Gear Grinding Techniques Parallel Axes Gears

by
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The fundamental purpose of gear grinding is to consistently and economically produce "hard" or "soft" gear tooth elements within the accuracy required by the gear functions. These gear elements include tooth profile, tooth spacing, lead or parallelism, axial profile, pitch line runout, surface finish, root fillet profile, and other gear geometry which contribute to the performance of a gear train.

The strength and wear resistance of gear teeth may be increased by hardening the tooth and root surface. Hardened gear teeth make it feasible to reduce the gear size and increase the transmitted load and speed. This is highly desirable from the standpoint of economy as well as the product efficiency. However, distortions occur during the hardending process which can be corrected only by abrasive machining or grinding.

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Ground Unhardened Gears

Low hardness or "soft" gears in the range of Rockwell C 25 to 40 are usually cut by a gear shaper, Shear-speed, or hobber, and then finish shaved to obtain a relatively high degree of accuracy, i.e. AGMA 10-11 (American Gear Manufacturers Association quality no.). In some applications, it may be more economical to grind the "soft" teeth in the solid gear blank or bar stock, especially in the range of 16 diametral pitch and finer.

High Alloy Gears Ground From Solid

The high temperature high alloy gears and splines afford an excellent area in which the economics of abrasive machining of gear teeth may be realized. It has been demonstrated that a 16/32 DP internal spline, which required 12 hours to shaper cut in a very high nickel-chrome alloy, could be form ground from the solid in approximately 4 hours. In addition to the time saved, a more accurate spline was produced at considerably less cost.

Medium Hardness Ground Gears

Through-hardened alloy gears in the range of Rockwell C 45 to 55 are usually cut, hardened and then finish ground or honed as required to obtain specified accuracy and surface finish. Although gears harder than Rockwell C 40 are not usually cut, it is possible to shaper cut through hardened gears up to about Rockwell C 50. This procedure is very costly due to rapid cutter wear and should be restricted to those applications where grinding after hardening is not possible.

Gas turbine manufacturers employ abrasive machining to effect considerable savings in the manufacture of splines and keyed through-hardened spacer rings. The solid through-hardened ring blanks are stacked on an arbor, then the splines, keyways and peripheral grooves are form ground from the solid. These rings were formerly made by cutting in the soft-blank, heat treating and then finish grinding individually. Form grinding from the solid blanks after hardening effected savings in excess of 50% of the original cost.

Case Hardened Ground Gears

Case hardened gears are usually employed in high speed and high load units which require maximum durability and reliability as well as high power performance. Aircraft, missile systems, truck and automotive transmissions, marine speed reducers, gas turbine gearing, farm and off-the-road equipment, and machining tools are typical of durable reliable high performance case hardened gear applications.

Gear tooth and root surfaces may be hardened locally by carburizing, nitriding, induction hardening, (and a number of shallow surface hardening methods which improve resistance to wear, but not the bending strength of fatigue life at the critical root fillet section.)

Carburized And Hardened Ground Gears

Due to their high impact and bending load capacity and their good wear resistant properties, carburized and hardened gears are the most widely used case hardened gears, where rugged high performance is required. Gears may be hardened all over, or masked off during carburizing to prevent hardening of the hub, web, and rim areas. Carburized gear blanks are frequently copper plated all-over prior to cutting the teeth and finish machining those surfaces to be hardened, such as functional bearing or mounting surfaces. The gear is then heated above the critical temperature, approximately 1700°F. in a carbon pack, salt bath or a carbon atmosphere, and held for the time required for the exposed machined surfaces to absorb carbon to the desired depth. The carburized case depth may vary from 0.010 to 0.020 inch for 20 diametral pitch gears, up to 0.025 to 0.035 inch depth for 12 diametral pitch, and 0.075 to 0.100 inch depth for gears of 2 diametral pitch and coarser.

A carburized gear may be hardened by quenching directly from the carburizing furnace, or it may be slow cooled in a protective atmosphere, then reheated in a protective atmosphere and quenched for grain refinement and case hardening. The case will quench out at about Rockwell C 63 to 65 and is then tempered to Rockwell C 58 or 60 to 63 before finish grinding or honing. Since about 85% of the distortion takes place during carburizing, it is sometimes advantageous to temper the carburized gear below Rockwell C 40, then finish shave prior to hardening. This procedure may make it possible to hone for surface finish only, or minimize the necessary grinding stock.

Most automotive transmission gears are small and of simple design, which makes it possible to shave them prior to carburizing and hardending. They only require honing to correct minor heat treat distortions. Unlike grinding, honing is not a metal removing process and should be used only to improve surface finish and correct very minor thermal distortions. Honing will also remove handling nicks and burrs.

Other high speed high performance gears are cut, carburized, hardened, and finish ground. The grinding stock should not exceed 0.005 to 0.007 inch for case depths up to 0.025 to 0.035 inch and 0.010 inch in the 0.075 to 0.100 inch depth range.

In order to minimize the grinding stock removal, the nominal pitch circle of the gear can be indicated after hardending and used to locate the centers, the bore, or the operating journals which will determine the gear axis during additional operations including gear tooth grinding. Since the pitch circle, distored in carburize and hardening, may be difficult to define, a proof circle near the root diameter, and a reference face perpendicular to the axis, should be provided to facilitate optimizing the concentricity and squareness of the gear teeth before finish grinding. Another popular approach is to use a pitch line chuck with either three or six pins to re-establish the center line in relation to the pitch circle.

It is absolutely essential that excessive case removal in the root fillet be avoided. Fig. 1(A) illustrates the shallow case which occurs in a sharp root fillet as a result of the small entrance area in the fillet during carburizing. View 1(B) shows the resulting removal of most of the case hardened fillet during grinding. Note the thinness of the hardened section at the root fillet of the gear tooth which will fail in bending fatigue due to insufficient case depth in this critical area. Sharp root fillets or steps should be avoided whenever possible, especially on case hardened gears.

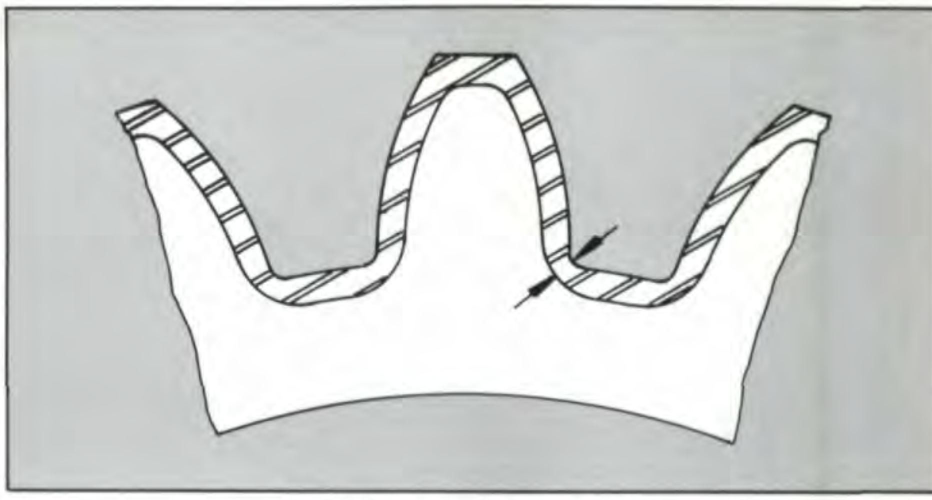


Fig. 1A – Shallow case depth in root fillets.

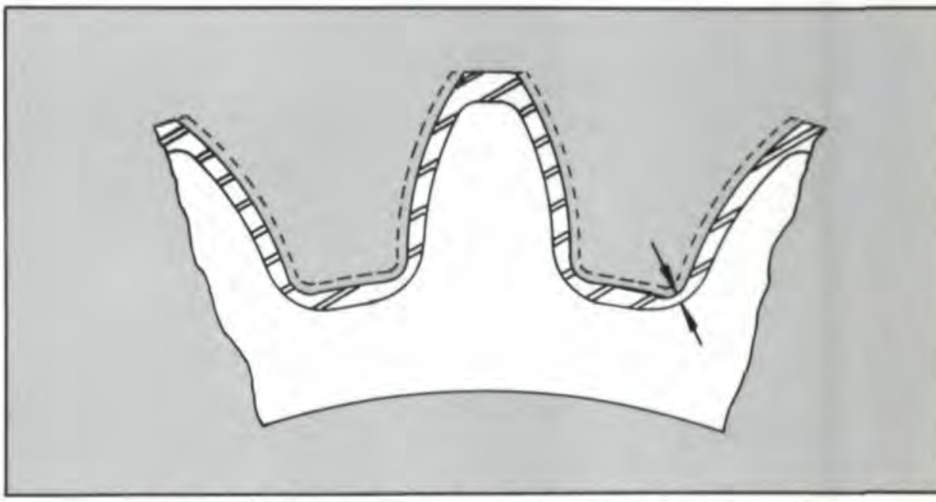


Fig. 1B – Excessive case removal in root fillet reduces bending strength.

Fig. 2(A) illustrates schematically a protuberance-cut full-fillet gear tooth and shows that the tendency towards a lean case in the fillet is greatly reduced. View 2(B) shows that adequate case depth remains after grinding in the root and fillet of a carburized protuberance-cut full-fillet gear.

Fig. 3(A) and 3(B) illustrate a protuberance cut and a full fillet after grinding only the tooth profiles. These roots remain unground, fully hardened and,

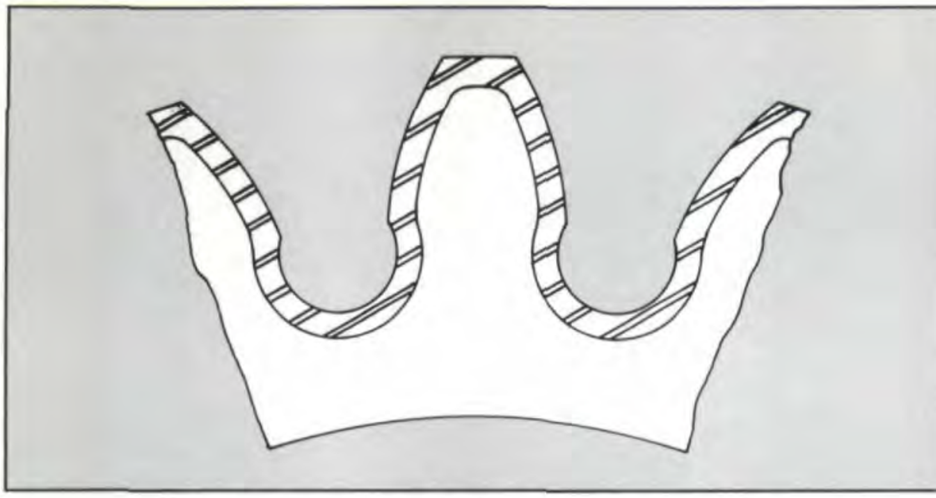


Fig. 2A – Protuberance cut full fillet improves case depth in fillet.

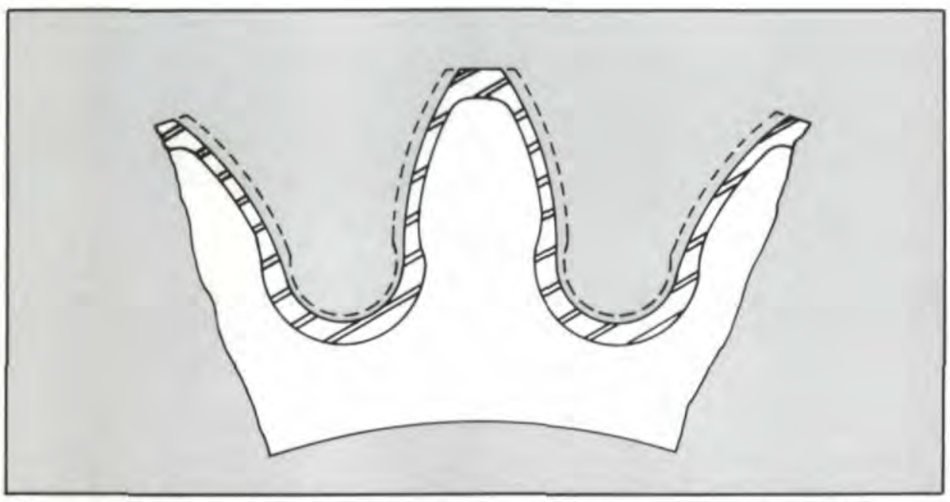


Fig. 2B – Ground protuberance cut fillet showing sufficient case in ground root fillet.

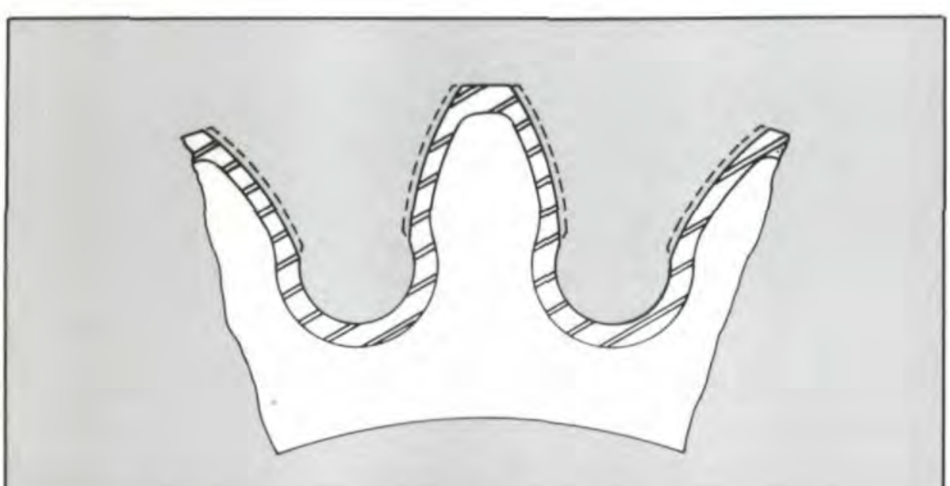


Fig. 3A – Ground tooth profile with unground protuberance cut full fillet root.

therefore, at maxiumum strength. However, care must be taken to remove all residual heat treat scale from the root and fillet. If not removed, the scale may act as a stress riser, or flake off in operation and abrade the tooth and bearing surfaces. Scale may be removed by grit blasting the gear teeth and fillet surfaces prior to finish grinding the tooth profiles. Grit blasting may be followed by shot-peening the tooth and fillet surfaces before finish grinding of the tooth profile, only.

Nitrided Case Hardened and Ground Gears

Nitriding steels contain nitride-forming elements such as aluminum, chromium, molybdenum, vanadium or tungsten which combine with atomic nitrogen (N) when heated from 925°F to 1100°F in an atmosphere of dissociated ammonia. The nitriding cycle requires 25 to 48 hours to produce a 0.015 to 0.022 inch deep case, which is very hard – Rockwell 15N 90 to 93 – and highly resistant to wear. The hardness of the relatively thin case drops off rapidly leaving a hard surface which is not well suited for application where impact loadings will be encountered.

Since nitriding is done at a temperature below the critical, heat treat distortions are minimum. In many cases, grinding after nitriding would not be necessary except to insure removal of the "white layer" from the tooth and fillet surfaces. The white layer is a brittle, weak, overrich nitride which forms during nitriding and ranges in thickness from 0.005 to 0.003 inch depending upon the nitride cycle used.

Nitrided gears are processed to take maximum advantage of the small thermal distortions. The gear blanks are normalized at 1800°F, annealed, rough machined, quenced from 1725°F, tempered for core properties, finish machined and gear teeth finish cut or shaved prior to nitriding. After nitriding, the grinding stock removal should be limited to 0.003", and extra care should be taken to avoid excessive case removal in the root fillets.

Gear Grinding Methods

The two basic methods used to grind gear and spline teeth are the form grinding method and the generating method.

Form grinding employs a disc-type grinding wheel, contoured by diamond dressing tools to grind the complete gear tooth space profile. This type of grinding is illustrated in Fig. 4. There are several different generating methods as shown in Figs. 5, 6 and 7. Each of the generating methods is identified in the industry by the name of the manufacturer who originally developed the particular method. All of the generating methods

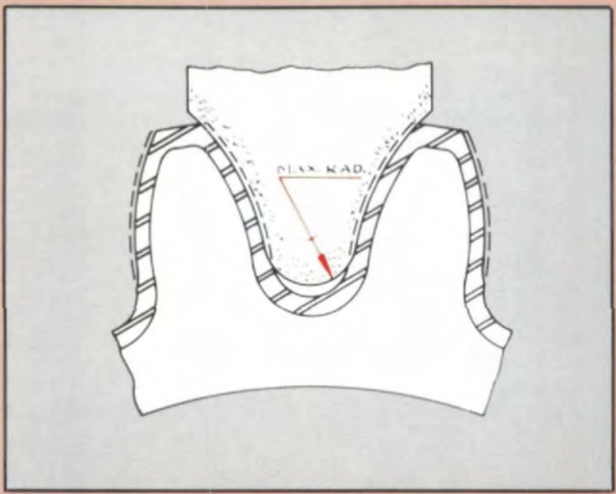


Fig. 3B – Ground tooth profile with unground full fillet root.

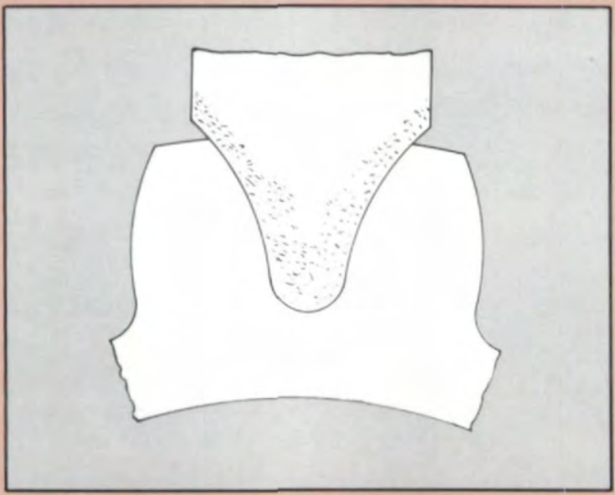


Fig. 4 – Formed-wheel gear grinding method.

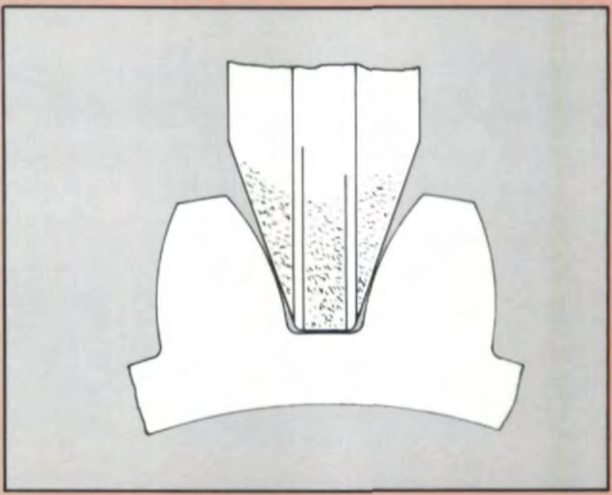


Fig. 5 – Conical wheel gear grinding method.

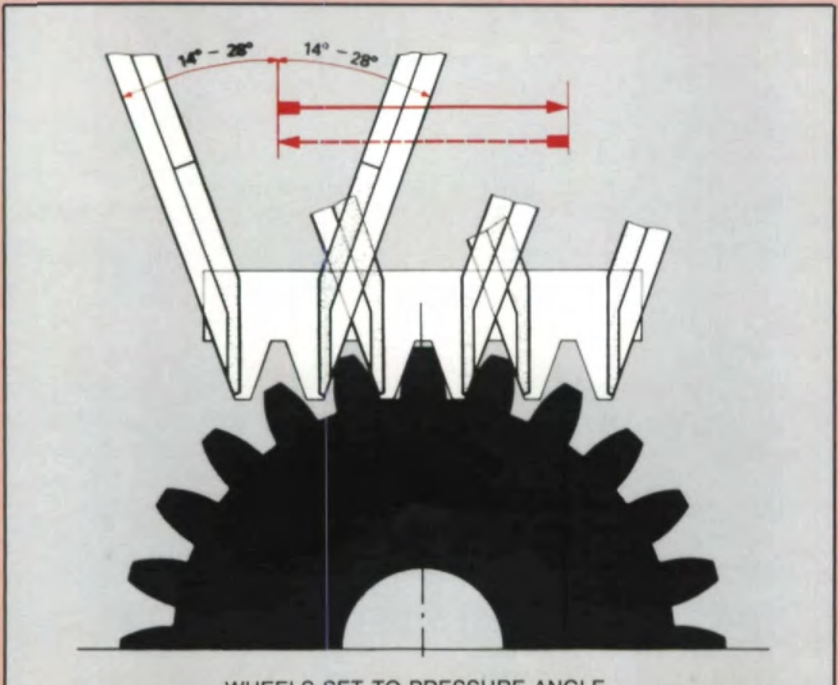


Fig. 6 – Saucer-shaped wheel gear grinding method.

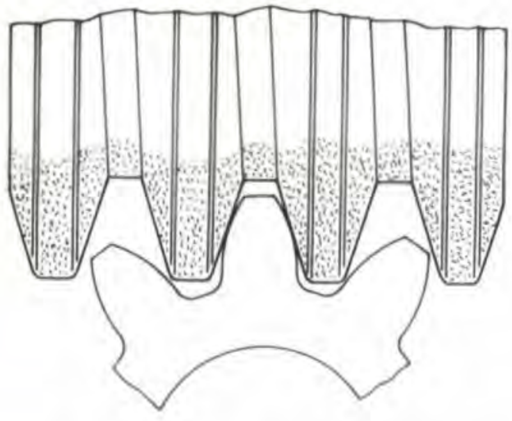


Fig. 7 – Threaded wheel gear grinding method.

Fig. 8 – Involute tooth profile generation.

employ the straight profile rack generating principle illustrated in Fig. 8. While the straight profile rack grinding wheel and the gear reciprocate relative to each other, the gear simultaneously rolls on its pitch circle, in timed relation to the rack without slipping, thereby, generating the involute tooth profile.

Form Gear Grinders

Examples of brand names are National Broach Company, Liebherr, Kapp.

Form gear grinders are capable of grinding both external and internal spur and helical gears up to 36 inch diameter and larger. (See Figs. 9A and 9B) The machines have a capacity for diametral pitches from approximately 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 the production basis by insuring 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.

The two diamond tools which dress the grinding wheel are actuated by templates through reduction cams or pantographs. (Also see comments under CNC application.) The grinding wheel is dressed wtih sufficient accuracy to produce tooth profiles ground within a tolerance band of .0002 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. (See Fig. 10 form grinding wheel contour dresser).

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. (See Fig. 11) Gears are normally ground with a maximum tooth spacing variation between adjacent teeth of .0002 inch and a maximum variation on the gear .0006 of an inch. The lead produced is within .0001 of an inch per inch of facewidth.

The grinders are 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 helps eliminate the hazard of surface tempering. However, additional insurance can be had and better finishes obtained by using a high grade, well filtered, sulphurized or chlorinated grinding oil. Oil mist extractors are suggested to eliminate contamination of oil misting the surrounding area.

Recommended grinding wheels are vitrified aluminum oxide wheels, 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. These machines have been adapted to Borazon grind wheels as will be discussed later.

Saucer-Shaped Wheel Gear Grinder

Examples of Brand Names: (Maag and Hurth)

The generating gear grinding machine, shown in Fig. 12, employs two saucer shaped grinding wheels as shown in Fig. 6. Maag grinders are suitable for grinding external and internal spur and helical gears with various models having capacities up to 198 inches, and diametral pitch ranges varying from as fine as 25DP to as coarse as .63DP.

On a vertical type Maag grinder, the axis of the workpiece is vertical. The planes established by the rim of the

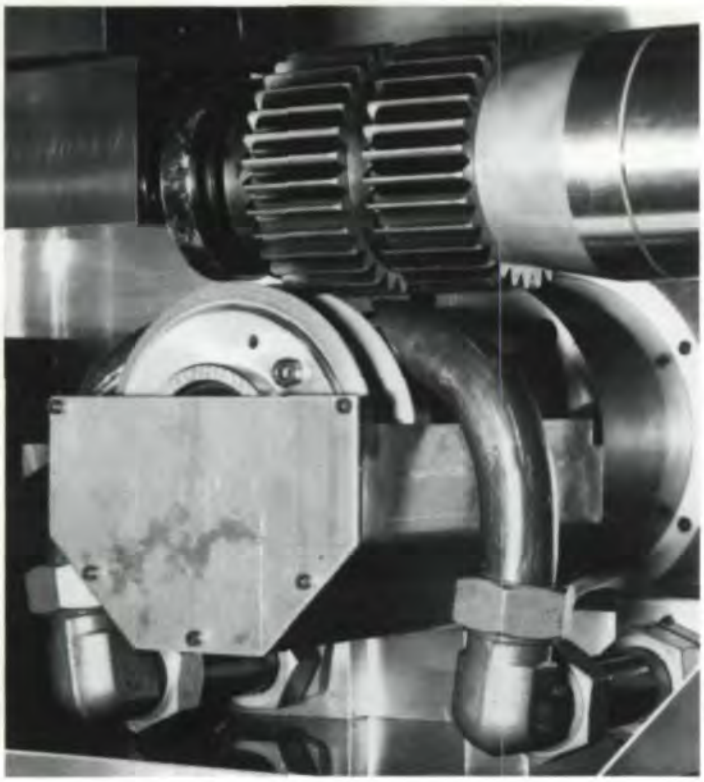


Fig. 9A – Form grinding on an external gear.

Fig. 9B – Form grinding on internal ring gear.

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 produced by a rotary motion imparted through a change gear train driving the work table/work piece and a transatory motion of the workpiece with a lead screw change gear drive train. The gear, in effect, rolls across a single tooth rack with a tooth of the rack being replaced by reciprocating grinding wheels, i.e. one right and one left flank ground per a rolling pass.

The vertical column, which can be swivelled to the desired helix angle, supports the two separately powered grinding wheel heads. The grinding head slide can be adjusted vertically to accommodate different gear facewidths and gear locations. The individual grinding heads can be swivelled to the angle corresponding to the gear pressure angle. The grinding heads are also displaced laterally for various pitches.

Theoretically, the rim of the saucer-shaped grinding wheel contacts the tooth flanks at one or two points depending upon the angle settting of the wheels. The point generation method removes metal over a small area, generating less heat and, thereby, alleviating the need for grinding coolants or oils. Grinding dust is removed by a dust collector provided with the machine.

The horizontal Maag grinder also uses two saucer type wheels, but they are set at a zero degree grinding pressure angle. The generating principle can be likened to the basic mechanical construction of an involute, i.e. a circular disc with a string wrapped around it, and unwinding the taut string produces a series of tangents to the "base circle" producing an involute curve. Replace that base circle disc with a segment "rolling block" and steel bands for string, and you have the fundamental operating principle of a Maag horizontal grinder. (See Fig 13).

One of the most important factors about a Maag gear grinding machine is that the active face of the grinding wheel must stay in a set position. This is accomplished by a grinding wheel wear compensating device that senses as little as .000040" wear in the face of the active grinding wheel. Through a mechanical drive train, the grinding wheel is moved back into its correct position automatically.

In order to compensate for tooth beam deflections under varying loads, it is desirable to relieve the tooth profile at the tip and on the flanks. Profile and longitudinal modifications are achieved by a hydromechanical cam operated system or a CNC controlled unit which moves the grinding spindles laterally in timed relation with the generating stroke and axial feed slide. (Fig. 14A and B).

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. On the horizontal machines, this is effected by a helical guide disc and sliding block arrangement which imparts a 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 additional rotary motion as required.

Both horizontal and vertical grinders are fitted with automatic infeed controls, indexing systems, wheel wear compensating units and diamond operated dressing devices for complete automatic operation.

Maag type grinders use vitrified bond type grinding wheels having a composition of aluminum oxide or silicone carbide. Grain sizes normally fall in the range of 46-80, depending upon diametral pitch, and also are in the soft ranges of F to I. Balancing of this type of grinding wheel is not that critical. Therefore, only a set of parallel bars and adjustable weights are used for balancing. It should be pointed out that Borazon grinding wheels are presently in use on Maag grinders for grinding of tool steel grade materials, i.e. shaving cutters and rolling dies. (See later comments regarding Borazon grinding).

Threaded-Wheel Gear Grinders

Examples: Reishauer and Okamoto

Reishauer and Okamoto gear grinders are fast precision machines employing a 3¾ inch diameter threaded grinding wheel as illustrated in Fig. 7. Operating principles of this type of grinder are illustrated in Fig. 15. A section of the threaded-wheel is an involute rack. These machines are designed for external spur or helical gears up to 28 inch diameter with helix angles up to 45°. Pitch and helix angle determine the maximum facewidth of helical gears. This type of grinder is capable of grinding DP's in the range of 3-48, depending on the size of the machine. 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 grinding

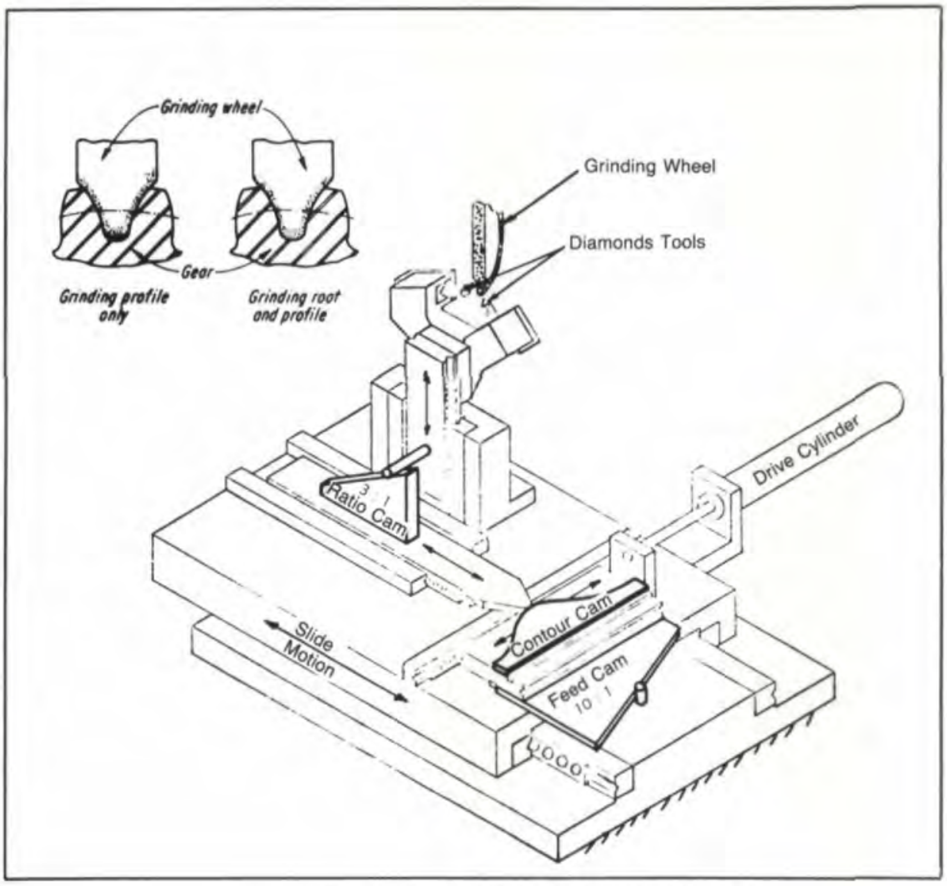


Fig. 10 – Form grinding wheel contour dressing.

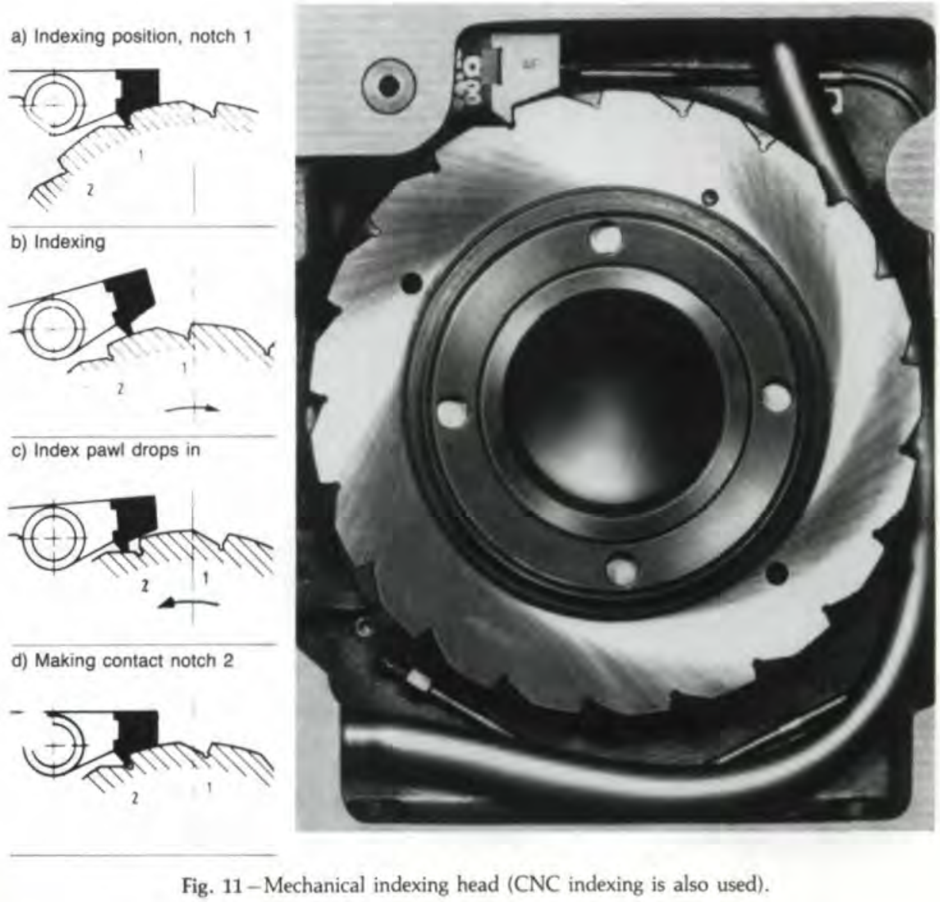


Fig. 11 – Mechanical indexing head (CNC indexing is also used).

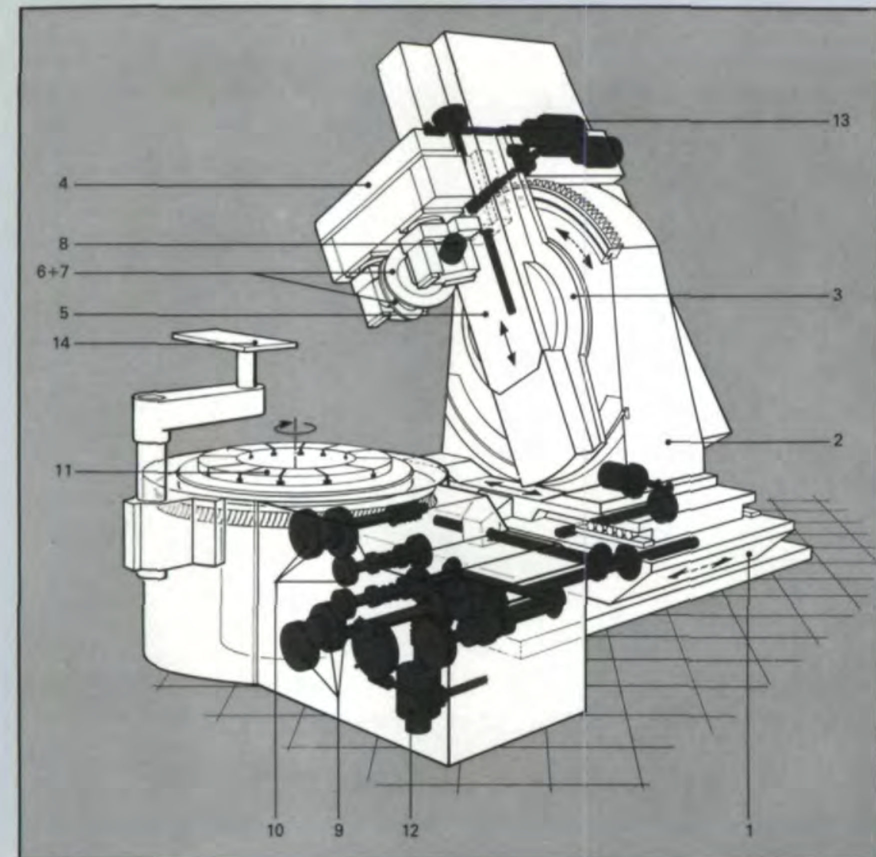


Fig. 12 – (Upper left) Kinematics of saucer – shaped wheel gear grinding machine, grinding wheels set to pressure angle of the gear.

1 column radial slide
2 column
3 swivel head (β)
4 crossbeam
5 ram
6 grinding wheel
7 grinding wheel
8 wheel head motor
9 module change gears
10 index change gears
11 work table with central hole
12 generating drive motor
13 ram drive reversing motor
14 hydraulically operated instrument table (for *ES-401* and *ES-430 measuring systems)*

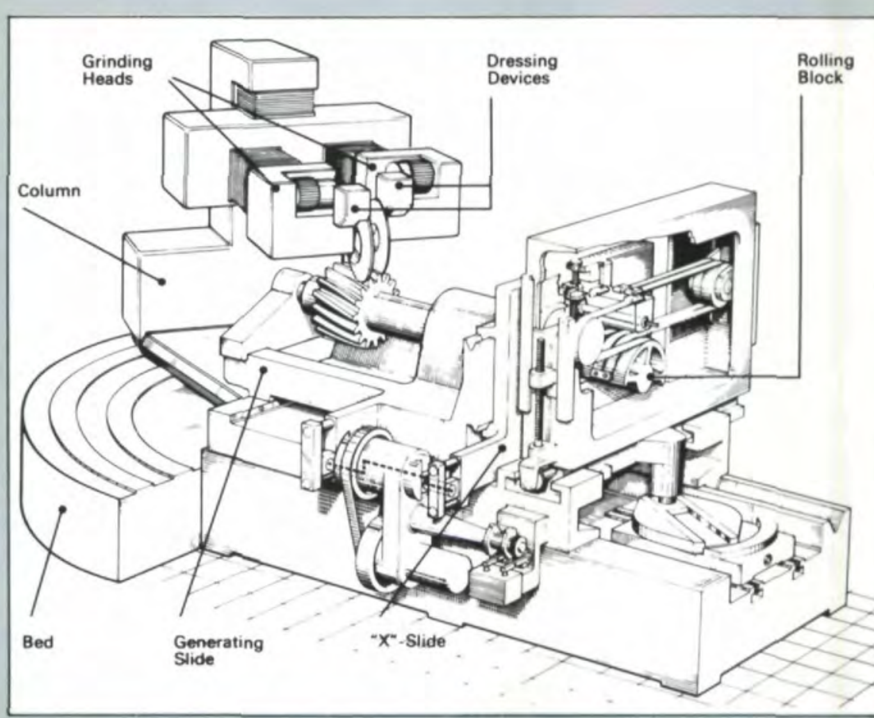


Fig. 13 – (Right) Kinematics of saucer-shaped wheel gear grinding machine.

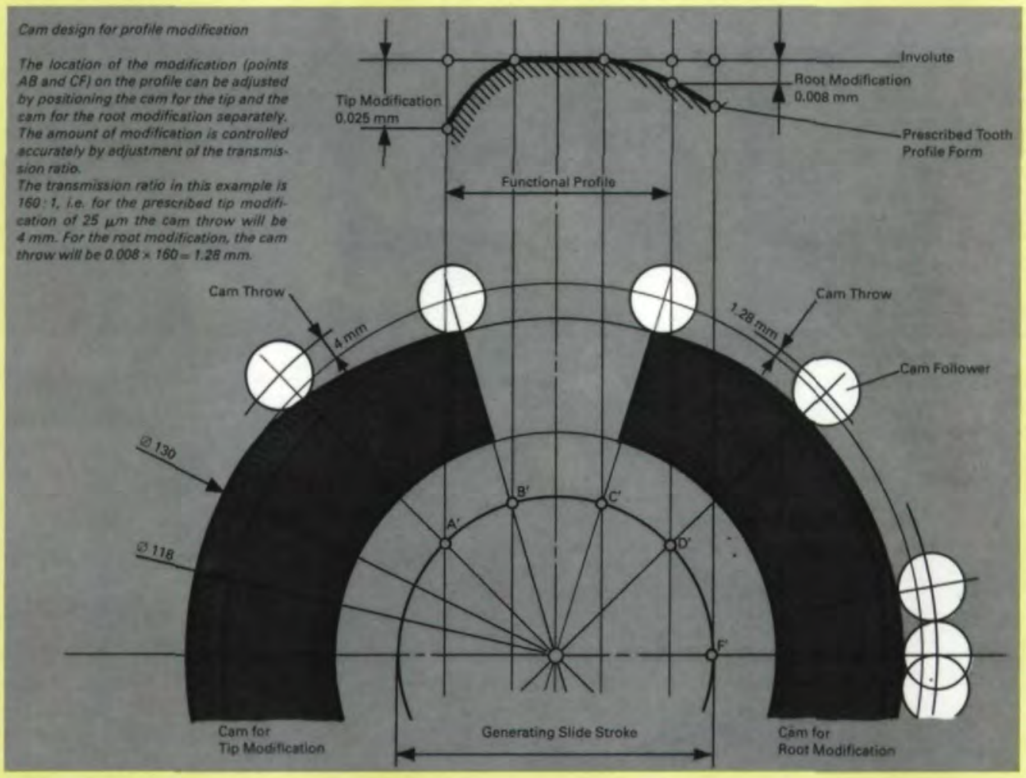


Fig. 14A – Correction cam for profile modification.

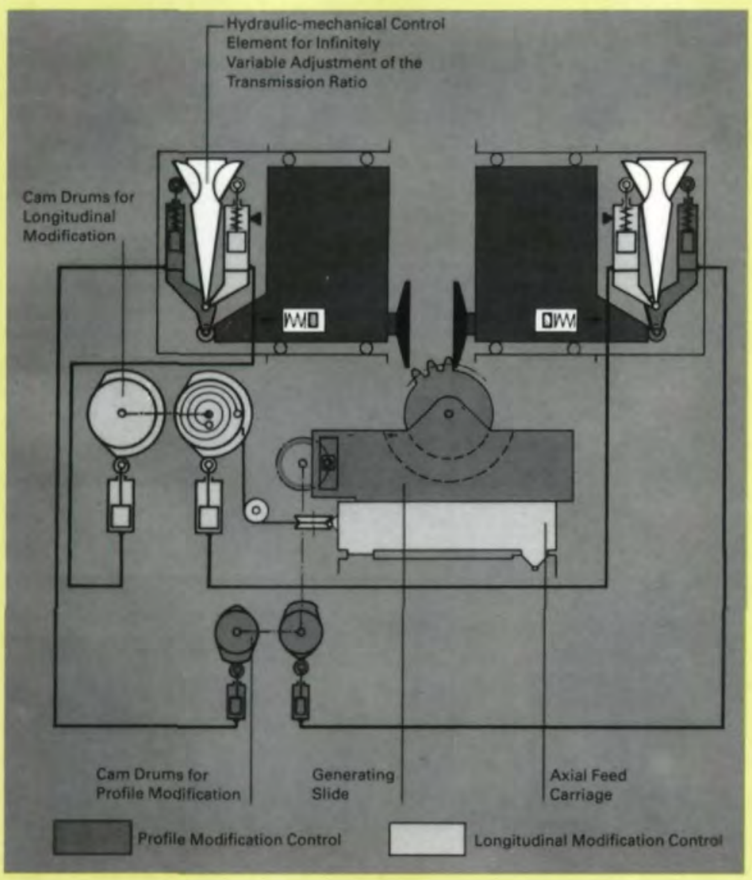
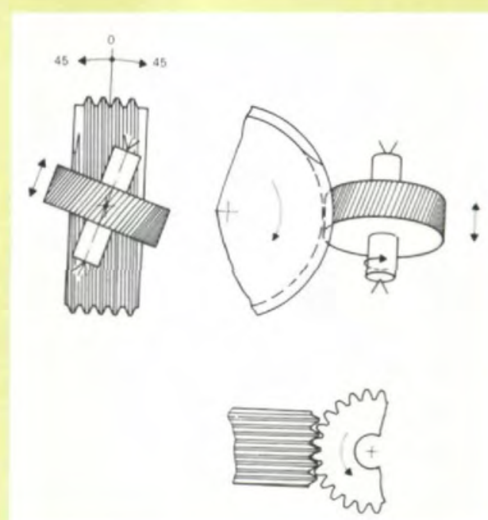
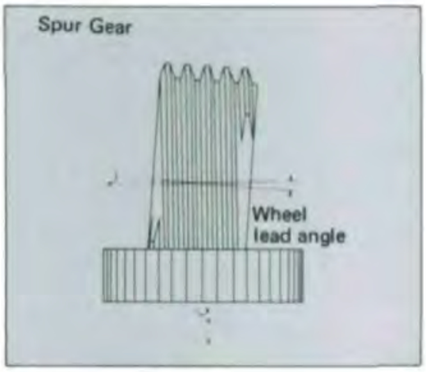


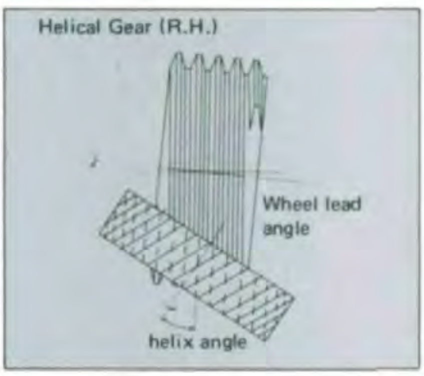
Fig. 14B – Kinematics of profile and longitudinal correction system.

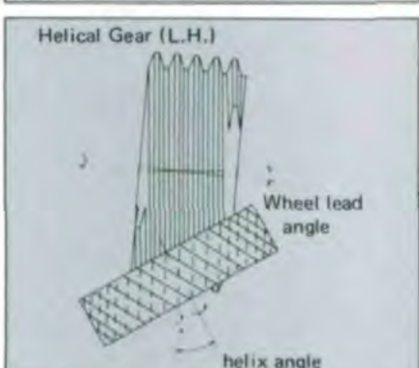
Fig. 15 – (Below) Operating principle of threaded-wheel gear grinder.



cycle. The grinding wheel is fed into the work at the end of each pass. The grinding feeds and speeds are automatically changed from rough to finish. A hydraulically actuated collet type clamping device can be disengaged to allow the workpiece to free wheel for exceptionally fine finishes. (See kinematic drawing, Fig. 16 for mechanical drive train machine).



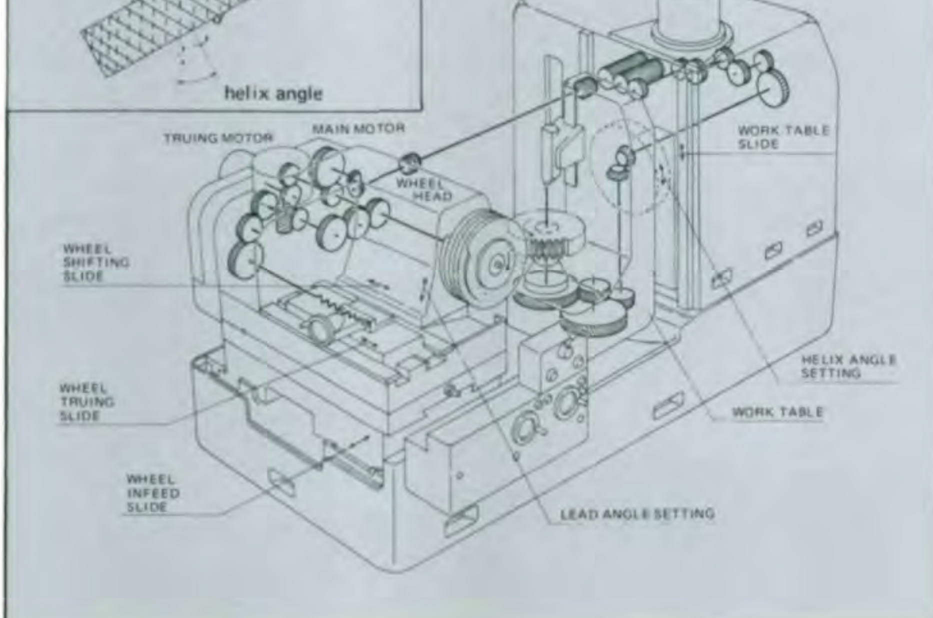




Crush forming a new grinding wheel thread can be a relatively lengthy process, especially when it's done on the machine. Off machine dressing apparatus' are available that reduce this dressing cycle without interfering with grinding machine productivity. Furthermore, pre-formed wheels are available from the grinding machine manufacturer. Dressing a pre-crushed wheel requires only about 20 minutes. However, if profile modifications are required, it could take somewhat longer. A universal truing attachment can dress the wheel to produce involute profile or modifed tips and flanks to a type of diamond plated rolls mounted on motorized spindles available for dressing the grinding wheels. A single roll requires a very precise roll, and it dresses both sides of the grinding wheel at one time. The two roll methods have 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. Generally, the best results are obtained with a good grinding oil and a vitrified aluminum oxide grinding wheel with a specification of 38A (150/180) (H/J) 9V.

Fig. 16 – Kinematics of mechanical machine drive train.



Reishauer does have available an NC controlled machine that eliminates indexing change gear drives and other drive elements. Quicker set-up times are possible with this new machine and higher accuracies are claimed. (See kinematic drawing, Fig. 17)

Conical Wheel Gear Grinder

Example Brand Names: Pratt & Whitney which is no longer manufactured, Hofler and Niles

These grinders are available with maximum diameter capacity up to 137.8", diametral pitch ranges from .8 to 8.5, and helix angles up to 35°. The machines are capable of grinding external spur and helical gears only.

Fig. 5 shows the cross section of the conical grinding wheel as a straight profile rack tooth. The overhead grinding wheel head ram reciprocates rapidly as the work table feeds slowly back and forth at a right angle to the gear axis. The reciprocation of the ram is accomplished either via mechanical means or by a hydraulic piston. The generation of the tooth profile on this type of gear grinding machine is based on the principle of rolling a gear along a rack. The grinding wheel has a trapezoidal cross section corresponding to an individual rack tooth. The involute is produced by the rolling motion of the workpiece along a straight flank of the grinding wheel. For helical gears, the grinding wheel slide complete with grinding wheel, is swivelled to the helix angle of the workpiece. The machine produces the involute profile by grinding the tooth flanks along straight lines. These lines correspond to the contact line with the mating gear. The production of the involute profile requires the work table and its slide to carry out a positively controlled generating rolling movement, i.e. the linear and rotary motion must be synchronized. This synchronization is achieved by change gears. The right hand flank is ground while the work table moves in one direction, and the left hand flank is ground during movement in the return direction. The difference between the thickness of the grinding wheel and the width of the tooth space is compensated via two posi-

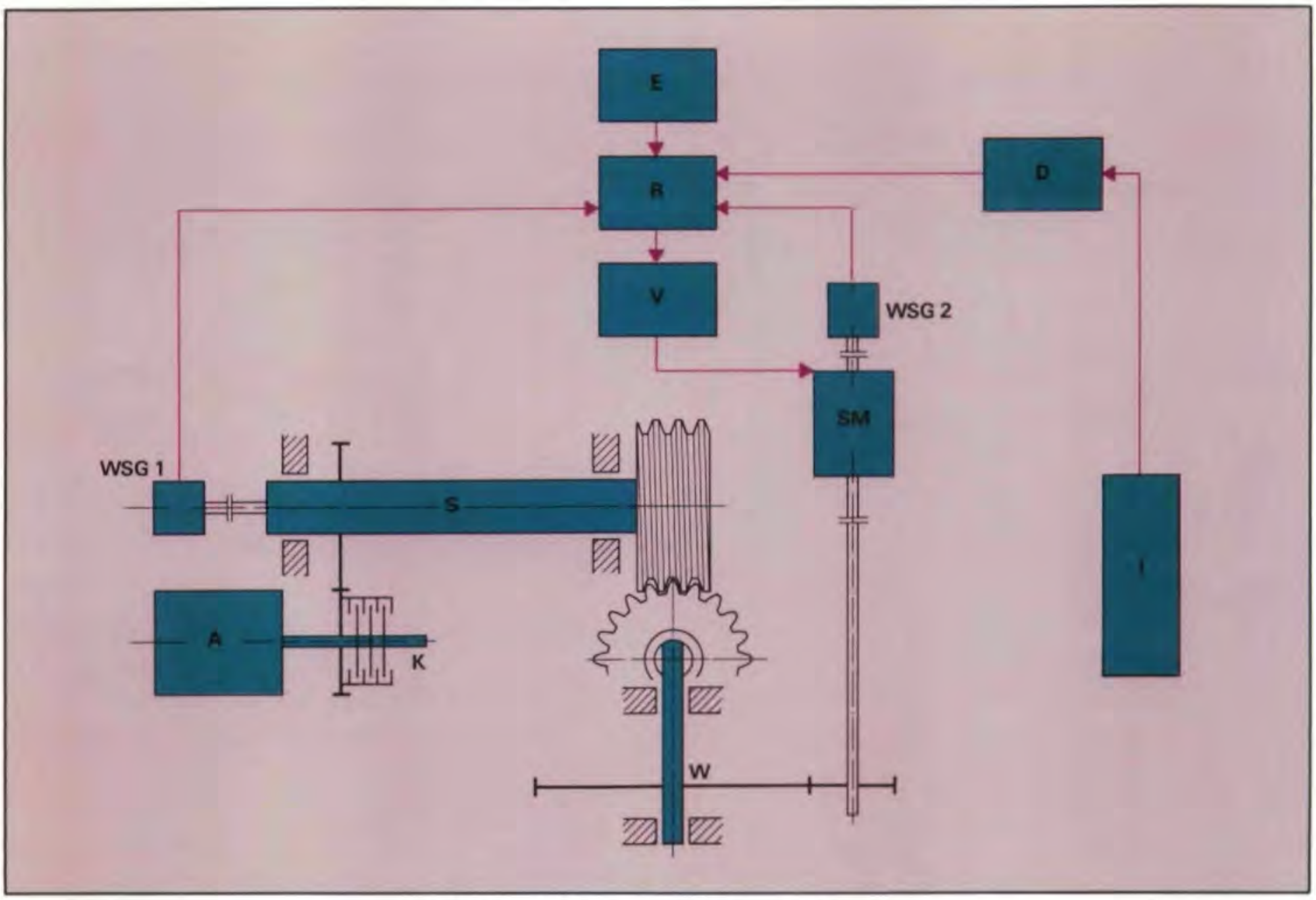


Fig. 17—Threaded-wheel gear grinder electronic drive train.

tioning elements. The indexing process of the machine, i.e. the indexing motion of the workpiece from tooth to tooth, takes place automatically through a change gear drive using a spur gear differential. (See Fig. 18).

The grinding wheel is dressed or shaped by means of dressing diamonds located in a dressing unit mounted on the grinding carriage. There is a single diamond dressing the O.D. of the conical wheel, and two side diamonds are required to dress the flanks of the grinding wheel. These side diamonds are adjusted to the required angle by spindles with graduated positioning scales, i.e. set to the required pressure angle. During the dressing process, the grinding wheel and its dressing units are moved radially in relation to the workpiece, the dressing unit being fed at a 45° angle. This operating procedure is necessary so the grinding wheel diameters are automatically compensated to remain in the same radial relationship to the workpiece. (See Fig. 19).

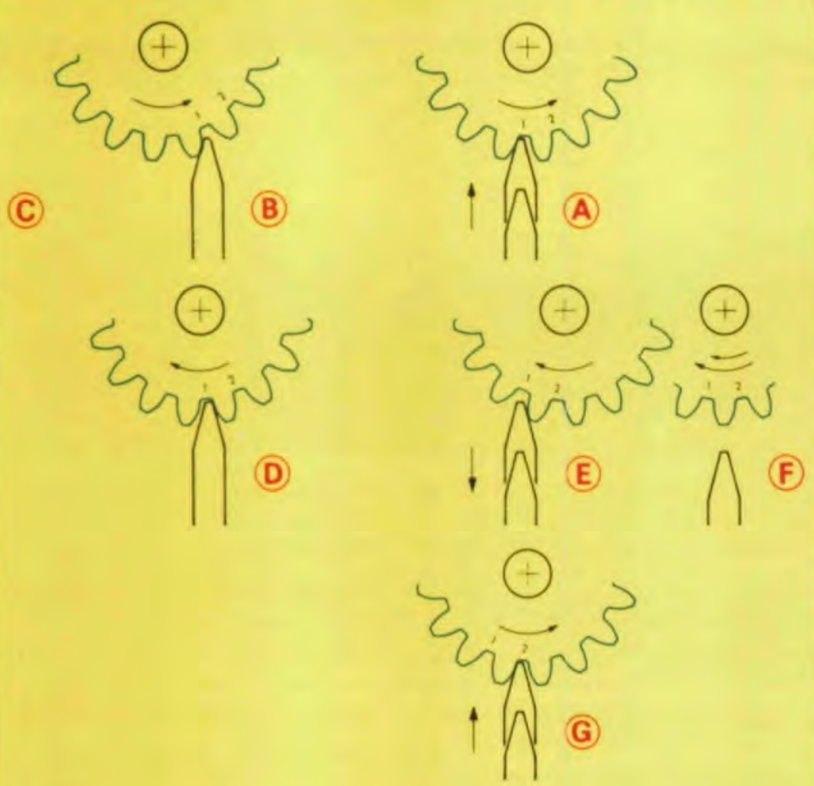
Fig. 20 illustrates how profile and longitudinal corrections are accomplished. For tip and root relief and the involute modifications, the grinding wheel is corrected by means of adjustable templates that alter the straight motion of the earlier mentioned side dressers. The rack tooth now contains the necessary tip and root relief corrections which are reproduced on the tooth profile during the grinding operation.

Longitudinal correction, crowning, is achieved during the stroke motion of the grinding slide with the tool slide following the adjustable template. The template device creates an addtional movement of the grinding wheels in a radial plane which results in a longitudinal correction. The amount of the correction depends on the form of the template and the magnification of the lever ratio. (See Fig. 20). Grinding wheel balancing, especially runout of the grinding wheel, is important in this grinding process. Some of the machines have built-in balancing devices.

As with any gear grinding machine, it is important that heat from the grinding process is not absorbed by the workpiece or the machine. Therefore, the hydraulics required for the machine drive and control is normally installed separately from the machine with a temperature control system. A considerable amount of heat is generated in this grinding process which normally dictates the need for a grinding oil coolant. Selection of the grinding oil is particularly important because the surface quality of the ground tooth is effected by the degree of purity of the oil. Both magnetic or continous band filter cleaning systems are needed to assure the coolant grinding oil remains clean. In most cases, an oil mist extractor is also required because of the unavoidable misting of the oil from the grinding operation.

CBN Grinding

Cubic Boron Nitride, also known under the trade name "Borazon" is the hardest material known to man, next to



(A) Grinding wheel is introduced into tooth space 1. Grinding of left hand flank.

(B) Grinding of left hand flank completed.

(C) Grinding action is changed over to right hand flank with compensation for flank clearance.

(D) Grinding of right hand flank begins.

(E) Grinding of right hand flank completed. Retraction of grinding wheel from tooth space 1. Indexing is initiated.

(F) Indexing whilst workslide is stationary.

(G) Reversal of feed motion, compensation for flank clearance, grinding wheel is introduced into tooth space 2. Grinding of left hand flank.

Fig. 18 – Generating process of a conical wheel gear grinder.

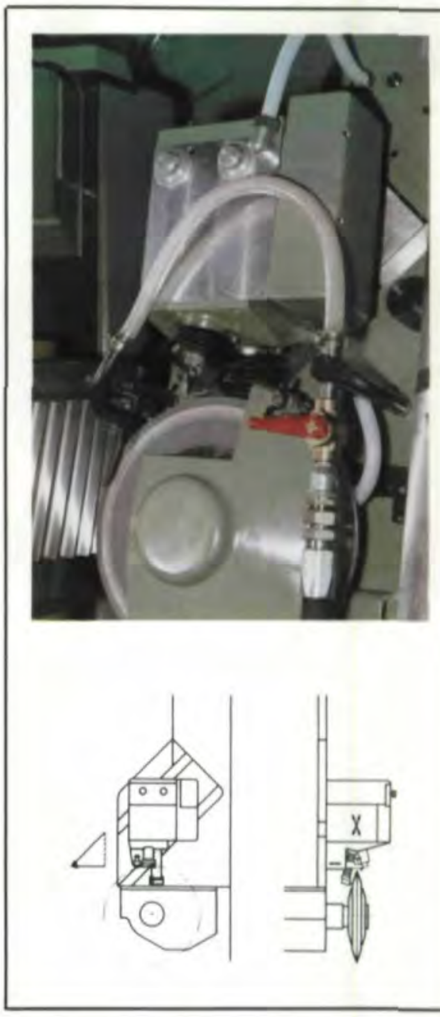


Fig. 19 – O.D. and side dressers for required pressure angle dressing.

a diamond. Its mechanical strength is more than double that of corundum. CBN also has the capacity to withstand thermic loads twice as high as that of a diamond. Furthermore, its cubic shape results in grains having a very pronounced cutting edge. All these features create an ideal condition for use as an abrasive in gear grinding. (See Fig. 21).

These attractive features can be looked at both positively and negatively. Dressing or forming the wheel can be very difficult because of the desirable abrasiveness of CBN. On the other hand, once the desired shape of the grinding wheel has been obtained, frequent dressing is not necessary, if not impossible. CBN grain size and bonding agent is as important as it is with conventional silicon carbide or aluminum oxide grinding wheels.

CBN grinding wheels can cost as much as 20-30 times more than conventional grinding wheels. This substantial difference in cost relates to the CBN raw material and the grinding wheel blank. Normally, a thin layer of CBN coating is applied to a steel wheel base. Of course, the wheel design relates to the grinding technique being used. This means that some grinding techniques can inherently benefit more than others from the use of CBN wheels. That benefit depends upon the increase in productivity in relation to the higher cost of the grinding wheel and the lot sizes.

CBN grinding has been effectively applied to the followed grinding techniques:

Form gear grinding, especially in the smaller diameter ranges, i.e. 12" and smaller, and finer pitches, i.e. 5 and up – a steel based wheel is formed to the required involute form and a thin layer of CBN is applied to the involute profile portion of the wheel. (See Fig. 22).

Saucer shaped wheel, as shown in Fig. 23 – CBN has been used quite extensively for the manufacture and sharpening of

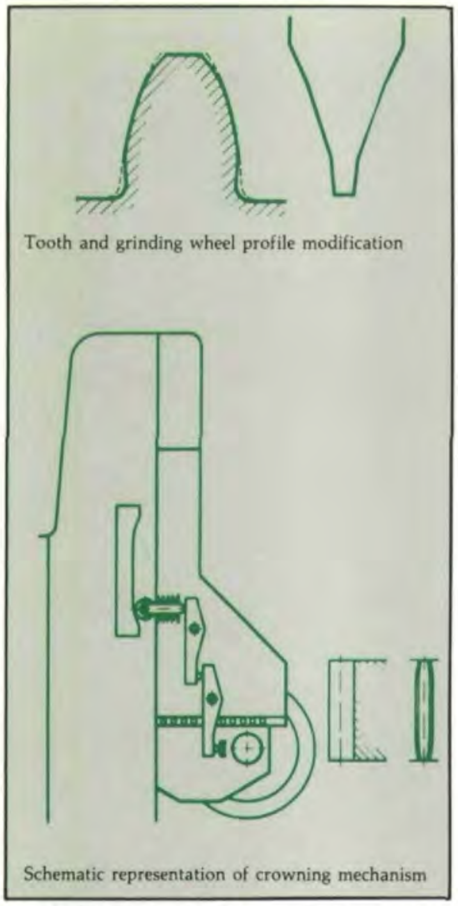


Fig. 20—Profile dressing for correction, longitudinal correction (crowning) by radial movement of grinding wheel head with a template.

rolling dies and for shaving cutters made of high speed steel. Recently, it has been applied to larger case hardened larger gears, i.e. 60" and coarser pitches, 2 DP.

Conical wheel gear grinders—CBN grinding is possible with this type of a machine and development work has been done in this area. The writer is not aware of any machine being used in production with CBN wheels.

Threaded-wheel gear grinders: Development work continues with these machines, as well as a variation of the threaded grinding wheel. However, rather than cylindrical, an hour glass designed wheel is used.

The Application of CNC (computer numerically controlled)

CNC has found its way into gear grinding machines only in the ast couple of years. One would associate CNC with gear grinding machines in several ways. First, as a controller used to set and monitor feeds and speeds. Second, in the case of a saucer type gear grinding

Fig. 21—Cubic boron nitride grain.

machine, it is used to program profile and longitudinal modifications or, with a form gear grinder, control the profile dressers.

Fig. 24 illustrates the history of tooth modifications, while Fig. 25 shows topological modification which can only be accomplished through the use of a CNC controller.

The third application has been the elimination of change gear drive trains, as in the case of the threaded-wheel type grinding machine. (See Fig. 17) In the case of form grinding machines, it has eliminated tooth indexing plates. In either case, set-up changes and tooling costs have been substantially reduced. Undoubtedly, CNC controlled machines and in-process inspection equipment will lead to the installation of gear grinding machines in flexible manufacturing cells or systems.

Grinding Time Estimate

Estimating, Production Control, Manufacturing and other departments, frequently require estimates of the time required for a specific gear grinding opera-

Fig. 22—A thin coating of CBN applied to a steel based wheel.

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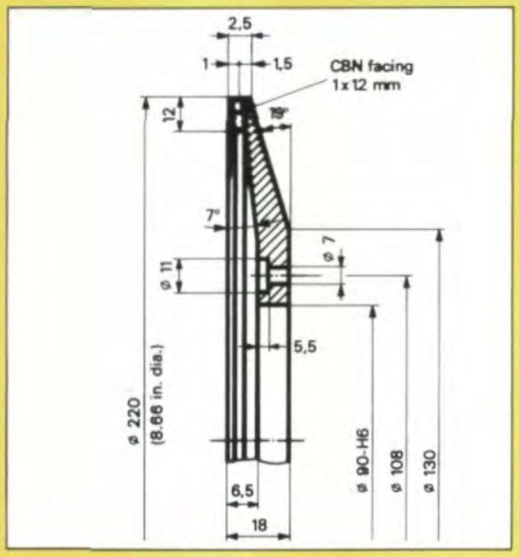

Fig. 23 – CBN saucer shaped wheel for shaving cutter sharpening.

Fig. 25 – NEW: Topological Modification variable modification"Z" of tooth profile across facewidth "X" as well as along profile "Y".

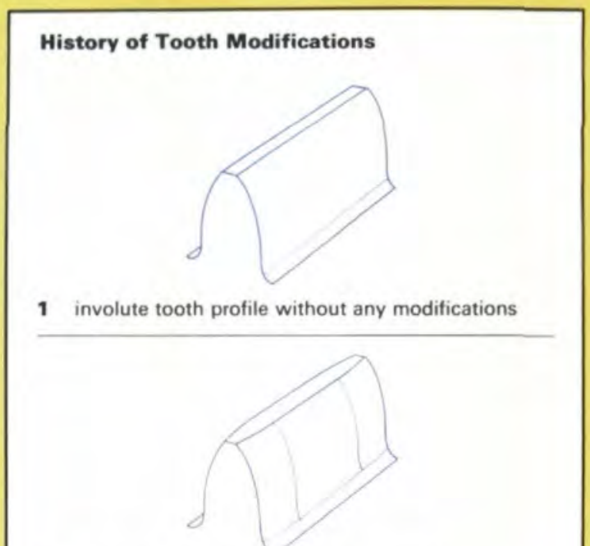

Fig. 24 – New topological modification variable modification "z" of tooth profile" across facewidth "x" as well as along profile "y".

tion. Many grinding machine manufacturers have published references that can assist a user in determining grinding times. Unfortunately, many of these references are old and no longer valid. Most manufacturers now have computer programs that will accurately calculate grinding times based on basic gear data input as well as grinding stock allowance per flank. However, production time estimates must be used with caution. Appreciable deviations from the estimated grinding times can occur because of gear blank quality, runout, grinding stock, grinding wheels used, tooling, loading fixtures, blank distortion due to the heat treating process, etc. Unfortunately, in quite a few cases, trial grinding is the only means possible to accurately determine grinding times.

A direct comparison of gear grinding cycle time with cycle time of other gear tooth finishing methods, such as finish cutting, shaving, honing and skiving, 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 hardended and ground precision gears may cost less to produce than comparable unground gears.