

CNC Gear Grinding Methods

Which technique is best for your application?

Dennis Richmond

Grinding in one form or another has been used for more than 50 years to correct distortions in gears caused by the high temperatures and quenching techniques associated with hardening. Grinding improves the lead, involute and spacing characteristics. This makes the gear capable of carrying the high loads and running at the high pitch line velocities required by today's most demanding applications. Gears that must meet or exceed the accuracy requirements specified by AGMA Quality 10-11 or DIN Class 6-7 must be ground or hard finished after heat treatment.

Few manufacturers have been successful at developing a machine that is without some compromise. As a result of the enormous challenge of trying to design one machine that fits all needs, the various manufacturers apparently have decided that specializing their products to target specific market niches is more efficient; therefore, over the past three decades, machine tool manufacturers have engineered their gear grinders specifically to be very efficient grinding certain types of parts. The remainder of this article is a survey of the various types of grinding processes available today.

Single Index Form Grinders

Although most of today's modern machine tools are quite good at grinding external spur and helical gears, very few manufacturers have been successful at incorporating the ability to handle internal gears without major compromises. Today, one of the only ways to efficiently grind internal gears is the single-index method with a dressable vitrified wheel or a bonded CBN-plated wheel. A plated wheel maintains its form well; however, its high purchase price and dedication to a single part result in a high perishable cost. A vitrified dressable wheel offers

greater flexibility and is much less expensive, but is more susceptible to process variables that can lead to gear geometry errors.

Single index form grinding is the easiest gear grinding process to understand. It is a "what you see is what you get" process. The form required on the workpiece is identical to the form or shape put into the grinding wheel. Gear teeth, or more accurately, gear space is ground one tooth at a time. The gear is indexed to correspond to the number of teeth on the workpiece. In machines under 400 mm capacity, the part to be ground is normally mounted between centers in a horizontal space. These machines have tables that reciprocate under a stationary wheel spindle. The wheel spindle is mounted to a vertical column supported by a feed device, which raises and lowers the wheel spindle to realize the center distance and facilitate wheel dressing (see Fig. 1).

Older machines use templates and a copy device to transfer the form onto a vitrified wheel. Newer machines use either steel body plated wheels that include the desired form or dressable wheels that are profiled through the machine control.

This process derives its appeal primarily from its simplicity and flexibility. Wheels can easily be made from aluminum oxide for either internal forms or external shapes (Fig. 2).

The operator has little to do with putting the form onto the wheel; therefore, the process demands fewer operator skills. For the past decade, machine builders have offered grinders that use superabrasives, such as cubic boron nitride (CBN), which are plated directly to a steel wheel body or made as a vitrified bonded wheel that can be dressed to the desired form. The user can expect to achieve profile tolerances of .0002" or less. Nickel is the bonding agent

that holds the CBN crystal to the steel wheel (Fig. 3).

The crystal is sifted to the desired size prior to the plating process so that a final lapping operation is not required. This allows the crystal to remain sharp and extends its useful life, permitting more parts to be ground between replating operations. To further optimize wheel life, roughing wheels and additional machine axes are used. A machine configured to mount more than one wheel can rough and finish the gear in the same pass, resulting in a higher productivity and extended wheel life. A high-volume/high-pressure coolant delivery system permits the removal of large amounts of stock while reducing or minimizing the risk of burning or cracking from excessive heat during grinding.

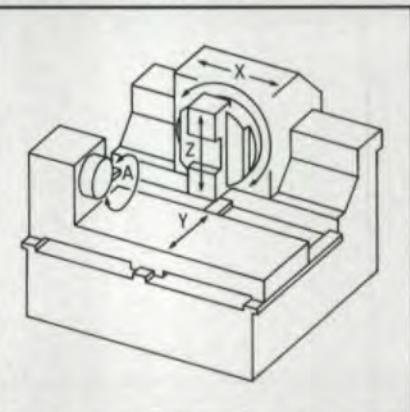


Fig. 1



Fig. 2

GEAR FUNDAMENTALS

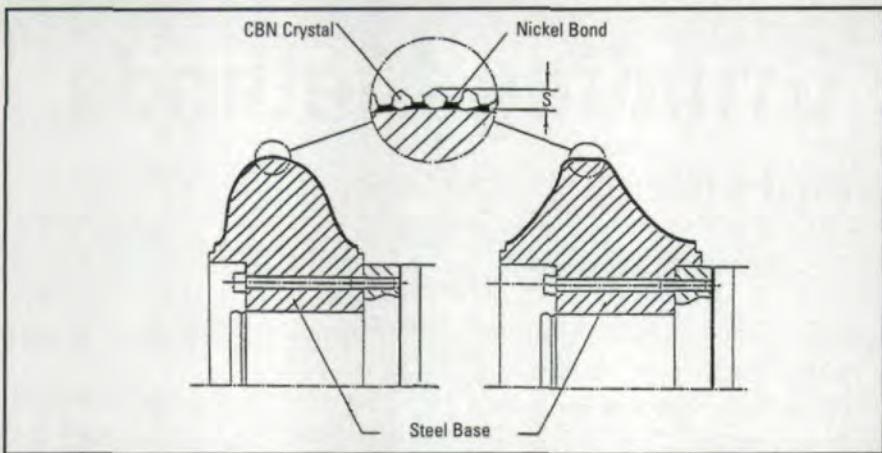


Fig. 3

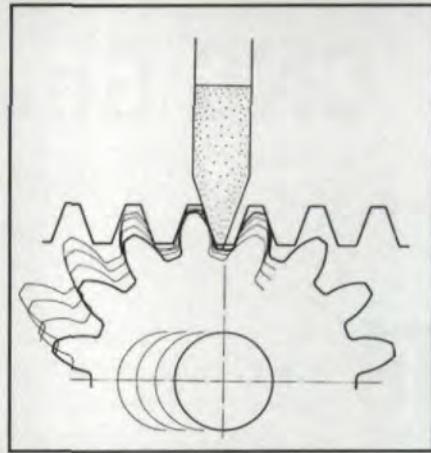


Fig. 4

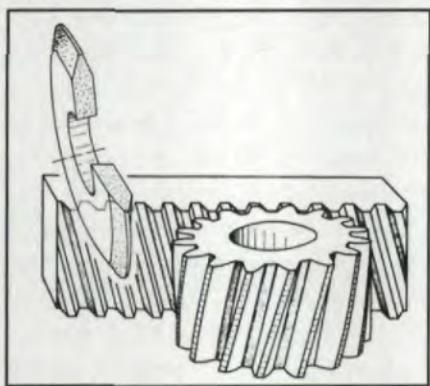


Fig. 5



Fig. 6

Modifications to the lead such as crowning, taper and end relief are simple inputs to the control. Cams and templates are a thing of the past for the newer breed of machine. In many cases, internal gears or forms can be ground on the same machine with the addition of a suitable grinding arm.

Forms such as vane pumps, male and female compressor rotors, gerotors, worm ball screw tracks, root-type rotary pistons, gear hobs and constant velocity joints—any precise form that is evenly indexable—can be ground on a single index form grinder.

These machines are well-suited for small to medium gears and non-gear parts. They are capable of achieving the accuracies required for applications such as aircraft and aerospace gears, machine tools, screw compressor rotors, ball screw tracks, gerotors, internal gears, vane pumps, worms, constant velocity joints and automobile transmissions.

Single Wheel Generating Grinders

Several different styles of gear grinding machines use the generating method. As with other types of machining, the style sometimes takes on the name of the original manufacturer who developed the method. The Höfler or Niles method is sometimes referred to as "a single tooth rack process" method. It can best be described as one in which a rack or single ribbed wheel strokes parallel to the axis of the workpiece while at the same time traversing tangentially to the workpiece (Fig. 4).

In addition to these two motions, the workpiece rotates to simulate the rolling action required to generate the profile (Fig. 5).

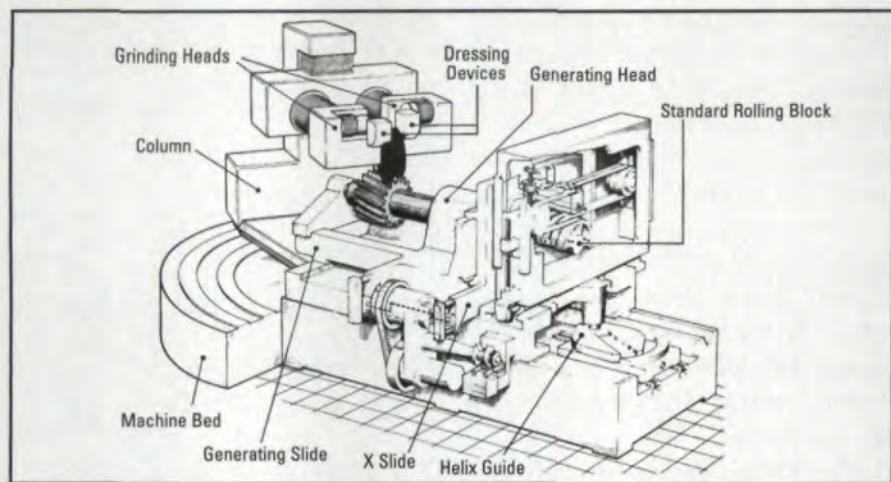


Fig. 7

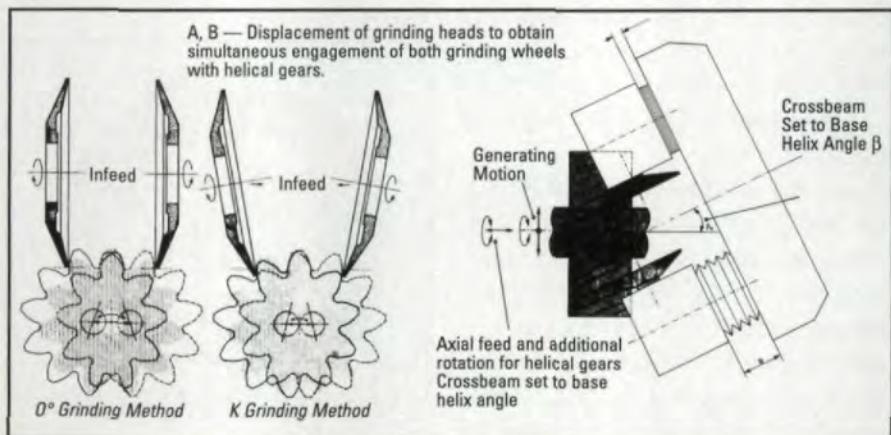


Fig. 8

The angle on the double-tapered wheel corresponds to the pressure angle of the gear. The generating path, or distance the wheel must travel, can be reduced by optimizing the wheel pressure angle, leading to shorter grinding times. Wheels can be made from either vitrified CBN or aluminum oxide. Automatic wheel balancing on the spindle has been incorporated into the newer machines, allowing them to achieve higher quality and better surface finish.

The latest grinders are capable of grinding both flanks in the same motion, resulting in a productivity advantage when double-flank grinding (Fig. 6).

During the grinding cycle infeed pass, the left and right flank of one tooth space is machined before the gear is indexed to the next tooth. The number of workpiece revolutions, typically two to four, will be determined by the grinding allowance on the flank of the gear.

Modifications to the lead and profile are easily realized by simple menu inputs to the control. Different modifications on left and right flanks are also possible when using the double-flank technique.

These machines are ideally suited for medium to large gears. The single wheel generating grinders are capable of achieving accuracies required for a variety of demanding applications such as large high speed marine transmissions, submarine drives, stationary turbines for power generation, machine tools, wind turbine generators, steel mills and large diesel engines.

Double Wheel Generating

This generating technique uses a pair of saucer-shaped wheels. Vertical and horizontal machines are built and dedicated to grinding gears and pinions respectively. The horizontal machines are equipped with devices to allow for lead modifications for pinions, while the vertical machines generally have no provisions for modifications, as they are primarily used for grinding large gears (Fig. 7).

Aluminum oxide wheels dressed with single point diamonds are the wheels of choice for this dry grinding process. The wheels on these machines act as a straight-sided rack that rolls past the gear during the grinding process. This motion

generates the involute profile. The axes of the wheels can be set parallel to each other or at a 10° angle (Fig. 8).

The workpiece is reciprocated or "rocked" in the axial direction to provide the infeed motion as two flanks of different teeth are ground in one pass. At the end of the pass, the entire gear is indexed using mechanical index plates having the exact number of notches or a multiple of the teeth in the gear. Prime numbered gears require dedicated index plates. The depth

of cut is determined by the infeed of the two grinding wheels toward each other.

When grinding spur gears, the axes of the grinding wheels are perpendicular to the axis of the gear. A simple motion to simulate the rolling of the gear on the rack represented by the wheels generates the involute. Steel bands attached to a stationary support on one end and a rolling block at the other produce the generating motion. The rolling block is generally the same diameter as the base circle of the

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AND . . .

GEAR FUNDAMENTALS

gear; however, the newer style machine incorporates the use of a variable diameter rolling block. When grinding a helical gear, an additional motion must be imparted to the workpiece to compensate for the helix angle. A helical guide mechanism is used to accomplish this motion.

The contact point between the wheels and the tooth flanks is confined to a very small area at any given time. This explains why the productivity of the process is described in hours per gear rather than gears per hour. "Time consuming" and "slow" also describe this very accurate process. If productivity is the shortcoming of this process, its abili-

ty to grind point by point lead and profile modifications is a strength.

The Maag is one of the only machines ever built to incorporate the point-by-point system for lead and involute modifications (Fig. 9). It has been said that the primary purpose for the design of this machine was to support the manufacture of Maag's own high-speed gearbox and transmission business and not necessarily as a commercial product. To summarize, the trade-off in productivity must be weighed against the advantage of flexibility.

These machines are best suited for small to medium lot size gears that require highly modified tooth forms. They are used in the following applications: gear rolling dies, shaving cutter sharpening, steel tooling, large marine transmissions, machine tools and high speed gearboxes.

Form Generating

Form generating is a unique process offered by a single manufacturer for high production grinding of helical automotive

transmission gears. This process (see Fig. 10) was first introduced to the market in the mid 1980s. It is ideal for large volume, highly automated manufacturing environments. Because the feed motion for stock removal is rotary and not axial, cycle times can generally be stated as one second per tooth, regardless of the gear face width. Simply put, the wheel and the workpiece do not traverse past one another during the grinding cycle.

The aluminum oxide wheel has a globoid shape when viewed from the end (Fig. 11). This shape is dressed into the wheel with a diamond-plated gear with the desired profile and lead characteristics required by the product gear. The wheel is positioned above the dressing gear so that its axis is perpendicular to the lead or helix angle of the dressing gear. It is then plunged into the dressing gear and allowed to rotate in two directions, resulting in a thinning of the thread on the wheel. The thinning of the wheel is necessary so that rotary

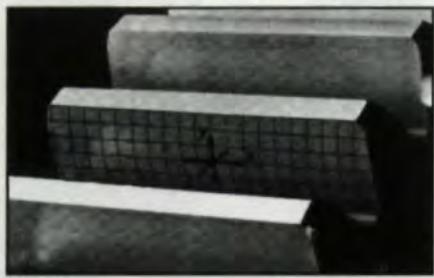


Fig. 9

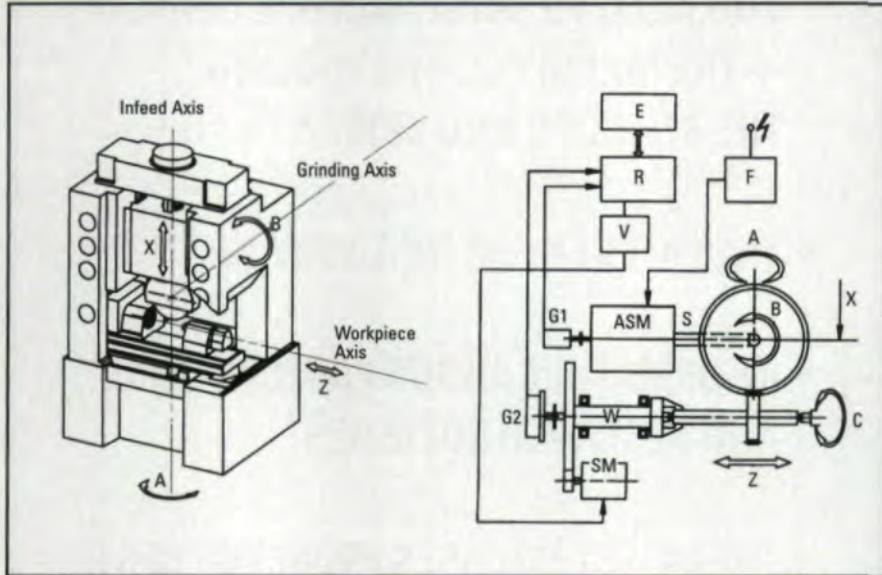


Fig. 10

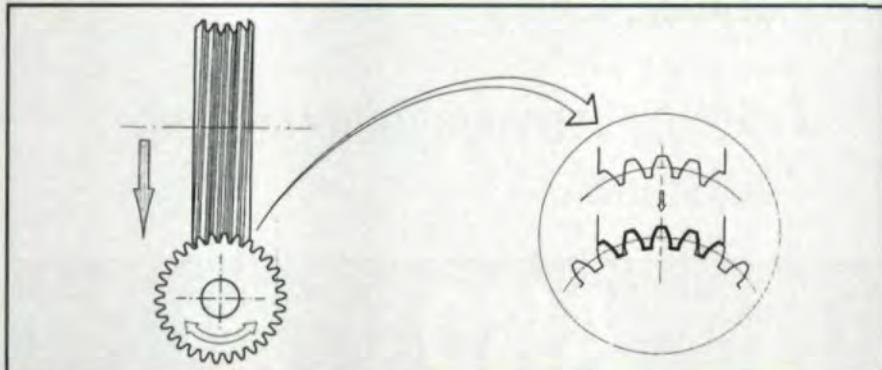


Fig. 11

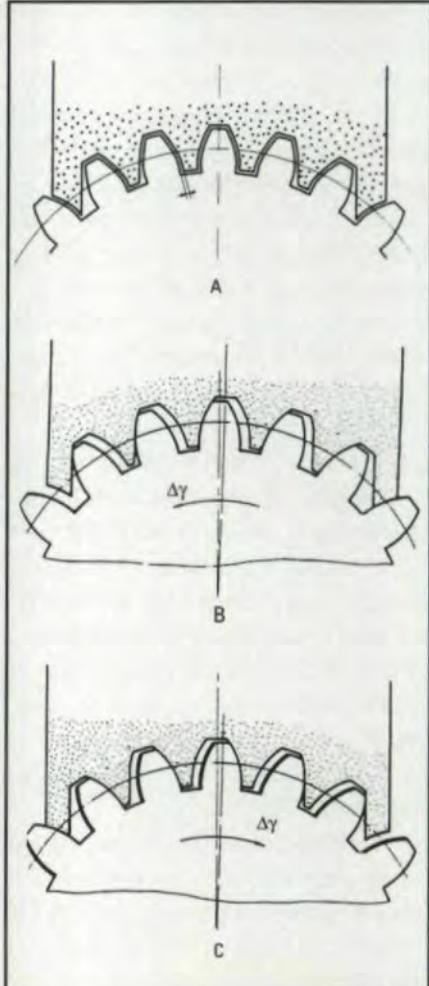


Fig. 12

feed can take place during the actual grinding. In this process, each side of the gear is ground separately.

The grinding sequence can be described as follows:

1. The workpiece is transferred into the machine with an auto loader, and a probe determines the optimum orientation considering the runout and stock conditions (Fig. 12a).

2. Rotary infeed begins, and the left flank is roughed and finished and allowed to spark out (Fig. 12b).

3. The workpiece is then electronically advanced so that the right flank comes into contact with the wheel (Fig. 12c).

4. Rotary feed begins, and the right flank is roughed, finished and allowed to spark out.

5. The workpiece is removed from the machine, and the next cycle can begin.

The profiling sequence can be described as follows (Fig. 13):

1. In the case of a shaft-type workpiece, the dressing gear is automatically loaded into the machine between centers.

2. The grinding wheel is plunged into the dressing gear.

3. Rotary feed is applied to the dressing gear, and the left and right flanks are sequentially dressed, allowing for a certain amount of dwell for both flanks.

4. The dressing gear is removed, and 15–30 gears are ground before the next dressing operation is necessary.

When grinding bore-type workpieces, the dressing gear is part of the work spindle and tooling and is mounted on the machine at all times. For shaft gears, the dressing gear is resident in the machine, but must be presented to the wheel in a separate sequence. This allows for slightly shorter dressing times.

This process is well suited to the manufacture of large-volume, automotive helical gears with annual quantities of approximately 200,000 gears per year of the same type.

Continuous Generating

This process is sometimes referred to as threaded wheel grinding and is by far the most wide-spread in use today. This technique has kinematics similar to those in hobbing (Fig. 14).

A threaded wheel similar to a gear hob without gashes is used as a cutting tool. The relationship of the workpiece and the wheel is described as follows:

$$\text{Wheel rpm} \times \text{no. of starts.} \\ \text{no. of teeth}$$

When grinding helical gears, the lead must be compensated for as it is in hobbing, through a mechanical or electronic differential. This differential imparts an additional rotary motion to the workpiece, allowing the wheel to traverse

along the lead or helix angle of the part. The similarities do not stop here. The tool or grinding wheel is sensitive to the same constraints that affect a hob. As long as the diametral pitch or pressure angles are not changed, the same wheel can be used to grind a variety of workpieces, regardless of the helix angle or number of teeth. This is a major difference from the single index technique, which is affected by both helix angle and varying the number of teeth.

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CNC Gear Grinding Techniques

Method	Manufacturer	Advantages	Disadvantages
Single Index Form Grinders	Kapp National Broach Okamoto Klingelnberg	<ul style="list-style-type: none"> • Accurate control of form. • Ability to grind finer pitches from the solid. • No wheel dressing required. • Wheel can be stripped and replated. • Ability to grind roots and tips. • Ability to integrate on-machine inspection. • High stock removal rates. • Ability to grind noninvolute shapes. • Grinds internal gears. 	<ul style="list-style-type: none"> • Dedicated steel wheel needed for each pitch, pressure angle and tooth number combination. • Form only correct once part is on size. • Steel wheels cannot be modified. • Expensive initial capital investment. • Potentially large inventory of wheels. • Horizontal workpiece axis.
Single Wheel Generating	Höfler; Niles	<ul style="list-style-type: none"> • Low perishable cost—wheels and diamond dressing tools. • Same wheel can be used for different pitches. • High achievable accuracy. • Fast setup. • Ability to integrate on-machine inspection equipment. • Coarse and fine pitches possible. • Vertical workpiece axis. • High stock removal per pass. • Machines available for large gears up to 157". 	<ul style="list-style-type: none"> • Fast process, but not considered high production. • High initial capital costs. • Large floor space required. • Special foundations needed for some applications. • Cannot grind roots or ODs.
Double Wheel Generating	Maag method	<ul style="list-style-type: none"> • Very accurate. • Long machine tool life. • Can be inspected prior to complete grinding of gear. • Dry process makes washing unnecessary for inspection. • Point-by-point grinding reduces the tendency to burn. • Ideal for low volume production. • Low tooling costs. 	<ul style="list-style-type: none"> • Cycle time quite long. • Expensive capital investment. • In gears with a large number of teeth a jump between the first and last tooth ground may be experienced.
Form Generating	Reishauer Type RZF	<ul style="list-style-type: none"> • Very short cycle times. • Low tooling costs. • Dedicated tooling—no development time needed. • Stable process with few variables. 	<ul style="list-style-type: none"> • Process suitable only for helical gears. • Workpiece diameters up to 200 mm. • Large capital investment.
Continuous Generating	Liebherr Okamoto Gleason Reishauer	<ul style="list-style-type: none"> • High productivity. • Good process stability. • Very low perishable costs. • Lead and profile modifications made easily. • Easily automated process. 	<ul style="list-style-type: none"> • Unable to grind close to shoulders. • No internal gear capability. • Large initial investment.

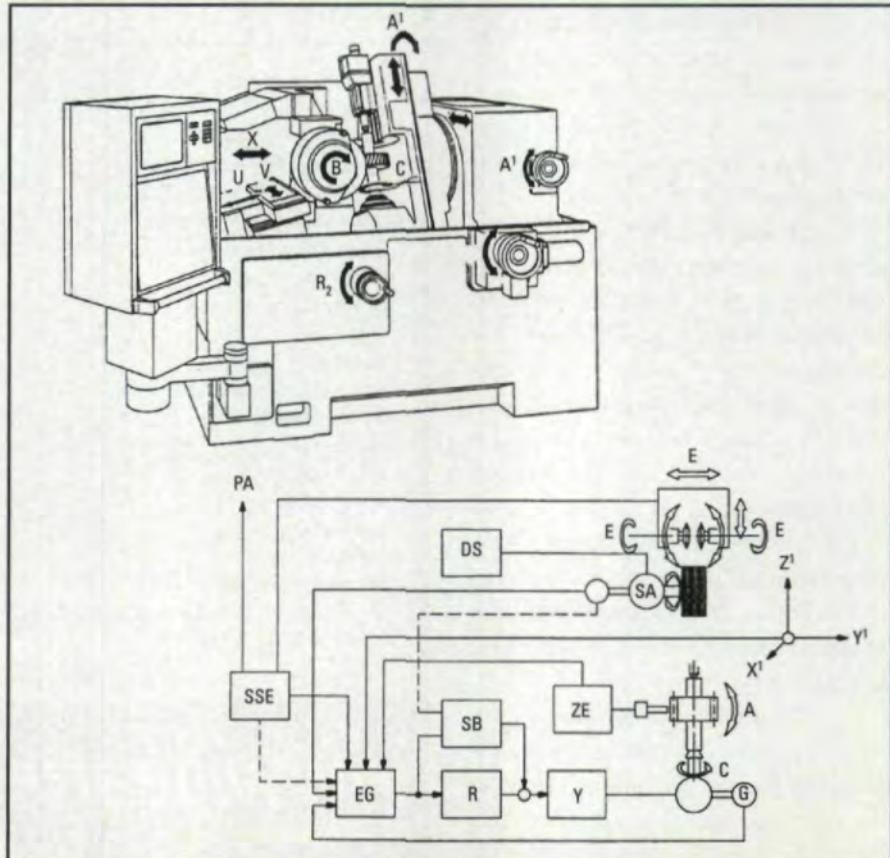
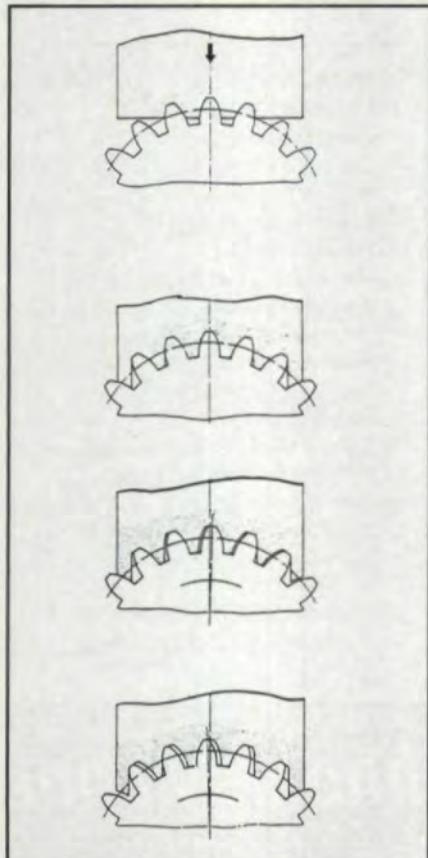


Fig. 13

GEAR FUNDAMENTALS

The continuous generation technique is aptly named. The threaded wheel has a rack or straight-sided shape with the side angle corresponding to the pressure angle of the gear. This rack is in continuous contact with the gear during the grinding operation while the involute generation is occurring (Fig. 15).

In order to be able to accomplish this process, the wheel, unlike the hob, must run at speeds of 45 m/s or 8,800 sfm. The indexing system must have mechanical and electronic integrity many times that of its roughing brother, the hobber. To think that one could simply modify a modern hobber and turn it into a grinder is, however, to misunderstand the kinematics required.

In the past, complicated mechanical systems provided the movements required for index and differential motions of the machines. Today commercially available electronic gearboxes are used for these machine motions. In addition to the relatively simple motions described here, the newest machines incorporate "shift grinding," which is akin to creep feed grinding in the cylindrical grinding world. The workpiece is shifted tangentially as it is fed past the grinding wheel (Fig. 16).

This tangential movement is constantly exposing the workpiece to a fresh cutting edge of the wheel, which results in fewer passes (typically one roughing and one finishing) and significantly reduces the cycle time when compared to a conventional continuous generating grinder using the multi-pass process (Fig. 17).

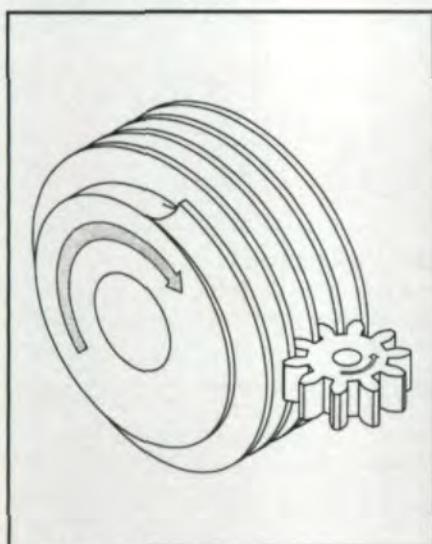


Fig. 15

Wheel technology and balancing maintenance have attempted to keep pace with machine tool advances. For most applications, the vitrified aluminum oxide wheel has been used with success. The newer breeds of machines have dictated that the wheels be "free cutting" to avoid burning. Wheels that have induced porosity and seeded gel achieve this goal. Wheels that change

in size because of the constant need for redressing must be balanced in two planes. This is automatically done when the machine senses an out-of-balance condition. One machine tool manufacturer has developed a machine around a steel-bodied, threaded wheel plated with Borazon, making the dressing and the balancing operations obsolete. This makes modifications to the

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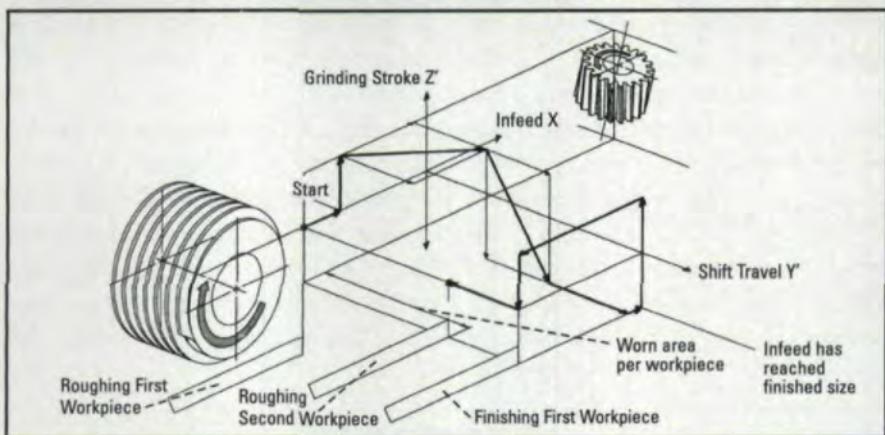


Fig. 16

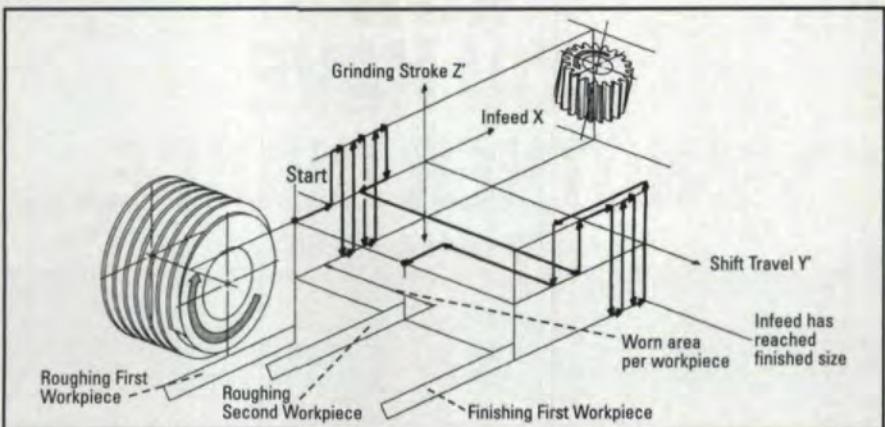


Fig. 17

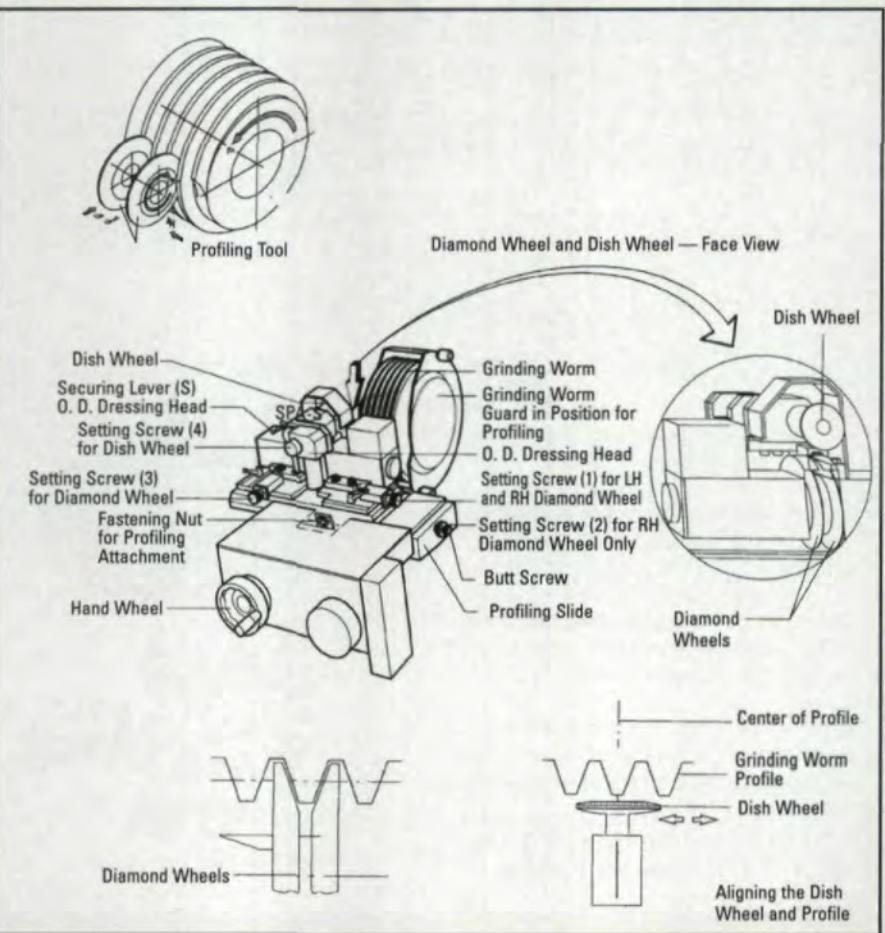


Fig. 18

wheel impossible without stripping the wheel of its coating and regrounding and replating the body. This compromise must be weighed against the productivity benefits.

Vitrified bonded wheels, regardless of their composition, must be dressed periodically to remain sharp and cut efficiently. This can be done in a number of ways, depending on the quantity of gears to be produced and the degree of flexibility required by the gear manufacturer (Fig. 18).

In the past it was difficult to automate these machines because the work spindle was in a different position after every cycle due to the part shifting across the face of the wheel. Microprocessors and modern machine controls makes this possible today.

These machines are well-suited for original equipment manufacturers as well as job shops. Productivity and flexibility standards are set today by the machines capable of using the continuous generating process. These machines can be found in the following industries: aircraft and aerospace, machine tools, printing press manufacturers, automotive truck and tractor, marine transmissions, wind turbine generators and high-speed industrial gearboxes. ◊

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