

Hard Finishing By Conventional Generating and Form Grinding

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Introduction

The quality of a gear and its performance is determined by the following five parameters, which should be specified for each gear: Pitch diameter, involute form, lead accuracy, spacing accuracy, and true axis of rotation. The first four parameters can be measured or charted and have to be within tolerance with respect to the fifth. Pitch diameter, involute, lead, and spacing of a gear can have master gear quality when measured or charted on a testing machine, but the gear might perform badly if the true axis of rotation after installation is no longer the same one used when testing the gear.

This fact leads to the first requirement which should be met when finishing gears: The surfaces used to position the gear in its final assembly should also be used to position the gear for either soft or hard finishing. A second requirement, which is increasingly accepted, is that the equipment used for soft or hard finishing gears should provide controlled motion to accurately produce involute, lead, and spacing.

Purpose of Grinding Gear Teeth

Gear teeth are ground to assure accuracy and consistency of tooth geometry. Grinding may also be the most economical method of finishing gear teeth. Generally ground gears are carburized and hardened. The heat treating process has the tendency to distort the gear blank, thus affecting the tooth accuracy, requiring hard finishing of the teeth. Grinding gear teeth provides a reliable method of finishing gear teeth.

Other methods used to hard finish gear teeth include skiving (using carbide cutters), lapping (using abrasive grit suspended in oil), and honing (using an abrasive grit stone in the form of a mating gear).

These four methods each have limitations, and one must decide which will best meet the requirements of the gear application. An understanding of each process will serve as a guide to using the best and most economical method.

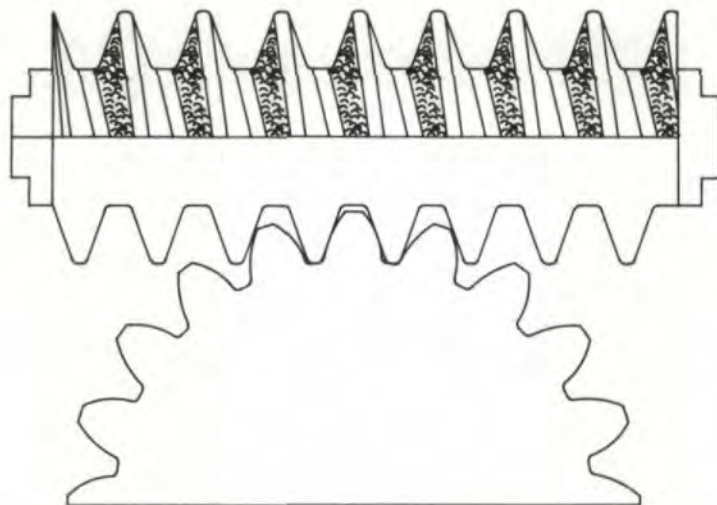
High-temperature, high-alloy gear materials used today are being ground out of the solid in less time than cutting in some cases. With the new grinding and abrasive technology used today, grinding out of the solid is becoming an economical alternative to other approaches.

High-performance and heavy loaded gears are generally carburized and hardened. To increase their life and durability, the teeth must be ground to achieve a controlled tooth geometry. In many cases modified involutes and crowning are required to reduce end loading. Grinding gear teeth is the method to use to achieve these modifications.

Case-Hardened Gear Teeth

Stock removal of the teeth of carburized and hardened gears must be controlled. It is recommended that no more than 20% of the effective case depth be removed. For example, the stock removal should not exceed .007 for case depths of .025 to .035.

Abusive grinding of gear teeth must be avoided. Generally abusive grinding will temper the gear tooth surface and reduce the surface hardness.



THREADED WHEEL GEAR GRINDING METHOD

Tempering of the tooth surface may not be seen by the naked eye, but can be determined by the Nital etch process. Severe tempering often causes local rehardening, which, in turn, can cause surface cracks, and can be determined by magnafluxing the gear.

Gear Grinding Methods

Gear teeth are ground by one of two basic methods — either form or generate grinding. Generate gear grinding machines all use the fundamental rack principal. There are three approaches to this principal, each using a different wheel geometry. They are dish-shaped wheels, threaded wheels, and conical wheels.

Form gear grinding is capable of grinding both external and internal spur and helical gear teeth. There is a wide range of sizes and diametral pitches in grinding machines. Form grinding machines use disk wheels, which are formed by dressing with a diamond to include the complete envelope of the involute tooth space.

Types of Generating Grinders

Threaded Wheel Gear Grinders. (Reishauer) (Okamoto). These gear grinders are fast, high-precision machines employing a 13 $\frac{3}{4}$ " diameter threaded grinding wheel. A section of the threaded wheel is an involute rack. The machine was designed for external spur or helical gears up to 30" in diameter with helix angles up to 45°.

The face width capacity ranges up to 11 inches. Pitch and helix angle determine the maximum face width of helical gears. The two screws provided pitch ranges from 6 to 48 DP or from 20 to 120 DP. The principle of the threaded wheel generating grinder is the same as the gear hobbing machine. The gear is mounted vertically and moves axially in both directions during the grinding cycle. The

GEAR GRINDING MACHINES

- **GENERATE GRIND**
- **DISH-SHAPED WHEEL** MAAG — SWITZERLAND
- **THREADED WHEEL** REISHAUER — SWITZERLAND
OKAMOTO — JAPAN
- **CONICAL WHEEL** REISHAUER — SWITZERLAND
HOFLER — GERMANY
LIEBHERR — GERMANY
PFAUTER-KAPP — GERMANY

grinding wheel is fed into the work at the end of each pass and is automatically changed from rough to finish grinding speed. A hydraulic, actuated collet type clamping device can be disengaged to

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allow the work to free the wheel for exceptionally fine finishes.

Crush-forming a new grinding wheel thread requires approximately four hours. For this reason most users stock pre-formed wheels. Dressing a pre-crushed wheel requires only about 20 minutes. Where profile modifications are required, it takes somewhat longer. The universal truing attachment can dress the wheel to produce involute profiles or modified tips and flanks. There are two types of diamond-plated rolls mounted on motorized

spindles available for dressing these wheels also. The single roll requires a very precise roll and dresses both sides of the wheel at one time. The two-roll method has two diamond rolls mounted on independent spindles and makes it easier to adjust for diamond roll wear.

As the work passes axially through the grinding wheel, the gear rocks axially to produce crowning. The magnitude and location of the axial profile modification is controlled by cams mounted on the work slide.

The threaded wheel gear grinder is capable of producing tooth profile, spacing, and lead within 200 millionths of an inch. The surface finish produced is excellent.

Generally best results are obtained with a good grinding oil and a vitrified, aluminum oxide grinding wheel specification of 38A (120/180) (H/J) 9V.

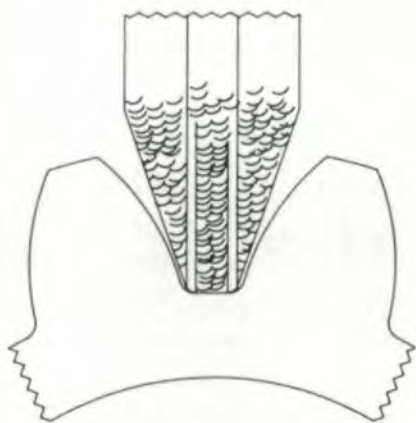
Conical Wheel Gear Grinder. (Pratt & Whitney Div., Colt Industries). These machines have not been manufactured since World War II; however, a large number of them are still in use in the U.S. The machines are capable of grinding spur and helical external gears only, with capacities for gears up to 18" in diameter.

The cross section of the conical grinding wheel is a straight profile rack tooth. The overhead grinding wheel head ram reciprocates rapidly as the work table feeds slowly back and forth at right angles to the gear axis. As the work table reciprocates slowly, the master gear rolls in mesh with the stationary rack, causing the work gear to roll in timed relation to the rapidly reciprocating grinding wheel. This results in a generating action. Indexing occurs at the end of the table stroke where the master rack is raised, and the master gear indexed one tooth.

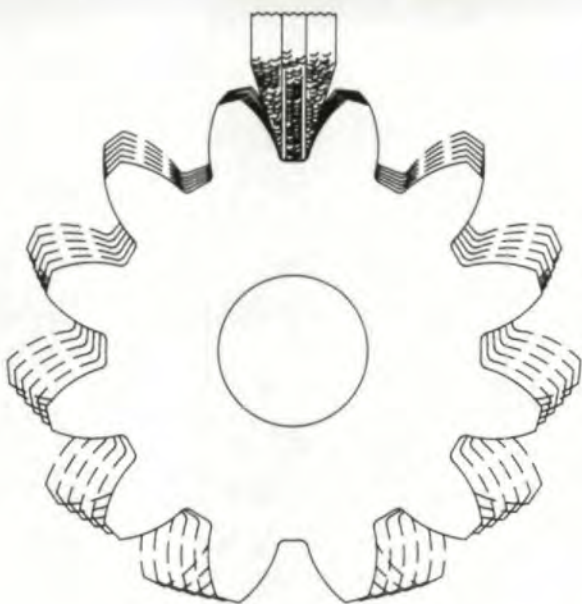
The wheel dresser is a simple diamond tool mechanism, set to dress the straight sides of the grinding wheel to the normal pressure angle of the gear.

The recommended grinding wheels and grinding coolants are similar to those recommended for form gear grinders.

Saucer-shaped wheel gear grinder (MAAG). The generating gear grinding machine employs two saucer-shaped grinding wheels. The grinders are suitable for grinding external spur and helical gears with the various models having capacities up to 142" in diameter. The diametral pitch range varies from 6 to 25 DP on the smallest machine



CONICAL WHEEL
GEAR GRINDING METHOD



INVOLUTE TOOTH PROFILE
GENERATION WITH CONICAL WHEEL

to 1 to 9 DP on the largest machine.

The planes established by the rim of the saucer-shaped grinding wheels represent the straight profile rack tooth on which the work gear rolls during the grinding cycle. The gear generating motion is effected by a pitch or base circle block and steel tapes. The work gear oscillates under the grinding wheels as the upper work table reciprocates rapidly at right angles to the axis of the gear.

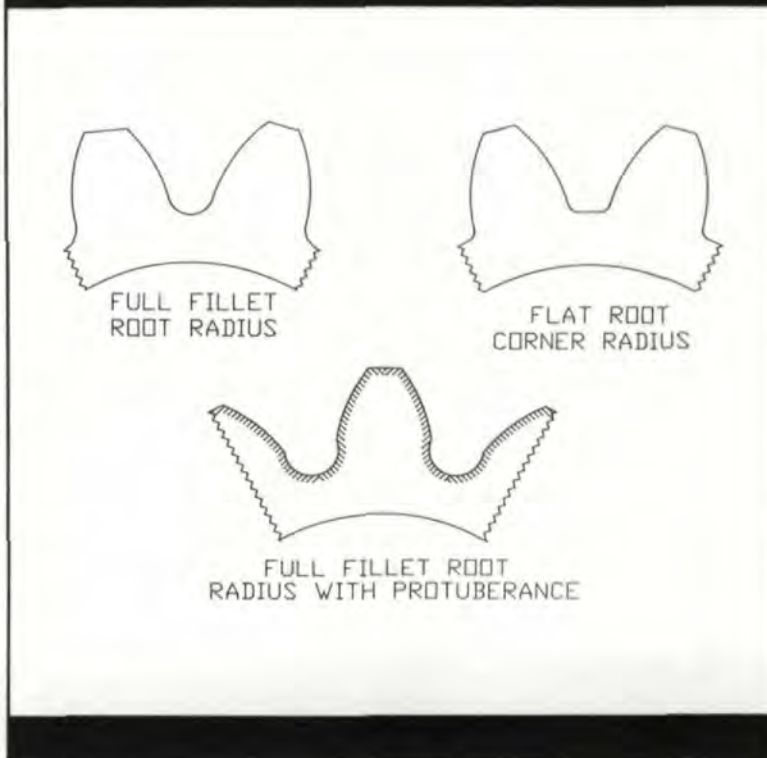
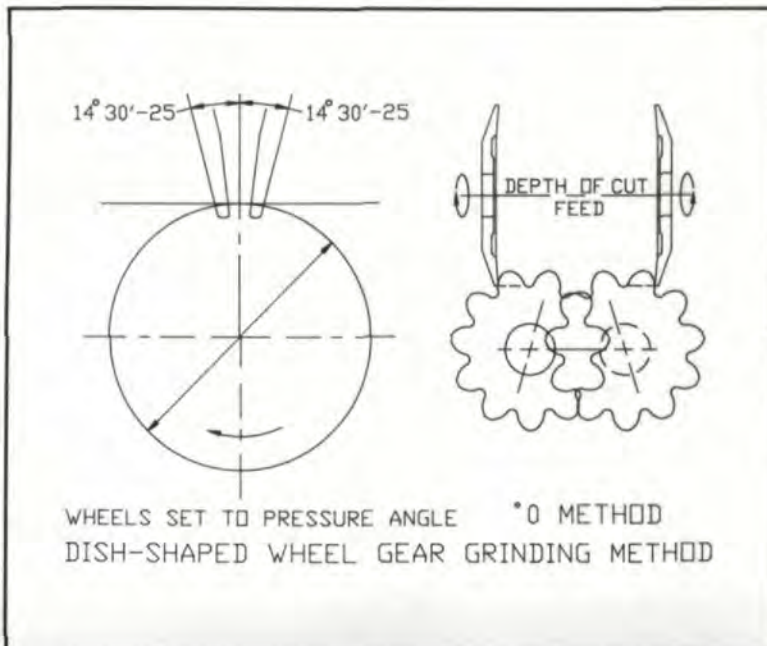
Helical gears require that an additional rotation be superimposed on the generating motion, the magnitude and direction of which is dependent upon the helix angle. This is effected by a sliding block and guide which impart transverse motion to the tape support stand in proportion to the axial feed motion. The lateral movement of the tape stand is converted by the pitch block and tapes into the additional rotary motion required.

Axial modification of the gear teeth is also effected by the axial feed motion which independently shifts the grinding wheels laterally in timed relation to the feed stroke by means of a cam-operated, hydromechanical reducing feed system.

The grinders employ a 15/20° method and a 0° method. In the 15/20° method, the grinding wheels are inclined at the pressure angle of the gear to be ground, and the pitch block coincides with the pitch circle of the gear. This method produces the familiar criss-cross grinding pattern and is the easiest to set up. The 15/20° method has the advantage that the rim of the saucer-shaped grinding wheel produces a generated fillet curve. The 15/20° method is not suitable for grinding profile or axial tooth modifications.

The 0° method is an extension of the 15/20° method. The parallel grinding wheels are set at 0° pressure angle, and a pitch block, which coincides with the base circle of the gear to be ground, is used. Theoretically only one point on the rim of the saucer-shaped grinding wheels contact the work. This method has the advantage of being two to three times as fast as the 15/20° method, and it also makes profile and axial tooth grinding modifications possible. Since the contact point on rim of the grinding wheel generates a cusp, it is necessary to protuberance-cut gears to be ground with the 0° method in order to avoid undesirable ridges in the root fillets.

The following ranges of specifications for grinding wheels are recommended for use with dry,



saucer-shaped generating wheels: (32A/38A) (46/80) (H/L) (5/9) V.

Theoretically the rim of the saucer-shaped grinding wheel contacts the tooth flank at one or two points, depending upon the angle setting of the wheels. The point generation method removes metal at a relatively slower rate than form grinding, but generates less heat and thereby obviates the need for grinding coolants or oils. The grinding dust is removed by a dust collector provided with the machine.

The vertical column, which can be swivelled to

the desired helix angle, supports the two separately powered grinding wheelheads. The grinding head slide can be adjusted vertically to accommodate different gear sizes. The individual grinding heads can be swivelled to the angle corresponding to the gear pressure angle or to vertical for zero-angle grinding. The grinding heads are also displaced laterally for various pitches.

In order to compensate for tooth beam deflections under varying loads, it is desirable to relieve the tooth profile at the tip and the flank. Profile modifications are achieved by a hydromechanical, cam-operated system, which moves the grinding spindles laterally in timed relation with the generating stroke.

Grinding Wheels

Grinding wheels have five wheel specifications to control them. They are abrasive, grit size, grade (hardness), structure, and bond.

Abrasive: Aluminum oxide is the most common abrasive used to grind gear teeth. Cubic Boron Nitride (CBN), referred to as Borazon,TM is being introduced as an alternative abrasive.

Grit size: Generally 50 to 80 grit size is used to grind carburized and hardened gear teeth. Micro-finish is a prime factor in judging what grit size is required.

Grade: Soft to medium grade (H, I, or J) is a good start for hard gears.

Structure: Structure should be medium, between 6 and 7.

Bond: Generally a vitrified bond is used. Vitrified wheels perform best on precision grinding where form is required to be held.

Wheel surface feed is important, and in most cases, 4,000 to 5,000 surface feet per minute is a desirable speed.

Basic Grinding Rules

The harder the part, the softer the grade.

The finer the grit, the better the finish.

Decreasing the surface speed will result in a softer effect of the grade.

Decreasing the surface speed will reduce tempering, but will effect wheel form.

Form Gear Grinders

The form gear grinder is capable of grinding both external and internal spur and helical gears up to 36" in diameter. The machines have capacity for diametral pitches from 64 to 2. An automatic grinding cycle is provided which reduces the necessary reliance on operator skill, and, at the same time, increases the accuracy of the gears ground on a production basis by insuring exact repeatability of the selected optimum grinding cycle.

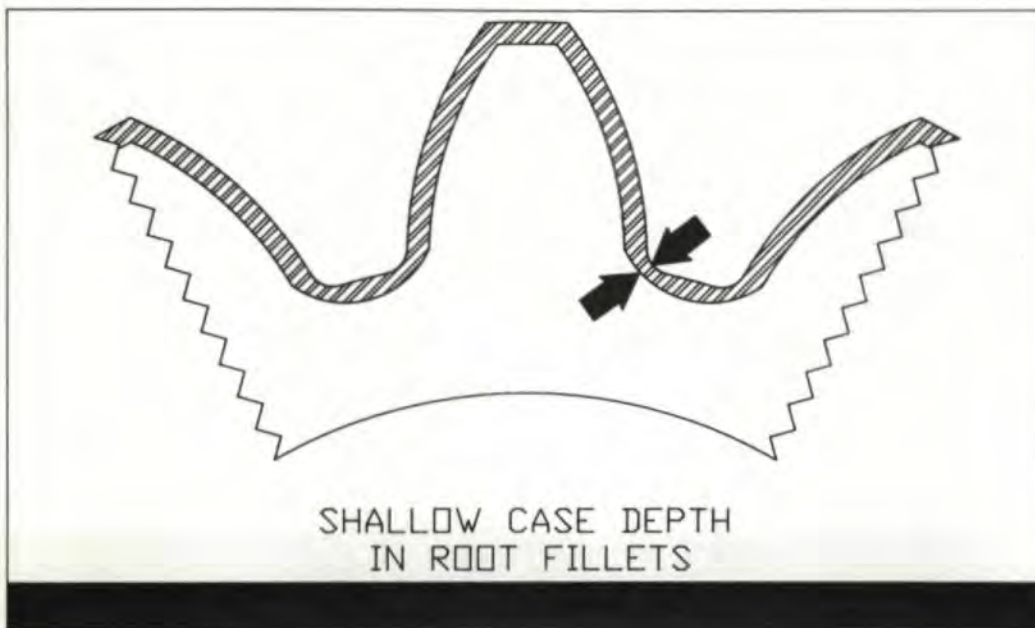
The gear to be ground is carried between centers in the index head and the tailstock. The index head, tailstock, and the dresser are mounted on the work table, which reciprocates under the grinding wheel. The grinding wheel head is mounted on column ways and supported by a grinding feed mechanism, which raises the grinding wheel after automatic dressing at finish size.

On the older machine models, the two diamond tools which dress the grinding wheel are actuated by templates through reduction cams or pantographs. The grinding wheel is dressed with sufficient accuracy to produce tooth profiles ground within a tolerance band of 200 millionths (0.000200) of an inch. Since the dresser is cam-actuated, non-involute tooth forms, such as cycloidal teeth, Wildhaber-Novikov gears, straight-sided splines, and parallel-sided splines, as well as half-round bearing grooves, can be produced with equal ease and accuracy.

Current dressing technology uses numerical



FORMED WHEEL
GEAR GRINDING METHOD



controlled dressers, which have ball screw feeds. They are more accurate and much easier to set up. The dressing of the wheel provides an exact duplication of the tooth space of the part being ground. This includes the profile, root, and root radius, and determines the tooth thickness.

The gear is indexed by accurately ground, hardened index plates with the number of gashes corresponding to the number of teeth in the gear to be ground. Gears are normally ground with a maximum tooth spacing variation between adja-

surance can be had and better finishes obtained by using a high grade, well-filtered, sulphurized or chlorinated grinding oil.

Recommended grinding wheels are vitrified aluminum oxide wheels with 29A semi-friable or hard brittle universal 38A abrasive. The grain sizes vary from 46 to 80 for combined rough and finish grind. The hardness varies from H to J, and the structure from a medium 5 to 9. The grinding wheel range is (29A/38A) (46/80) (H/J) 5/9/ V.

GEAR GRINDING MACHINES

- **FORM GRIND**
 - **RED RING/NATIONAL BROACH & MACHINE — U.S.A.**
 - **KAPP — GERMANY**
 - **LEIBHERR — GERMANY**
 - **OKAMOTO — JAPAN**

cent teeth of 200 millionths (0.000200) of an inch. The lead produced is within 100 millionths of an inch per inch of face width.

The grinders also equipped with crowning or axial modification devices. The vertical motion of the grinding wheel is superimposed on the grinding feed and produces a fully crowned tooth or end ease-off designed to prevent end loading of the teeth due to mounting support deflections under varying operating loads.

The automatic grinding cycle reduces the hazard of surface tempering. However, additional in-

Conclusion

Production time estimates must be used with caution. Appreciable deviations from the estimated grinding time will be effected by variations in the accuracy required, gear blank quality, grinding stock, grinding cycle, grinding wheel used, coolant efficiency, tooling loading fixtures, etc.

A direct comparison of the gear grinding cycle time with the cycle time of other gear tooth finishing methods, such as finish cutting, shaving, and honing, does not reflect the true relative cost of producing ground gears with the cost of producing quality unground gears. Gear grinding can effect substantial cost savings in cutting, perishable tools, and inspection. Studies have shown that hardened and ground precision gears may cost less to product than comparable unground gears.

Acknowledgement: This article was presented at the AGMA Gear Manufacturing Symposium, April 1-3, 1990, Cincinnati, OH. Printed with permission of the copyright holder, the American Gear Manufacturers Association, 1500 King Street, Suite 201, Alexandria, VA, 22314. The opinions, statements, and conclusions presented in the paper are those of the Author and in no way represent the position or opinion of the AMERICAN GEAR MANUFACTURERS ASSOCIATION.