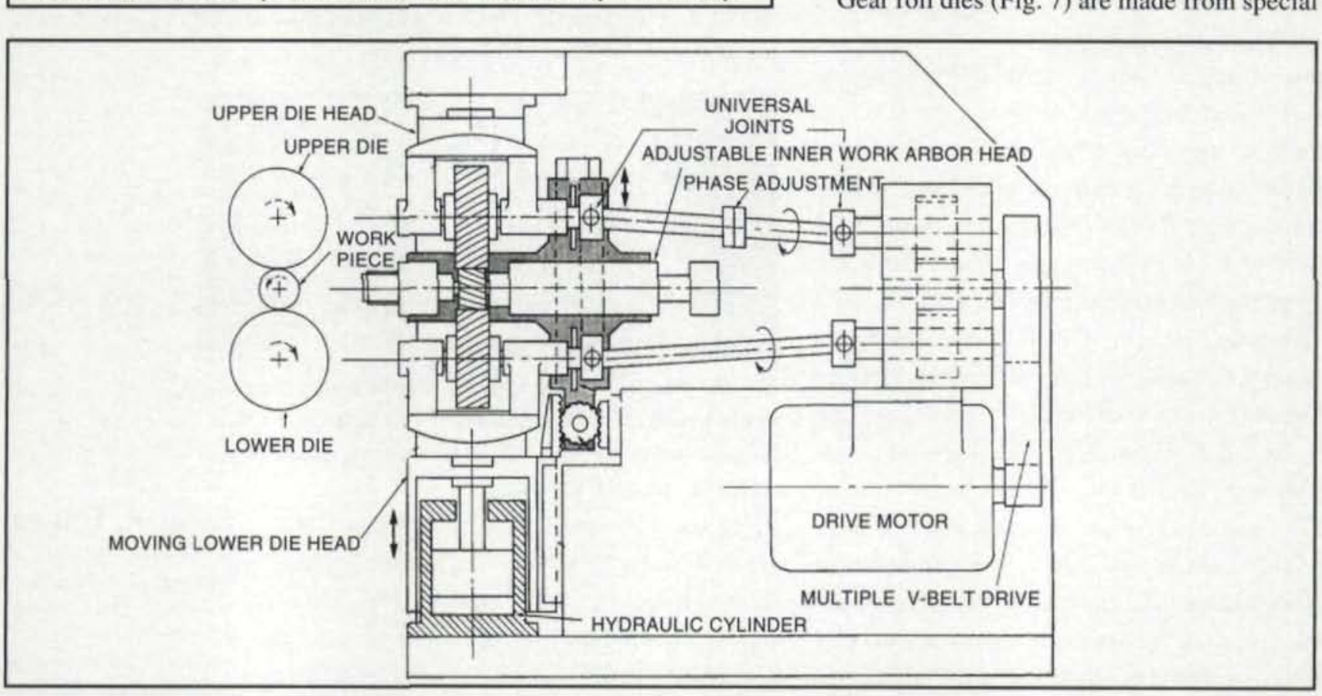

Fig. 8 - Schematic of vertical roll machine.

fatigue- and impact-resistant high-speed steel to the tolerances shown in Table 1.

Gear Rolling Machines - Several important design considerations have to be met in a roll-finishing machine. These include rigidity, strength, high-speed loading capability, die phasing, and independent adjustment for die axis and die positioning.

The force required to roll-finish a gear depends on its width, diametral pitch, tooth shape, cycle time, material, and hardness.

Double-Die Gear Rolling - The double-die gear roll machine shown in Fig. 8 is a vertical design with the dies mounted one above the other. It is designed to handle gears up to 10 cm (4") wide and 15 cm (6") in diameter. Die speeds are from 40 to 160 r/min. Dies up to 11.4 cm (4 1/2") wide and 24.4 cm (9 5/8") in diameter can be mounted in the machine.

The upper die head is fixed and the lower die is fed upward by a hydraulic cylinder. The gears are fed into rolling position by an air-operated automatic loader (Fig. 9). Here they are picked up on a work arbor that is advanced by a hydraulic rotary actuator utilizing a gear rack arrangement. The work gears are advanced against a pneumatically loaded cup.

The work arbor is pre-rotated by a hydraulic motor at a speed slightly slower or faster than the die speed to ensure clash-free engagement. The lower die then feeds upward to a predetermined operating position to control finish-rolled gear size.

Table 2 illustrates the range of gearing for which gear rolling dies have been produced for finish-rolling production applications.

Single-Die Gear Rolling - Machines have been developed to finish-roll gears with a single die. This process has proven economical in low and medium production.

A single gear rolling die is mounted in a heavy-duty gear head above the work piece (Fig. 10). The die is driven by an electric motor to provide rotation of the work piece that meshes with it. Normally semiautomatic loading methods are utilized on single-die roll-finishing machines whose work cycles are somewhat longer than those of the fully automatic, double-die machines. The work piece is mounted on an arbor between head and tailstock (Fig. 11). In operation, the table supporting the head and

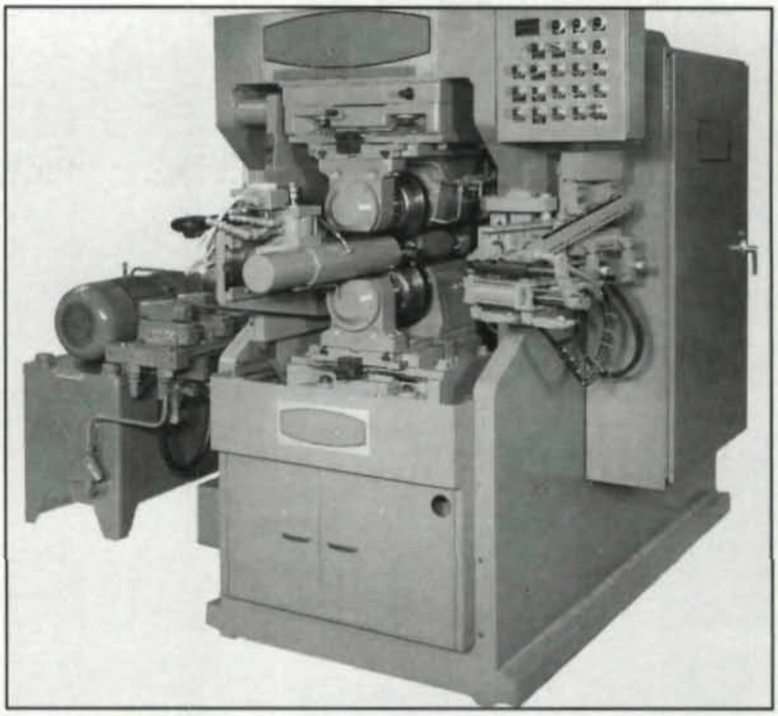

Fig. 9 - Hinge-type auto loader on gear roll machine.

Table II - Data on Roll-Finished Gears

No. Teeth	Pitch Diameter (in.)	Normal Diametral Pitch	Normal Pressure Angle	Helix Angle	Hand	Face Width (In.)	Material
26	4.6666	6.539	18° 28'	23° 25'	L	1.380	8620
25	3.3667	8.8709783	16° 30'	33° 10'	L	0.918	8620
14	1.0711	14	20°	21°	L	0.727	5140H
17	1.2143	15.1535	18° 35' 09"	22° 30'	L	0.758	4024
28	2.0000	15.1535	18° 35' 09"	22° 30'	R	3.04	4024
18	1.2542	15.5	17° 30'	22° 11' 30"	R	1.935	4620
16	0.9621	18	18° 30'	22° 30'	R	0.728	5130, Fine Grain (5-8)
34	2.0445	18	18° 30'	22° 30'	L	0.860	5130, Fine Grain (5-8)
20	1.1580	18.5	18°	21°	R	0.874	4027H
19	1.0549	19.3	20°	21° 03' 42"	R	0.705	4027H

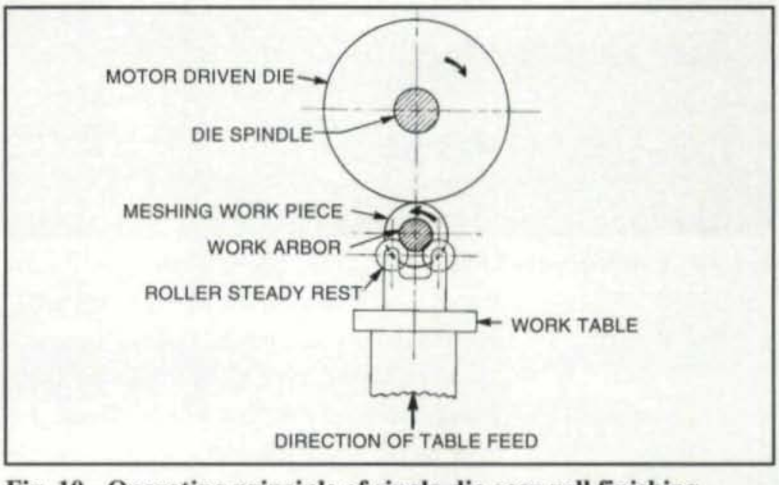

Fig. 10 - Operating principle of single-die gear roll finishing.

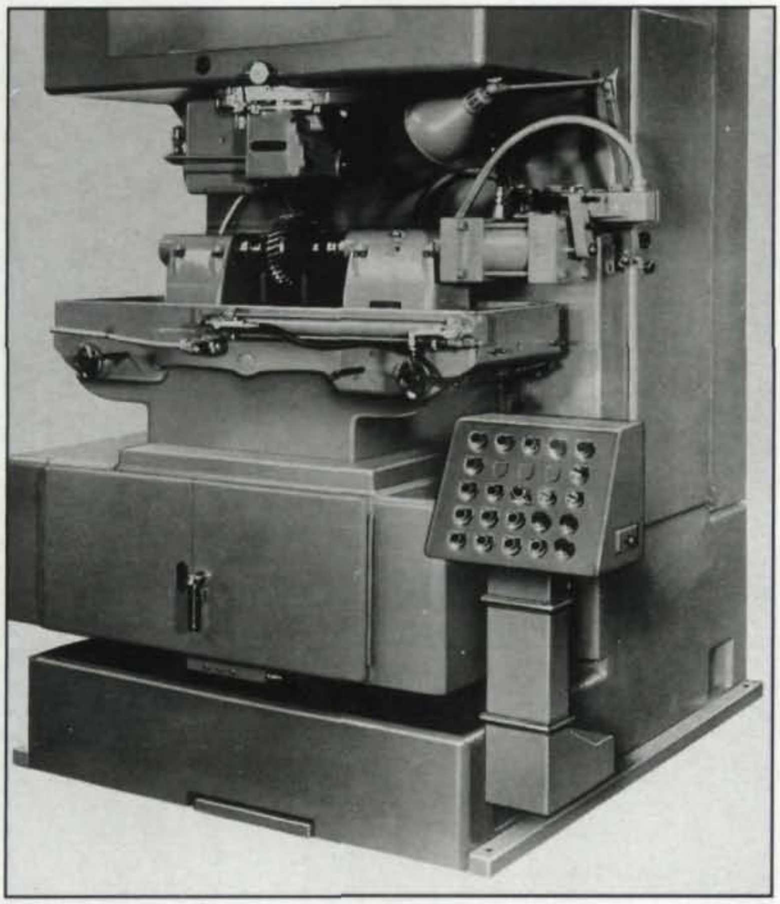

Fig. 11 - Single-die gear roll machine.

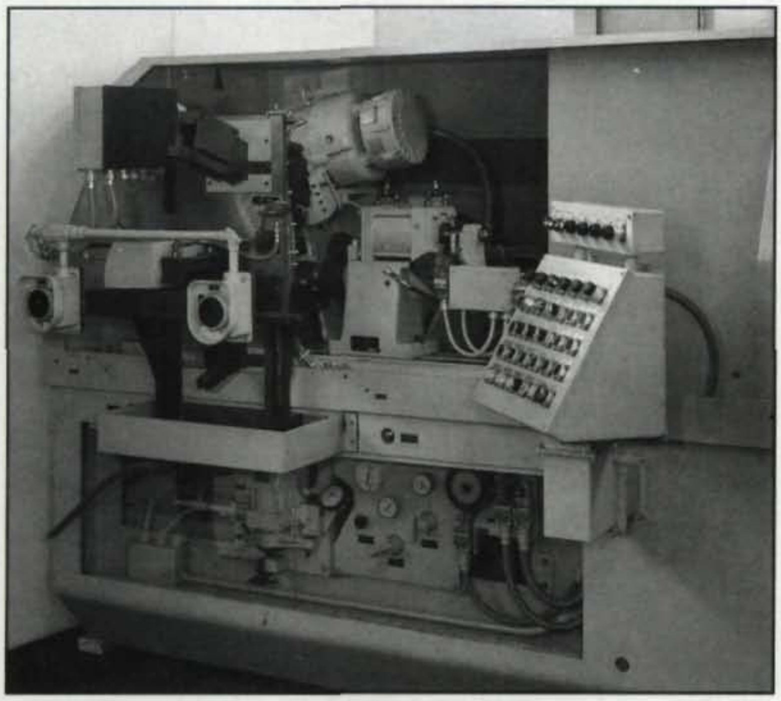

Fig. 12 - External gear honer.

tailstock is fed upward by a unique, air-powered, heavy-duty radial feed system. The continuous upfeed of the table provides the large force necessary to roll-finish the gear teeth.

During the work cycle, the work piece can be rotated in one direction for one part of the cycle, then reversed and rotated in the other direction for the balance of the cycle. This double rotation sequence tends to balance the metal flow action on the approach and trail sides of the work gear teeth.

Tooth thickness size of the work piece is controlled by adjusting the height of the table with a handwheel-controlled elevating screw.

Rotary Gear Honing

Rotary gear honing is a hard gear finishing process that was developed to improve the sound characteristics of hardened gears by:

1. Removing nicks and burrs
2. Improving surface finish
3. Making minor corrections in tooth irregularities caused by heat-treat distortion.

The process was originally developed to remove nicks and burrs that are often unavoidably encountered in production gears because of careless handling. Further development work with the process has shown that minor corrections in tooth irregularities and surface finish quality improvement can be achieved. These latter improvements can add significantly to the wear life and sound qualities of both shaved and ground hardened gears.

Gear honing does not raise tooth surface temperature, nor does it produce heat cracks or burned spots or reduce skin hardness. It does not cold work or alter the microstructure of the gear material, nor does it generate internal stresses.

Honing machines are available for external (Fig. 12) and internal (Fig. 13) spur and helical gears. Both taper and crown honing operations can be carried out on these machines.

How the Process Works - The process uses an abrasive-impregnated, helical-gear-shaped tool. This tool is generally run in tight mesh with the hardened work gear in crossed axes relationship under low, controlled center-distance pressure.

The work gear is normally driven by the honing tool at speeds of approximately 183 surface m (600 surface ft) per minute. During the work cycle, the work gear is traversed back and forth in a path parallel to the work gear axis. The work gear is rotated in both directions during the honing cycle. The process is carried out with conventional honing oil as a coolant.

The honing tool is a throw-away type that is discarded at the end of its useful life. The teeth are thinned as the tool wears. This tooth thickness reduction can continue until root or fillet interference occurs with the work gear. The O.D. of the hone can be reduced to provide proper clearance.

Eventually, thinning of the hone teeth also results in root interference with the outside diameter of the work gear. When this condition occurs, the hone is generally considered to be at the end of its useful life. In some isolated cases, it has been found practical to recut the hone root diameter with a grinding wheel to provide additional hone life.

Usually the amount of stock removed from the gear tooth by honing ranges from 0.013 to 0.05 mm (0.0005 to 0.002") measured over pins.

The production rate at which honing operations can be carried out depends on the pitch diameter and face width of the work. A gear 2.5 cm (1") in diameter by 2.5 cm (1") in width can be honed in approximately 15s. A gear 61 cm (24") in diameter by 7.6 cm (3") in face width will require approximately 10 min. of honing time. Of course, honing of salvage gears required longer cycles.

A typical external gear honing machine has the motor-driven honing tool mounted at the rear of the work spindle. The work spindle is mounted on a tilting table that can be positioned to provide four selective modes of operation.

The first mode is called loose backlash, where the hone and work gear are positioned in loose backlash operation on a fixed center distance. This method is sometimes utilized to slightly improve surface finish only, primarily on fine-pitch gears with minimum stock removal.

The second mode of operation is called zero backlash. Here the work gear is positioned in tight mesh with the honing tool. The table is locked in fixed center-distance location with a preselected hone pressure. This method is sometimes used to provide maximum gear tooth runout correction with a minimum stock removal.

The third and most generally applied mode of operation is called constant pressure. The work gear is held in mesh with the honing tool at a constant pressure. This method removes nicks and burrs and provides maximum surface finish improvement in minimum time.

The fourth mode of operation is called differential pressure. A preselected low pressure is

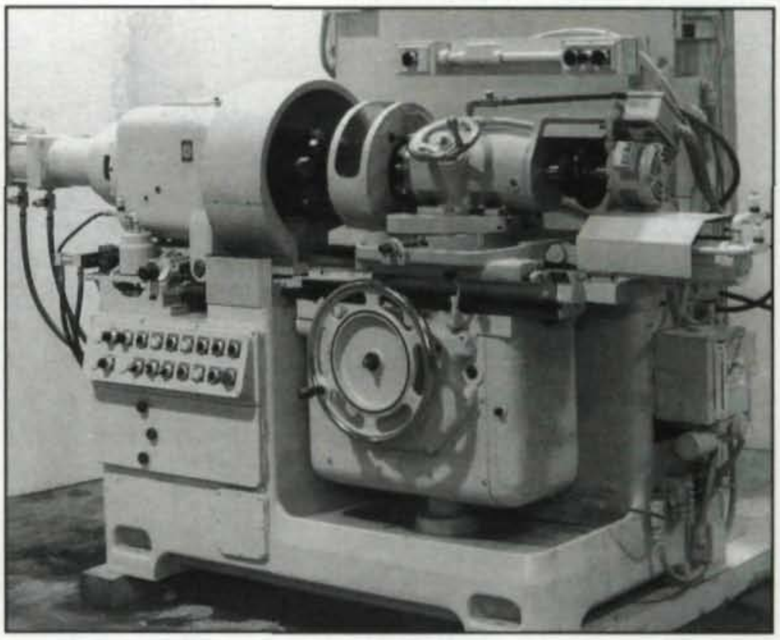

Fig. 13 - Internal gear honer.

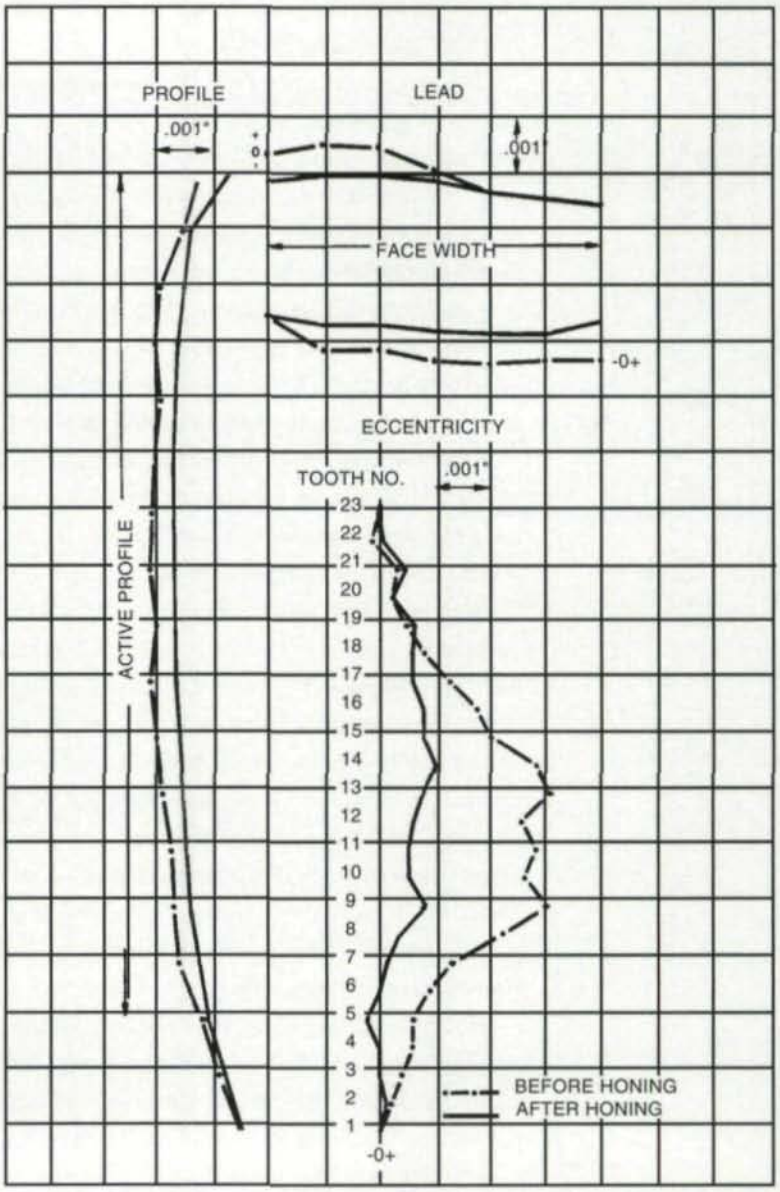

Fig. 14 - Improvement in tooth accuracy achieved by honing.

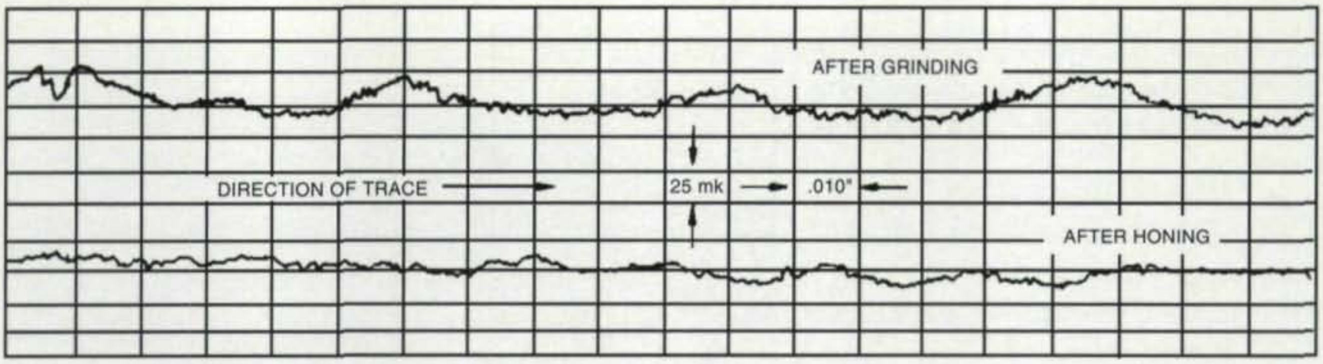

Fig. 15 - Surface finish improvement after honing.

present between the hone and the low point of an eccentric gear; and a preselected increased amount of pressure is present between the hone and the high point of eccentricity. This method has all of the desirable features of the constant pressure method plus the ability to slightly correct eccentricity. The amount of eccentricity in the gears with differential pressure honing may cause the hone to wear faster than with the constant pressure method.

Rotary Gear Honing Tools - Standard rotary gear honing tools are a mixture of plastic resins and abrasive grains such as silicon carbide, which are formed in a precision mold. They are made in a wide variety of mix numbers with grits ranging from 60 to 500, to suit special production and parts requirements.

Special tools have been developed to do salvage-type honing. The tools are made from hardened steel and the active tooth surface is plated with carbide or diamond. These harder materials give the process the ability to remove an increased amount of stock and thereby make larger corrections in tooth irregularities.

Honing Shaved Gears - Traditionally, tooth surface finishes in the range from 15 to 40μ in. have been provided by the rotary gear shaving operation. The honing process, because it is not basically a heavy stock removal or tooth correction process, cannot substitute for gear shaving, which is performed on the soft gear. In fact, the tendency of a hone to charge a gear under 40 Rockwell C hardness with abrasive particles makes honing of soft gears a questionable application.

However, because a gear has to be heat treated, a process that usually roughens the tooth surface to a degree, the honing process tends to restore the hardened tooth surface finish to its original shaved condition and actually improves it. In all cases, the honed surface finish is better than the surface finish before honing. (Fig. 14).

To hone production gears, economy dictates that one grit of tool and a relatively short honing cycle be used. What is produced then, in the way of surface finish, represents a compromise. First, the honing tool must remove nicks and burrs, then it should make minor tooth corrections that will improve sound level and wear life. The improvement in surface finish, which is in reality a by-product of the honing process, is a valuable adjunct that will help promote long wear life as well as improve sound characteristics.

Honing Ground Gears - In the aerospace industry, gears are traditionally operated at high speeds under heavy loads. They are usually cut, heat treated, and ground to provide tooth surfaces (usually of sophisticated modified forms) of the highest order of accuracy. However, tests with exotic surface measuring equipment have shown that ground surfaces have a jagged, wavy profile that will not support heavy loads or wear long unless costly break-in procedures are carried out.

Ground tooth surfaces usually have a surface finish in the 16-μ to 32-μ in range. Honing with type AA honing tools can bring the surface finish down to the 8- 10-μ in range (Fig. 15). In one 39-tooth, 5-m (5-D.P.), 20° P.A., 20-cm (7.800-in.) P.D. spur helicopter drive gear, honing of the gear teeth down to 8-μ in surface finish increased wear life by 1000% and increased load-carrying capacity by 30%. Other tests by the gearing industry have shown 100% load-carrying capacity increases by honing ground gears. ■

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