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THE JOURNAL OF GEAR MANUFACTURING

JANUARY / FEBRUARY 1993

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CONTENTS

JANUARY/FEBRUARY 1993

FEATURES

SPECIAL FEATURES

DEPARTMENTS

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GEAR TECHNOLOGY

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A Hopeful New Year

It always strikes me as something of an irony that the brightest holidays of the year fall in the deepest part of the darkest season. They come when the days are the shortest, the clouds the thickest, the weather (at least in Chicago), the worst. And yet it is at precisely this time when we celebrate the happier human emotions of family, love, and charity and somewhat arbitrarily declare a "new" year.

We indulge in the symbolically optimistic exercises of opening our new calendars and making our New Year's resolutions. Underlying all the hype and hoopla of the holidays is the implicit assumption that we have a clean slate, a fresh start, another chance. Next year, we think, however briefly, will be better.

PUBLISHER'S PAGE

And why not? Maybe it will be.

This year, on a national scale, the notion of the clean slate is even stronger. Soon there will be a new president in Washington, dozens of new congresspeople, a lot of new faces. In November nearly two-thirds of the voters in America said quite clearly that it was time for something new. They may not have been sure what that something new was, but they were sure they wanted it - and they got it. Reason enough to be hopeful, at least in the short term.

The causes for optimism are not entirely artificial either. Slowly, slowly the economy is getting better. Exports remain strong. There are some signs that unemployment is declining. Psychologically, perhaps because there will be new faces in Washington, perhaps because of the holiday season, perhaps because people are just tired of feeling gloomy, consumer confidence seems a bit stronger.

In our own industry, the overall export situation is good news, and cutting tool sales here in America are very strong. The sense that the recession may be winding down breeds optimism for us too. We are by no means out of the woods yet, but a feeling exists in the gear industry that finding the way may be possible after all.

It's a new year kind of feeling. We have another chance to do it right.

At *Gear Technology*, we are no less susceptible to this ingrained optimism than anyone else. We have great plans for the new year too. For the first time, in 1993 we are assigning special themes to certain issues. For example, this January/February issue deals with matters relating to cutting tools. Other focuses for the year include heat treating and the computer in design and manufacturing, as well as our traditional Gear Expo pre-show and show issues. Our final new venture for the year will be a Buyer's Guide Supplement. These plans are the fulfillment of our on-going New Year's resolution to make *Gear Technology* even better and more useful to you, our readers and advertisers.

Actually, we could use your help with keeping this important resolution. In this issue, you will find a Reader Survey similar to the one we ran in the last issue. Please take a few minutes to fill it out and return it to us either by mail or fax. The answers you give will help us in planning for the coming year.

At the same time, we'd like to say a special thanks to those of you who returned the survey last month. We loved the compliments, and we welcome your suggestions for improvement.

PUBLISHER'S PAGE

Enjoy this year & every year after...

One of the things that pleased us most about the survey was the number of you who said that you used *Gear Technology* as a resource when purchasing new equipment. That's good news both for us and our advertisers. It's important for them - and us - to know that their ad dollars are well-spent in our pages. When you contact them to purchase products, be sure to let them know you saw their ad in *Gear Technology* and that you appreciate their support of the magazine. They are the ones who make it possible for us to bring you the information you tell us is so valuable.

Based on the results of the survey, we do have a lot to be optimistic about, even though as I write this editorial, the days are still growing shorter, and the sun has not shined in 20 days. Still, the new year is on the way. Its arrival is always a sign of hope, which Ambrose Bierce described as desire and expectation rolled into one. And perhaps it is appropriate that the new year does arrive just at the time when things seem the darkest. After all, the days will soon begin to get longer; the weather will slowly warm again; we do get a clean calendar and a clean slate; and we all desire and expect this year will be better than last. That desire, expectation, and hope is our wish for you at the beginning of 1993.

Michael Goldstein,
Publisher/Editor-in-Chief

ADVERTISER'S INDEX

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High Technology Hobs	❑	❑	❑	❑	❑
Line of Action: Concepts & Calculations	❑	❑	❑	❑	❑
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THANKS FOR YOUR HELP.

Application Analysis

William. A. Bradley
Don McVittie

Question: I have heard the terms "safety factor," "service factor," and "application factor" used in discussing gear design. What are these factors and how do they differ from one another? Why are they important?

Bill Bradley & Don McVittie reply:

In any gear design, it is critical to make allowances for unknown variables in materials, machining tolerances, loading, etc. Various terms (factor of safety, service factor, and application factor) are used in the gear industry to describe this important concept. These terms are among the many formula variables (influence factors) which are used for determining the calculated load capacity of gears produced for various designs, manufacturing methods, and uses. Many of these factors have been empirically developed from accumulated experience. Therefore, it is critical that they be used in the manner originally intended. The influence factors are normally used as modifiers to either a calculated stress from part configuration and applied load, or to an allowable stress number based on material properties. The gear designer can then compare the modified calculated stress to the modified allowable stress number for a specific design, to determine suitability for a given application.

The gear designer, manufacturer, buyer, and user must all have a clear understanding of the meaning and implications of these terms when comparing gear capacity using different standards. The following definitions are given to explain the difference between these terms as applied to gearing.

Factor of Safety

The term "factor of safety" or "safety factor" has historically been used by designers and engineers to describe a general derating factor for limiting the design stress in proportion to the material strength. A factor of safety accounts for uncertainties in design analysis accuracy, material characteristics, and manufacturing quality.

When using a factor of safety, one must also consider the risk to human safety and the economic consequences of failure or machine "down-time." The greater the uncertainties or consequences of these considerations, the higher the factor of safety should be. As these items become known with more certainty, the value of the influence factors can be more accurately determined. For example, an automobile transmission which is subjected to full-size, full-load prototype testing and rigorous quality control of dimensions, materials, and processes during manufacture, could have a more precise factor of safety than a

SHOP FLOOR

Address your gearing questions to our panel of experts. Write to them care of Shop Floor, Gear Technology, P. O. Box 1426, Elk Grove Village, IL 60009, or call our editorial staff at (708) 437-6604.

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hoist made in small quantities under normal commercial practices.

Gear testing, field experience, and material analysis are among the ways one can obtain more knowledge for design. As your design practices become more comprehensive, some influence factors can be removed from the unknown area of "factor of safety" and introduced as predictable portions of the design method. The AGMA material reliability factor, C_R, is an example.

Factor of safety has also been used to account for uncertainties in "applied loading" or unknown overloads. In gear design, however, service factors or application factors have been used to cover this uncertainty.

Application Factor

An application factor is used to make allowance for any externally applied overloads (loads in excess of the nominal transmitted load). Application factors are established only with considerable field experience with a specific design. In determining the application factor, consider the fact that systems develop momentary peak torques appreciably greater than those determined by the nominal ratings of the prime mover or driven equipment. Many possible sources of overloads, such as system vibrations, acceleration torques, over-speeds, variations in system operation, split-path load sharing among multiple prime movers, and changes in process load conditions, also must be considered.

Service Factor

A service factor is traditionally applied as a multiplier of the nominal application load to determine catalog selections of pre-designed gear units. In AGMA gear rating, the service factor has been used to include the combined effects of the required life cycles, material reliability, and application factors in an empirically determined single influence factor. The specific mathematical contribution of each of these items has not been satisfactorily established. In addition, the term "service factor" has been used when including human safety or economic risk, which has developed confusion between the terms factor of safety, application factor, and service factor.

To avoid confusion, it is recommended that the application factor be used as defined - for external variability in applied loading. A factor of safety should be applied where there is human risk, economic risk, or remaining uncertainties due to design, material, or manufacturing quality variation.

When an application factor is used in place of a service factor and a long service life is desired, give consideration to the allowable stress levels. In the absence of specific knowledge, a life factor of 0.85 (multiplier for service capacity) for pitting resistance and 0.80 for bending strength should be considered.

Apply a service factor ONLY to a gear assembly, typically to a catalog drive rating, and then only in the absence of more specific application load data. Furthermore a service factor should be used only with the calculation method used at the time this experience factor was developed. It should not be used with other gear-calculation methods, unless sufficient knowledge and experience exists to make a satisfactory conversion.

Other Considerations

Important considerations for your design analysis of gear-drive systems which are related to factor of safety, application factor, and service factor selection include:

Test and field experience. The proper selection of application factors and factors of safety for power transmission systems often are not given enough attention. Without complete testing and field experience on each specific design, the application of gears has many unknowns. Therefore, conservative selection of all gear capacity calculation influence factors is recommended unless operating experience of an identical design is known.

Thermal Rating. The thermal power rating of a gear system is defined as the power that the unit will transmit continuously without exceeding established temperature limits. This important consideration is necessary to maintain proper lubrication. Excessive temperatures are detrimental to the lubrication of gear teeth and to elastomeric seals, such that the system may not be able to transmit the rated power without excessive wear and failure.

Non-Gear Components. Every component of a gear unit must allow for the proper transmission of power, considering both internal and any external loading. Components, such as housing supports, shafting, keys, splines, bearings, and fasteners (bolts, nuts, etc.), must be designed and manufactured to maintain the gears in proper position as well as transmit the required power.

Gear Quality. The term "quality" can have a number of meanings. In reference to gear manufacture, it is generally used to classify the tolerances applied to the gear tooth geom-

SHOP FLOOR

▼

When using a safety factor, also consider risk to human saftey and the economic consequences of failure or machine "down-time".

▲

etry and the quality of gear materials and heat treatment. Unless the appropriate gear quality level is used to calculate the power rating of a gear system and that quality level is, in fact, duplicated or exceeded in manufacturing, the unit produced may not have the desired life.

Variation of Manufacture. In addition to gears, the metallurgical quality of all stressed parts and the geometrical accuracy of all other components of the drive must exceed the values assumed in the design calculations and test units.

Some standards do not mention these topics or do not cover them thoroughly. It is important to know that factors contained within AGMA standards, such as service factor, should not be abstracted and applied to other standard methods of calculating gear capacity. Mixing factors from different standards can result in an inadequate design.

Summary

When designing and rating gearing, there is a need to use factors of safety, service factors, and application factors. There must be a thorough knowledge of these terms for proper design. As the variables in design, materials, manufacturing, and loading become better controlled, the factor of safety can be reduced; the application factors will represent actual loading or be replaced by a load spectrum analysis, such as Miner's Rule; and service factors may be replaced with factors of safety, application factors, life factors, and reliability factors.

One must clearly understand that the gear design or analysis must account for these uncertainties, based on experience. That is the primary responsibility of the gear engineer. ■

Editor's Note: *This information is based on a presentation made at the International Federation for the Theory of Machines and Mechanisms gear meeting in Hiroshima, Japan, in November, 1991. It also appeared in the AGMA News Digest, Nov/Dec, 1992. Reprinted with permission.*

Go Back To Page 10.

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Your opinions matter to us.

New Cutting Tool Developments in Gear Shaping Technology

J. C. Crockett
Consultant, International Sales and Engineering, Otterton, Devon, England

The advent of CNC technology as applied to gear shaping machines has, in the last 10 years, led to an astonishing improvement in both productivity and quality. As is usual when developments such as this take place, the technology of the machine tool suddenly jumps ahead of that of the cutting tool, and the machine is then capable of producing faster than the cutting tool can withstand.

The cutting tool technology was improved considerably some years ago with the advent of titanium nitride (TiN) coatings for gear cutting tools, and tool life increased dramatically, together with the ability of the tool to be used for cutting with increased speeds and feeds. The TiN coating technique also meant that tool life could be improved irrespective of whether the machine tool on which it was used was old or new, although the best results are obviously obtained when operating under optimum conditions with up-to-date machines.

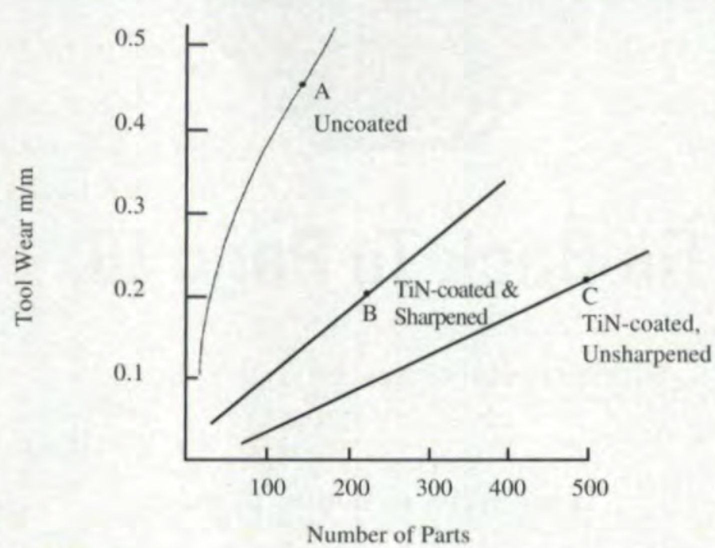


Fig. 1

The tool life improvement of a coated tool relative to an uncoated one obviously varies with the application, but values up to five to eight times the life, with only half the tool wear per sharpening, have been experienced in many cases. What also became quickly apparent was that the very best results were obtained when the cutter was new and its cutting face was still TiN-coated. Once the cutter has been used and sharpened, the coating no longer exists on the front face of the tool, and only the coating on the flanks remains. This reduces the 5:1 advantage to the order of 2 or 3:1.

Fig.1 shows the same part produced at the same feed and speed by cutters treated in three different ways. From this example we see that the coated tools produced between two to four times the number of parts for half the amount of tool wear. The tool wear can take place on both the front cutting face and the side flanks of the tool, wear on the latter being caused primarily by interference on the relief or return stroke of the cutter and by trapping of the chips between the flanks of the tool and the gear. The wear on the front face is usually a form of cratering caused by the high loading combined with the high temperature of the chips produced.

This is, of course, an oversimplification, but draws attention to the two types of tool wear which occur. The high lubricity and surface hardness of the TiN coating handles both these factors very well, but once the coating is removed from the front face of the cutter, the cratering tendency returns more quickly.

Wafer Cutters

The next step in the improvements in cutting tool technology took place a few years later with the development of what is now called the wafer cutter. This technology has lead to a further improvement in tool life for suitable applications.

Fig. 2 shows a typical wafer cutter assembly consisting of the wafer cutter blade itself (typically 0.025" to 0.050" thick), together with the clamp and backup ring. In the case shown, the entire assembly is mounted on an adapter as used in quick-change tooling.

The wafer is centrally mounted by means of the clamping ring and is fixed by several screws to the support ring. This ring is produced with teeth which give maximum support to the teeth of the wafer blade. The rake angle of the cutter face is formed by deflecting the blade back against the support ring, the face of which is formed with the required angle. A keyway is provided so that as each wafer blade is replaced, a tooth can be placed in the same alignment. Of course, it also resists the torque applied by the heavy cutting.

The wafer is in effect a disposable blade, which is used until the wear factor is unacceptable or the part quality deteriorates outside the acceptable limits, and then the blade is thrown away; i.e., it is not resharpened.

One of the big advantages of this technique is that the wafer is TiN-coated all over and, therefore, the optimum face is always presented to the workpiece. From the user's point of view, the most important factor is the blade quality, which is entirely the responsibility of the cutting tool supplier. It can be optimized in design and produced to the tool supplier's quality standards without the issue of loss of accuracy through poor sharpening arising. Sharpening inaccuracies are now eliminated, together with the sharpening costs.

On conventional gear shaper cutters, the cutter reduces in diameter after it is sharpened and, therefore, the machine tool has to be reset, since now it is necessary to adjust the center distance between the cutter and the workpiece and the position of the cutting edge relative to the gear face. (See Fig. 3.) The setup time on any machine is non-productive, and anything that can be done to reduce this element is worth considering. Obviously CNC facilities reduce setup time enormously, but the wafer technique can be applied to any shaping machine and show savings even if CNC is not available.

Wafer cutters are manufactured to a consistent size, therefore they can be replaced when

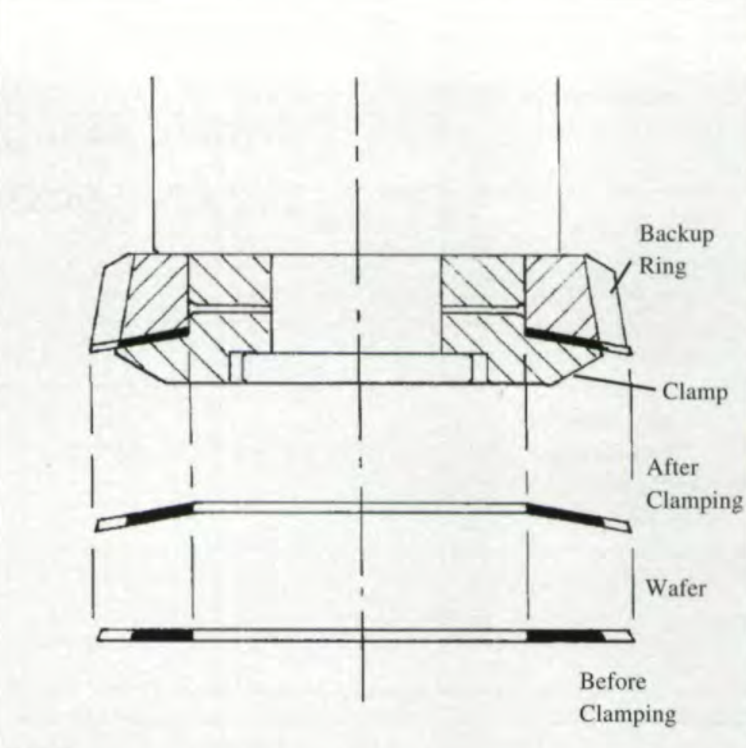


Fig. 2

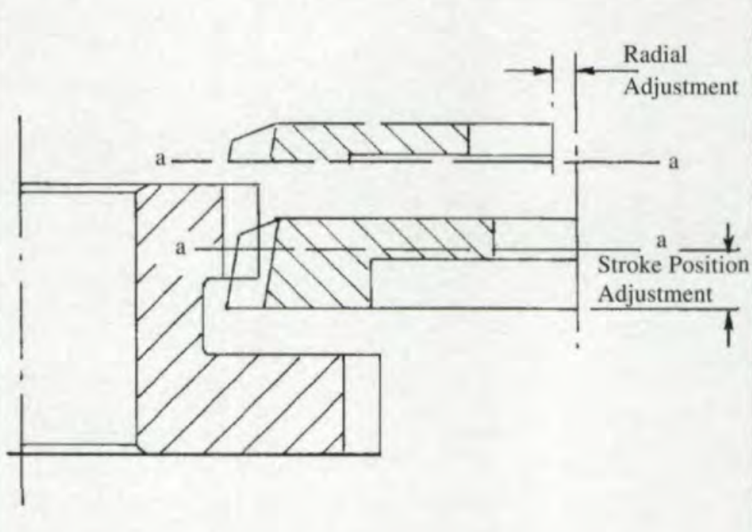


Fig. 3

J.C. Crockett
has been a gear consultant to major gear machine and cutting tool companies worldwide. He is the author of the book, Gear Cutting Practice, and numerous technical papers. He is currently a consultant to Lorenz in Germany.

Table I		
Gear Material: 20 Mo Cr 4 E	Type of Cutter	
32 Teeth, 10 Face Width	Standard	Wafer
Module	2.116	2.116
Pressure Angle	30°	30°
Number of teeth	66	66
Cutter Material TiN-Coated	(PM) S6-5-3-8	S6-5-2
N° of Parts Produced		
Before Sharpening	1400	7000
After Sharpening	700	

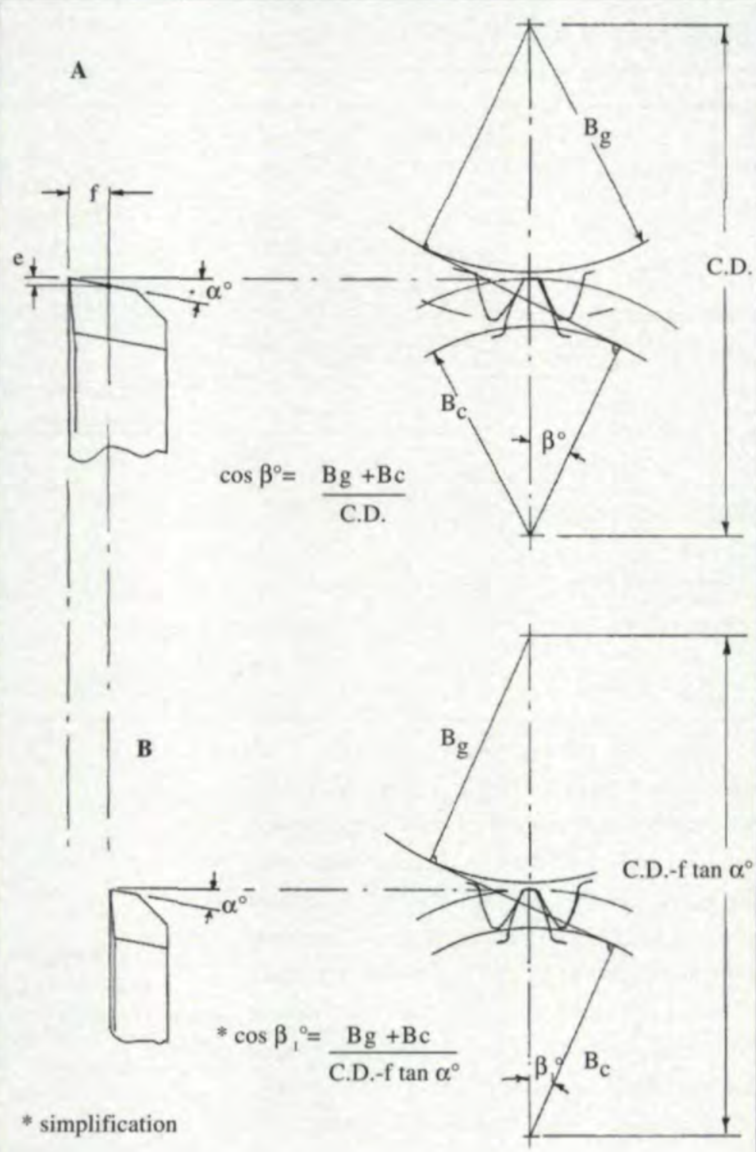


Fig. 4

worn out without changing the machine settings. A saving is thus experienced in both the time taken to change the tool and reset the machine and the time needed to qualify the part. The part size has to be requalified after a change in machine size, and this can be costly if inspection is a bottleneck. When using the wafer concept, no change in machine setting is necessary.

A typical example of the improvement in the tool life of wafer tools compared to standard type cutters is shown in Table I, where we see that when the standard coated tool was new, it achieved 1,400 parts, while after sharpening it only achieved 700 parts: whereas the wafer produced 7,000 parts, which in this instance gives an advantage of some five to 10:1.

One of the other advantages of the wafer cutter not readily obvious is the fact that it can be designed to give the optimum rake angles and cutting conditions. To understand this, it is necessary to consider the basic geometry of a standard type gear shaper cutter in both its new and worn out condition. (See Fig. 4.)

We see that when the front face of the cutter is sharpened by *f*, the outside diameter reduces by $2 f \tan \alpha$ for each sharpening. The cutter profile is generated from a base circle, which remains constant through the life of the cutter and ensures that the cutter will always produce a true involute profile on the gear throughout the cutter's life. (See Fig. 4a.)

However, other factors must also be considered. When the cutter reduces on diameter, it has to be moved in to a closer center distance with the gear being produced in order to maintain the correct tooth thickness. (Note: The formula $2 f \tan \alpha$ given is a simplification merely to illustrate the point. To find the exact center distance, it is necessary to calculate the tight meshing centers as shown in Fig 4b.) The effect of this change in center distance is to change the meshing pressure angle between the cutter and the gear, and for many applications, this is of no importance, since the cutter still produces the correct profile.

However, there are times when the tool designer requires the flexibility to design the cutter to mesh with the gear at a higher or lower pressure angle. For example, we know that the weakest point of the cutter tooth is the tip, which tends to crater under load, and we also know that the condition can be improved by providing a full tip radius on the tool. The larger the tip radius, the better for the tool life. This tip radius can be increased by designing the tool with a lower meshing pressure angle. (See Fig. 5a.) The same thing can be done with a conventional cutter, but since the meshing pressure angle changes as the cutter is sharpened back, the tip radius is not constant throughout its life and does not fully blend with the tooth flanks all through its life.

When we consider gears which have to be shaved after generating, it is essential that the protuberance on the tip of the cutter be provided in such a way that it undercuts the gear flank at the point where the tip of the shaving tool engages the gear flank. The tool designer has to choose a meshing pressure angle that will meet this condition both when the cutter is new and when worn out. This often necessitates a compromise. (See Fig. 5b.)

The same applies to tools which have to chamfer the tips of the gear in addition to providing the undercut for shaving, since the optimum meshing pressure angle for the chamfer position will not be the same as for the undercut position. This varies again as the tool changes in diameter and, therefore, further compromises have to be made. If the tool does not change in diameter, the position is eased, and the tool designer has more choice of the optimum conditions.

One further point concerns chip flow conditions. When the chip is being generated, the flow path for the chips is continually changing, and a position can be reached where the chip rolls off the leading cutting edge, but gets trapped on the trailing edge. This is where major damage to the tool flank can occur.

Fig. 6 shows successive cutter teeth (at high feed rate for clarity), and we see that there is an opening on the trailing flank where the chip cannot flow easily. The chips flow at high speed and under high pressure, and when extruding through small openings, they can become trapped and tend to weld and smear along the cutter tooth flanks.

To obtain the largest openings the meshing pressure angle must be increased, therefore, the tool designer is faced with a number of variables, and the position is eased if the meshing conditions of the cutter do not change throughout its life. The wafer cutter meets this

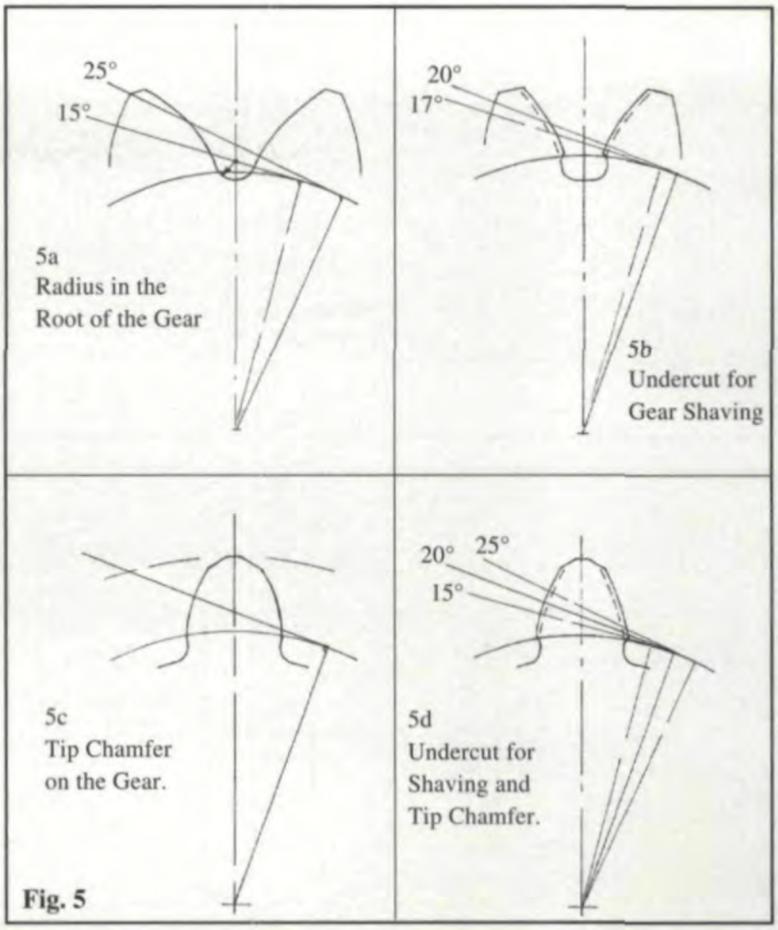


Fig. 5

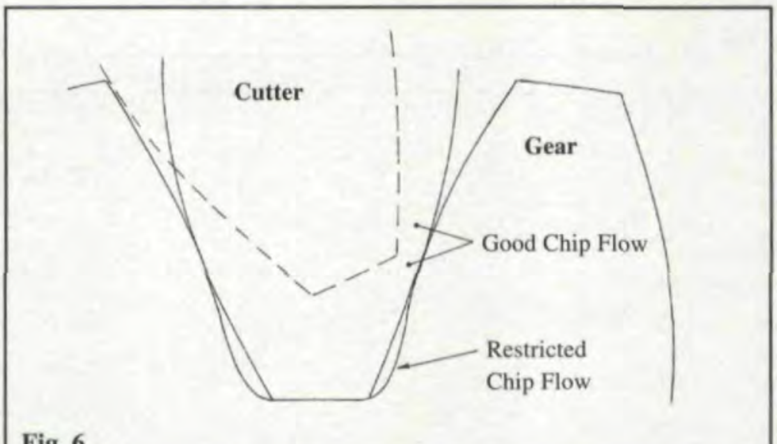


Fig. 6

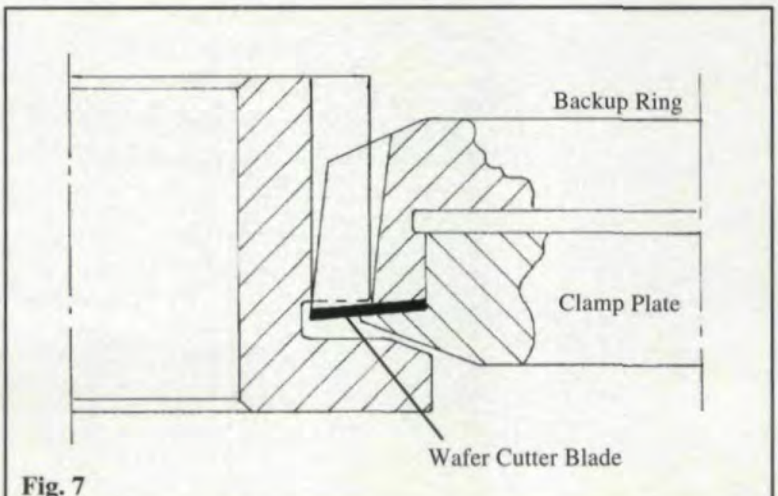


Fig. 7

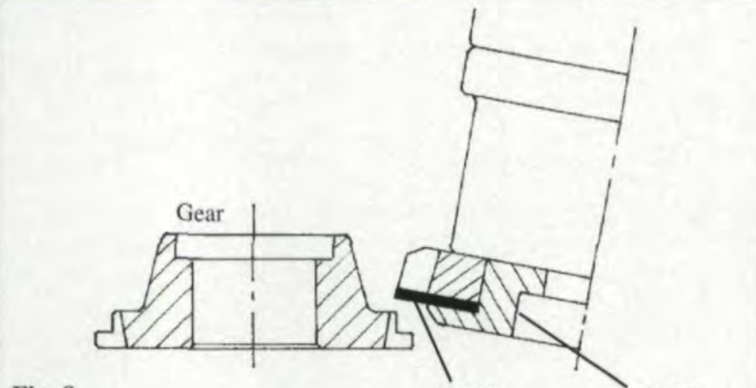


Fig. 8

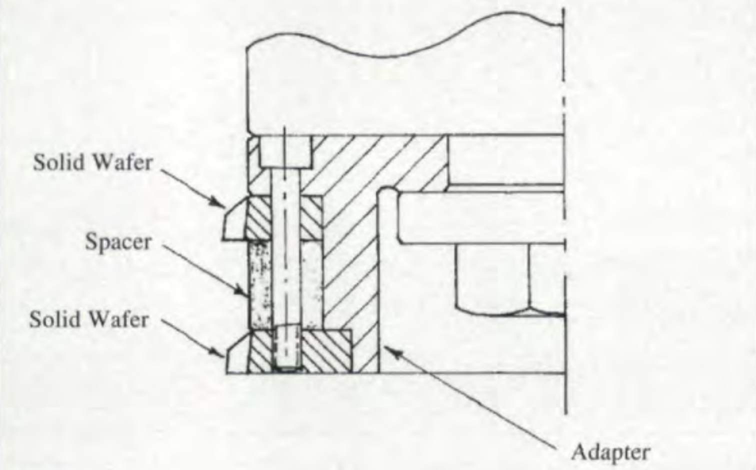


Fig. 9

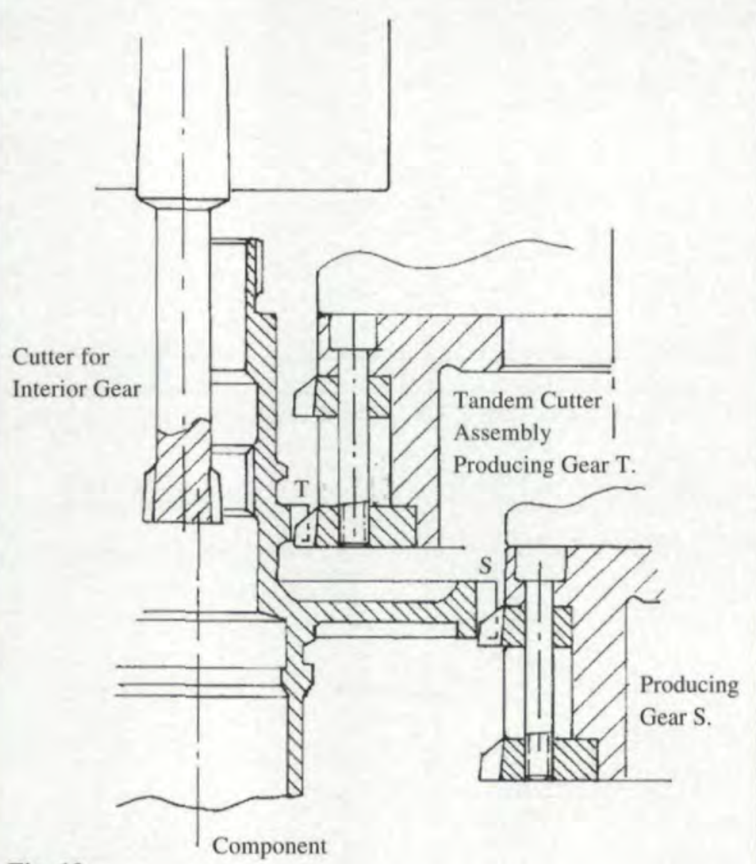


Fig. 10

condition since it is not sharpened after use.

Limitations

As with any process, the wafer technique has limitations, and these must be borne in mind when considering the application. At present, the wafer cutter is only suitable for spur gears, since it relies on the deflection of the blade to the support face to produce the rake angle, and it is not possible to achieve a helical orientation. Helical cutters can be produced to a limited degree if they are flat-faced sharpened, but this does not always offer a satisfactory solution, particularly on higher helix angles. One further point to consider is the fact that the front face of the wafer needs to be clamped, sometimes creating a fouling point as Fig. 7 illustrates.

An excellent application for the wafer cutter is the synchro-cone shown in Fig. 8, where the teeth are tapered and the axis of the work is inclined relative to the cutter. This part is produced in 26 seconds, the rotary feed being as high as 2.5 per stroke. The cutter produced some 10,500 parts in 77 hours.

Solid Wafer

The most recent development has been the solid wafer, which utilizes the same basic principle as the wafer cutter, but uses a wider blade and, consequently, does not need a front clamp plate. Fig. 9 shows a typical example where two cutters are mounted in tandem for a double cutting operation. This development enables helical gears to be produced, and the cutters may be ground with the cutting faces at right angles to the helix angle, as would be necessary for high-production cutting. This type of tool is particularly useful for multi-cutter setups where two or more cutters are used on the same adapter to perform several operations at one setup.

As with the wafer cutter, the solid wafer is not sharpened, but is used virtually to destruction, or until the workpiece is outside its acceptable limits. The blade is TiN-coated on all its faces.

Applications

Fig. 10 shows an excellent example of what can be done with a modern CNC gear shaping machine and solid type wafer cutter technology. The part in question is an aircraft gear, and the teeth *T* and *S* are produced at one clamping of the workpiece. Apart from the obvious saving in the handling time, the technique offers another advantage in that the two gears are now cut around exactly the same axis and are, therefore, concentric to each other.

The lower cutter produces the gear *T*, and the machine then automatically changes its program and resets. This can involve changing index, rotary feed, radial feed, crank speed, center distance, and stroke length if necessary.

The upper cutter now produces gear *S* to its required size, the two cutters having been measured for size prior to the start of the setup, and the data placed in the machine memory. The tools are not sharpened, but discarded when the wear factor can no longer be tolerated, and the replacement blades are clamped to the body of the adapter. Production continues with no change in machine setting.

A further example of the versatility of the solid wafer and CNC machine technology is shown in Fig. 11. The part in question is a long shaft with two gears having different numbers of teeth spaced either side of a flange or shoulder. The arrangement is such that the gears cannot be cut in the same direction. Under normal circumstances this would be a two-cutter setup job involving turning the part over and resetting the machine for up-cutting.

The wafer cutter itself is also an unusual application in that it consists of two segments, one arranged for up-cutting and the other segment for conventional down-cutting, but both segments being integral with each other on the same tool body. (See Fig. 12.)

The segment B has 70 teeth to produce the 35-tooth gear in two cuts, at which point the component will lie in the gap between the two segments. The segment A has 52 teeth to produce the 26- tooth gear in 2 cuts, but cutting in the opposite direction, the segment cutter being manufactured with cutting faces opposed to each other. The CNC machine automatically resets and changes its program so the index-stroke position and the cutting direction are changed automatically.

The two gears are produced at one clamping and are concentric to each other and give excellent control over the tooth size. The workpiece is large, heavy, and difficult to handle without mechanical aids; therefore, producing both gears in one clamping is big advantage.

Fig. 13 shows a second speed gear from an automobile gear box which has to be shaped

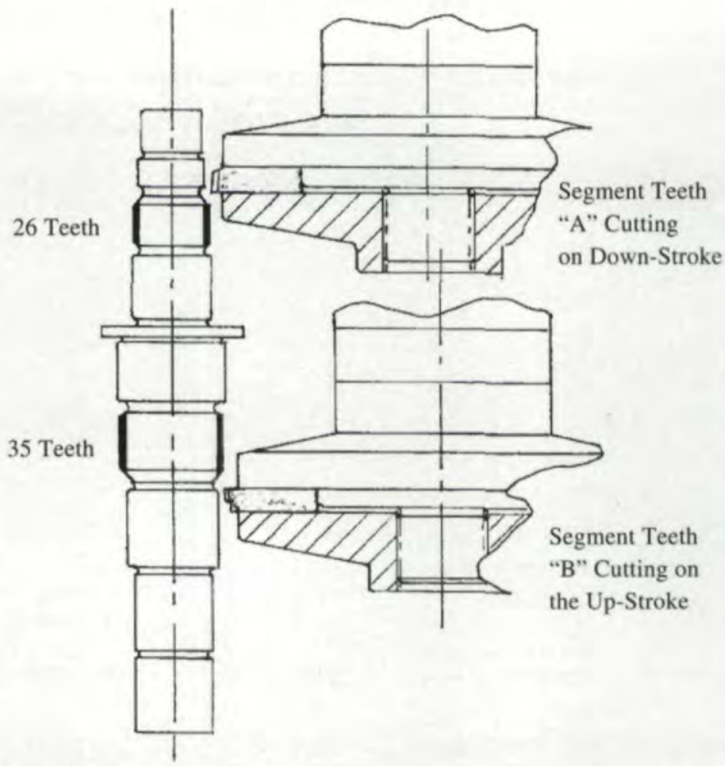


Fig. 11

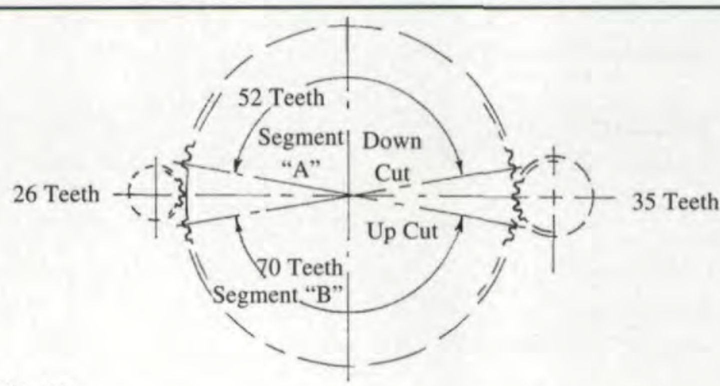


Fig. 12

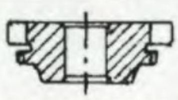
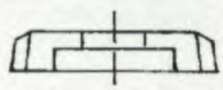
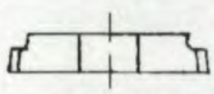
Component Data	**Disc Type Cutter**	**Solid Wafer**
 37 teeth 1-9 N. Mod 25° 30' Helix Angle 17.7 Face Width.	 TiN-coated disc after sharpening	 Solid wafer TiN-coated
Output per tool sharpening	250	2500
Number of teeth in the cutter	64	64
Useful length per tooth	2.83 mm	28.34 mm

Fig. 13

Table II - Cost Comparison		
Conventional Shaper Cutter/Solid-Wafer		
	Shaper Cutter	**Solid-Wafer**
Module	1.9	1.9
Normal Pressure Angle	15°	15°
Number of Teeth *Zo*	64	64
Helix Angle	25° 30'	25° 30'
Useful Width	14	—
Number of Resharpenings (Average)	32	—
Tool Price Per Unit	DM 1,600	DM 1,000
Costs Per Tool Per Sharpening	DM 50	DM 1,000
Costs Per Resharpening	DM 100	—
Wage Costs For Tool Changing	DM 15	DM 5
Total Costs Per Tool Per Sharpening	DM 165	DM 1,005
Cycle Time	1.14 min.	1.14 min.
Output (Number ofGears)	250	2,500
Tool Life Per Tool Sharpening	285 min.	2,850 min.
Time For Tool Cutting	15 min.	5 min.
Total Time per Sharpening	300 min.	2,855 min.
10 Shifts: 8 x 10h = 80 hours or 4800 minutes		
Number of Tool chucks Per 10 Shifts	16	1.681
Tool Costs Incl. Resharpening & Wage Costs For Tool Changing	DM 165 x 16 DM 2,640	DM 1,005 x 1.681 DM 1,689
Number of Gears Per 10 Shifts	4000	4202
Costs Per Unit	DM 0.66	DM 0.40

because of the adjacent shoulder formed by the snychro-teeth. It shows a comparison of results obtained by conventional and solid wafer cutters, both tools being TiN-coated. We see that the solid wafer cuts 10 times the length of tooth that a conventional cutter does.

This is further expanded in Table II, where the cost of producing the same gear by both types of cutter is compared. The example shown is currently being produced in Germany and from the figures quoted, we can see that the cost per gear is reduced by approximately one third. The time lost in tool sharpening and machine change-over time is dramatically reduced, since for the same cycle time and 80 hours of production, the standard cutter is changed 16 times, while the wafer cutter is only changed 1.681 times. The saving in downtime is therefore considerable.

Another factor which should be considered is the inventory level of the number of cutters required. The old rules of one cutter in use, one in sharpening, and one in the stores; i.e., a minimum of three, no longer need apply, since the sharpening operation is deleted. The stock level could be reduced by 30%

The application shown in Fig. 14 is a planetary gear from an automatic transmission, the data being

upper gear 1.99 Mod. 16 teeth 9.5 face width
lower gear 1.058 Mod. 31 teeth 22.0 face width

The tooth thickness for both parts is critical and the diameter over pins has to be held within 40μ (.0112") on diameter. Cutting with conventional cutters proved to be a problem, and the requirements of continuous automatic production and with continuous quality control could not be met for several reasons.

1) The pairing of the two cutters for size is done by the cutter manufacturer initially, but it must be maintained in production by the user.

2) Holding this size limitation throughout the life of the cutters places further restrictions on the choice of optimum meshing pressure angle.

3) The lower cutter does considerably more work than the upper cutter and reaches its critical wear point long before the upper cutter. This means that tool life has to be sacrificed unnecessarily on the upper cutter, since it has to be sharpened by more than the amount it is worn in order to maintain the relation-

ship between the two tools.

4) Inaccurate pairing of the cutters after sharpening in production causes lost "machine downtime" for qualifying parts.

The solid wafer solved this problem in the following manner:

The two cutters are mounted in tandem and ground to the exact size by the supplier, and since they are not to be sharpened when worn, they do not have to be requalified for size. Two lower cutters are manufactured for each upper cutter, since the rate of relative wear between the two tools is approximately 2:1. When the lower cutter is worn, then this cutter only is changed. By the time this second lower cutter is worn, the upper cutter is now also ready to be changed. All cutters are ground to a matched size by the tool supplier so that they are all readily interchangeable.

The tool life improved dramatically from 280 gears between sharpenings when using conventional tools, to 3,200 gears when using the solid wafer, approximately an 11:1 improvement. The machine now runs for approximately six working days without stopping for a tool change, and the quality of the gears produced is improved, thus the requirement of an automatic production process with continuous quality control has now been met.

Non-Involute Profiles

A further advantage of the wafer system is its ability to handle special profiles and non-involute forms. To appreciate the reason for this advantage over the conventional tool, it is necessary to consider the following:

Involute System. The advantage of this system is that the basic rack is simple and constant through the life of the tool. An involute shaper cutter will produce an involute gear of any number of teeth throughout its life.

Special Forms (Non-Involute Profiles). In this category the basic rack varies for each change of shape, change of number of teeth, and change of diameter of both workpiece and cutting tool.

Having appreciated the fact that the basic rack of the non-involute profile varies with each minor change in profile, diameter, and number of teeth, we next have to take into consideration the point made earlier in Fig. 4.

The meshing pressure angle on an involute tool changes as it is sharpened back, but the basic rack remains constant; whereas with non-involute tools, the basic rack changes with the diameter of the cutter, and the profile is therefore different from the front to the back of the tool.

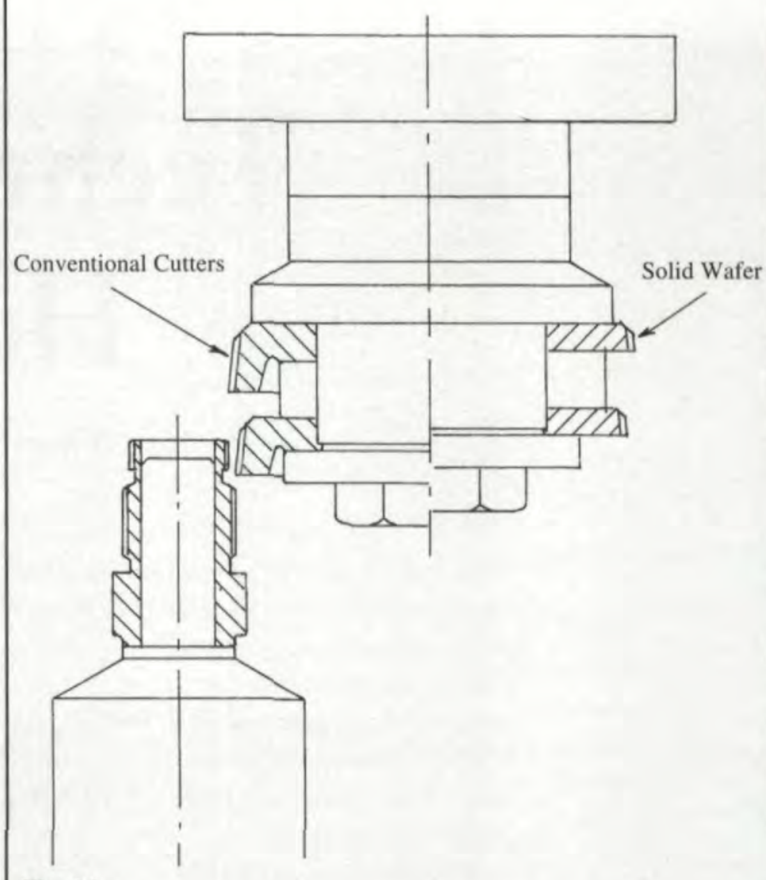


Fig. 14

The tool supplier has to compromise when manufacturing conventional cutters for non-involute profiles and has to try to keep the change in the basic rack to a minimum. One way of doing this is to reduce the top rake angle of the cutter so that the change in diameter, when sharpened, is kept to a minimum, thus reducing the required change in profile shape. The wafer cutter, therefore, has the advantage that the diameter does not change because it is not sharpened, so it is only necessary to consider the basic rack at the one diameter. It is, therefore, necessary to reduce the top angle of the tool, and this allows the cutting rakes to be optimized. The quality of the profile of the cutter is also improved because it is only necessary to consider the form of the cutter at the one position. ■

Acknowledgement: *The author would like to thank Lorenz for permission to use the various case studies cited in this article.*

High Technology Hobs

William L. Janninck

Today's high technology hobs are visibly different from their predecessors. Gear hobs have taken on a different appearance and function with present day technology and tool and material development. This article shows the newer products being offered today and the reasons for investigating their potential for use in today's modern gear hobbers, where cost reduction and higher productivity are wanted.

Even after some 150 years since the first hob patent was granted, gear hobbing continues to be the favored process for the production of many different types of gears, and no alternate method of making gears has yet appeared. At this time hobs appear to be one of the basic elements in gear manufacturing, like a wheel or lever, and so far, seem to be irreplaceable.

Hobbing is used for making a large variety of gears, including the smaller fine pitch gears used in instruments, timers, clocks and gages, where some pinions are as small as .050" in diameter and have pitches as fine as 150 diametral pitch (DP). On the large side there are gears that range beyond 20' in diameter and have pitches coarser than 1 diametral pitch. Such large gears are used in bridges, stamping and forging presses, drag lines, and mining and processing machinery. Between these two ends of the gearing spectrum lie the masses of gears that are used in the intermediate sizes and pitches. Here is where the demand for huge quantities of gears exists, and this is the most likely zone of opportunity for advancements in both machine tools for cutting the gears and in those gear cutting tools called hobs. While developments in the machine tools have moved at a substantial pace, the same has not been totally true of gear hobs, where even small changes in tool material metallurgy or tool processing were only accepted after a substantial period of trial and evaluation. Today hobs and machines are more closely linked together in the gear cutting process than ever before, and machine and tool builders have an opportunity to integrate the gear making system utilizing both machine advances and the latest improvements in the cutting tool field.

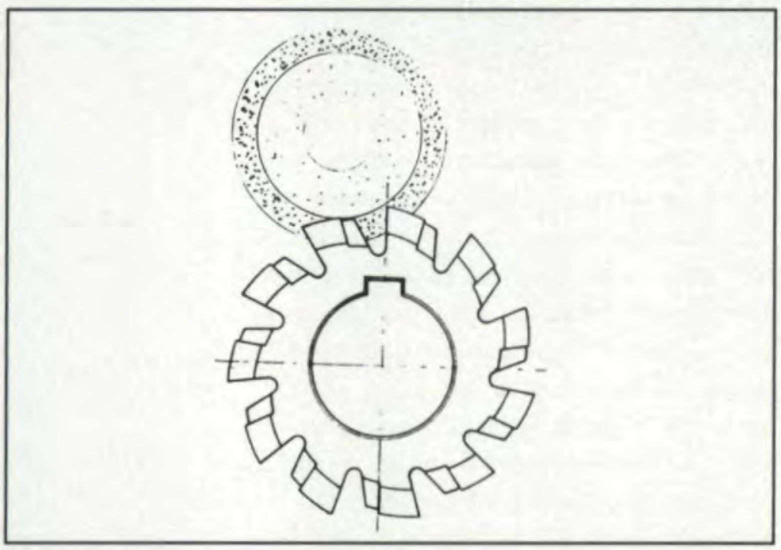


Fig. 1 - Conventional hob form grinding. (Courtesy FHUSA-Fabricacion de Herramientas y Utensilios.)

Five specific areas relating to possible improvements in cutting tool performance can be addressed. These are tool materials, tool coatings, tool accuracy, tool construction, and tool design.

Tool Materials

Almost all hobs are made from one of a large family of high-speed steels composed of iron plus some 17% to 27% of other metals - molybdenum, tungsten, vanadium, cobalt, and chrome. Usually selection is made on the basis of suitability to the material being cut, its treatment, and configuration. Some consideration must be given to all the factors involved and allowances made for tool material toughness, brittleness, wear, grindability, and cost. For coated tools the tool material is really a substrate for the coating, and usually the higher alloy super high-speed steels are most beneficial. Some gear materials are relatively free machining and only require the standard tool steels for the best economy.

Tool Coatings

A development with perhaps even more impact has been the use of the metallic compound titanium nitride (TiN) as a thin coating on hobs. The result in suitable applications can extend tool life by two to three times compared to an uncoated tool, which is a major improvement. This is attributed to the extremely high hardness, above 8O RC, and the dissimilar nature of the coating relative to the material being cut. The coating is resistant to high temperature and corrosion, welding, seizing, and, therefore, wear. The gains offered by the coating can be taken several ways, but by strategizing the operating parameters of speed and feed, the real advantage is to minimize the cost per gear as registered by a gear cutting cost analysis. TiN is not the only coating possible, and there are many that may yet be developed and offered. Titanium carbonitriding (TiCN) is one that is showing real promise for even greater cost reduction and is being actively used today.

Tool Accuracy

Tool accuracy may not directly influence cutting tool performance, but can yield benefits further down the processing line. Gear hobbing is strictly linked geometrically, gear to hob, in the cutting process. Inaccuracies in the cutting process, whether caused by the original hob quality or induced later in mounting or resharpening, have a way of being discovered later in the finished gears. Subsequent secondary finishing operations on the gear, such as shaving or rolling, may not remove all traces of hob runout, wobble, thread spacing, or profile errors. Since one of the major objectives today is to keep the hob in the machine as long as possible, then consistency of the hob across its entire length becomes imperative, since the hob will be shifted in use across its entire face width, and no significant variations in the gears cut can be allowed. On the multiple-start hobs that are frequently used, thread spacing also becomes critical, and most of these super hobs have unique tolerances specified that

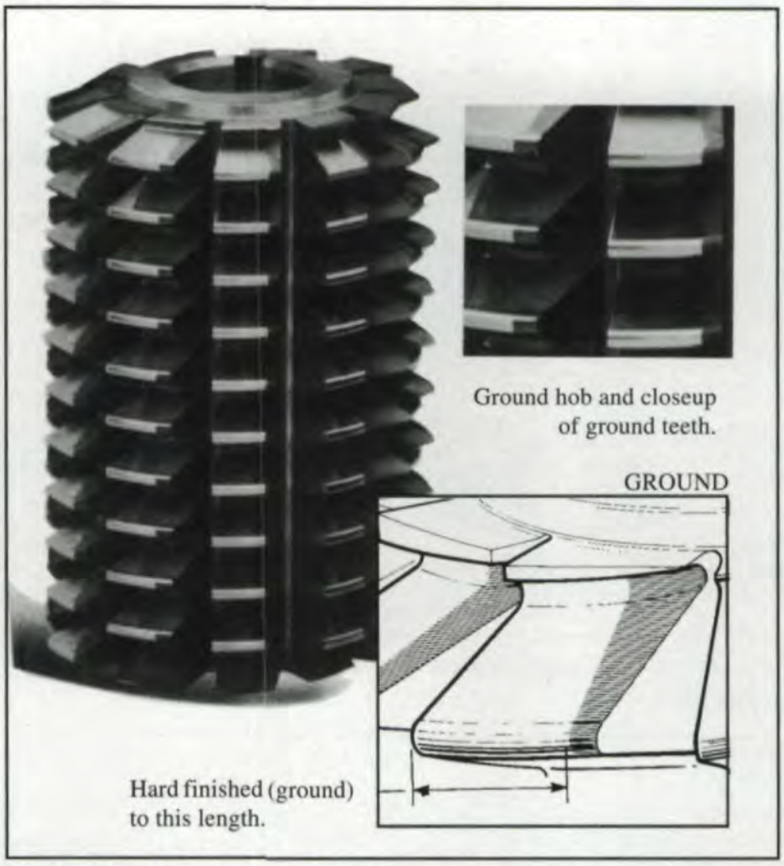


Fig. 2 - Star Cutter's conventionally ground form hob. (Courtesy Star Cutter Company.)

are nonexistent in the usual trade standards.

Hob Construction

The original solid or monoblock hob, which is the most frequently used construction, does have some limitations on its utility. This is especially so with those hobs that are ground on form to improve tool surfaces and increase total hob accuracy. Fig. 1 shows the small restricted size of a grinding wheel required to grind the hob flank as far back as possible. The wheel must eventually leave the flank being ground and be lifted out to start the grinding cycle on the next hob flute. A portion of the hob tooth length is then not useable because of a change of geometry in that area. Sometimes a sacrifice or compromise is made to reduce the clearance on the tool to let the wheel move further toward the next flute extending the ground length, but reduced clearance generally means increased wear. In the end, one cannot get full utilization of the available tool material.

Fig. 2 shows a traditionally ground solid Star Cutter hob and the unusable area is shown. Fig. 3 is an example of a new development by Star Cutter, a hob that is finished by a skiving process, and as with grinding, the operation is performed with the hob in the hardened state.

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Fig. 3 - Skived finish hob made by Star Cutter. (Courtesy Star Cutter Company.)

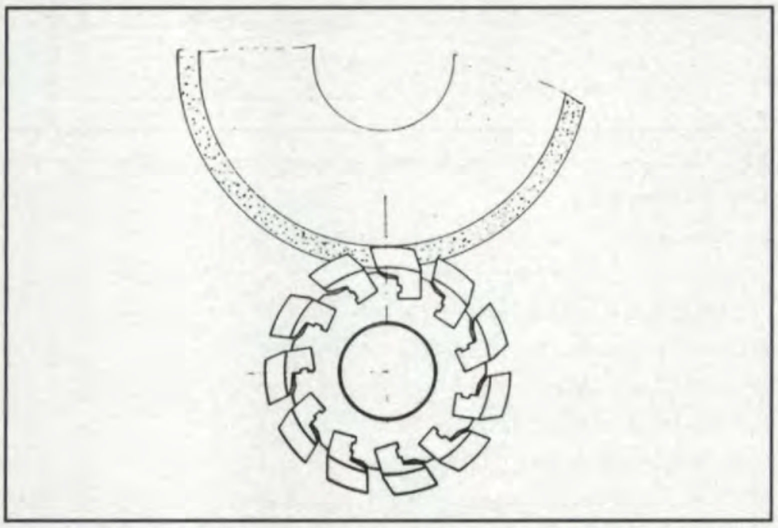

Fig. 4 - Segement hob blades in form grinding. (Courtesy FHUSA-Fabricacion de Herramientas y Utensilios.)

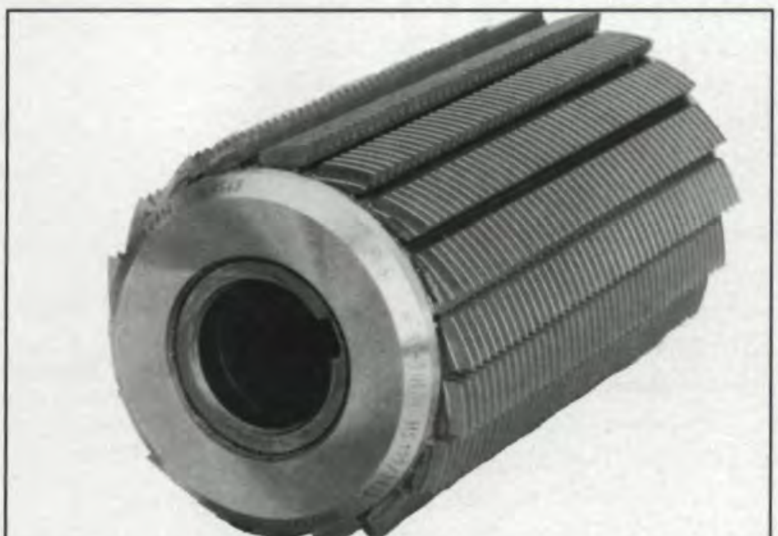

Fig. 5 - A FHUSA segmental hob. (Courtesy FHUSA-Fabricacion de Herramientas y Utensilios.)

The form on the hob is finished almost all the way back to the next flute and can be fully used, yielding the maximum resharpening. The skived surface has a super finish, good accuracy, and is suitable for coating with TiN and TiCN. It is limited to approximately 17.5°pressure angle and higher.

Inserted blade hobs are another way to address the accuracy and utility problems. When the blades are made for these hobs, they are ground while in a tipped-down position, and a set of blades is presented to the grinding wheel as a worm thread surface. As seen in Fig. 4, the grinding wheel is five to 10 times larger in diameter than that used on a solid hob, and no cam jump is involved. Very smooth flank finish and good accuracy is achieved. When the blades are mounted into the body in the cutting position tipped up, the tool clearance angles are usually higher than solid hobs and are conducive to longer tool life. The entire length of the hob tooth is consumable in the sharpening cycle, and the blades can be coated with TiN. An example is shown in Fig. 5 of a multiple-start hob made by FHUSA in Barcelona, Spain.

Hob Design

In hob design there are many variables that can be studied. The simple dimension of hob face width can be important when trying to increase machine up-time. Doubling the hob length will double time between hob sharpenings, minimizing machine down-time, machine reset, and setup proofing. Fig. 6 is an extra length hob with a reduced diameter made by Pfauter-Maag Cutting Tools. For comparison a conventional hob is shown behind it.

Hob diameter is another variable that can be used to advantage. A smaller hob diameter permits higher hob rotational speed, while keeping the surface speed the same. In turn this reduces approach time and allows faster part indexing, both of which reduce gear cutting time.

Another factor which reduces part cutting time is the use of multiple-start hobs. Since the gear being cut and the hob are locked together in the hob starts/gear teeth ratio, a two-start hob will increase the indexing or turning rate to twice that of a single start. Three starts will increase it three times, and so on. The net result is a significant reduction in the time it takes to cut a gear.

The surface of a hobbed gear flank is composed of a pattern of facets; feed scallops in the longitudinal direction, and generating flats in the lateral direction. The feed scallops are controlled by the feed rate, and the generating flats are a function of the flutes and starts in the hob. Since gears with larger numbers of teeth require fewer generating flats, and those with fewer teeth need more, the flutes must be chosen carefully. One must depart from the tradition of using standard fluting, which yields a somewhat large number of resharpenings, and balance the flutes, generating flats, and sharpening life to give the best results on the gear cost analysis sheet.

Optimized Designs

The design of high-production hobs today requires much more planning and data to arrive at a final specification. Part data, processing method; (i.e., finishing, pre-shave, pre-roll, or pre-grind), gear material and its physical properties, targeted part production rates, gear machine capacities and capabilities, loading and unloading methods, tool change timing, number of sharpenings desired, along with generating flats and scallops permissible, and chip load per cutting edge are used to develop the hob design and specification. The optimization will be in the tool material, tool coating, hob diameter and length, number of starts. and number of flutes.

Fig. 7 shows a hob based on the above concept made by Pfauter-Maag Cutting Tools. This Opti-Gash™ hob has several resharpenings planned into it. If the sharpenings are reduced to zero, the hob becomes a single-use, disposable hob. In this case the hob diameter is an additional variable, and it is made as small as possible to permit higher hob spindle speeds.

The Wafer™ hob, shown in Fig. 8 is a disposable or throw-away hob by Pfauter-Maag Cutting Tools. After it is dulled, it is retired and not resharpened. The hob tooth is just thick enough to support the cutting load, and the hob may be of an integral arbor type to facilitate the smallest diameter and maintain rigidity. These tools are coated by the Tinite™ process for further life enhancement.

Fette Tool Systems offers its version of a high-output hob, the Gash-master,™ shown in Fig. 9. It is available in 8.5 DP or finer, is TiN coated, and is a single-use, non-resharpenable hob. As many as 48 flutes can be used. Fette also offers a heavy duty hob which will have eight to 10 sharpenings designed into it. The hob is de-

Fig. 6 - Extra-length hob with conventional hob in back from Pfauter-Maag Cutting Tools. (Courtesy Pfauter-Maag Cutting Tools.)

Fig. 7 - Opti-Gash™ produced by Pfauter-Maag Cutting Tools. (Courtesy Pfauter-Maag Cutting Tools.)

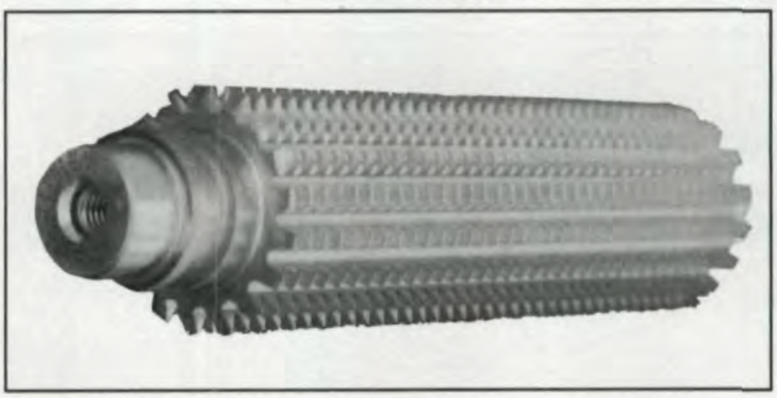

Fig. 8 - The Wafer™ hob offered by Pfauter-Maag Cutting Tools. (Courtesy Pfauter-Maag Cutting Tools.)

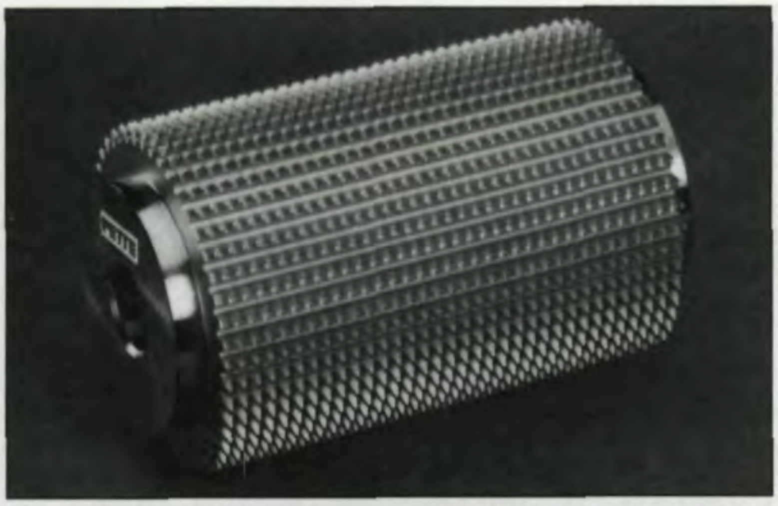

Fig. 9 - Gash-Master™ hob manufactured by Fette Tool Systems, Inc. (Courtesy Fette Tool Systems.)

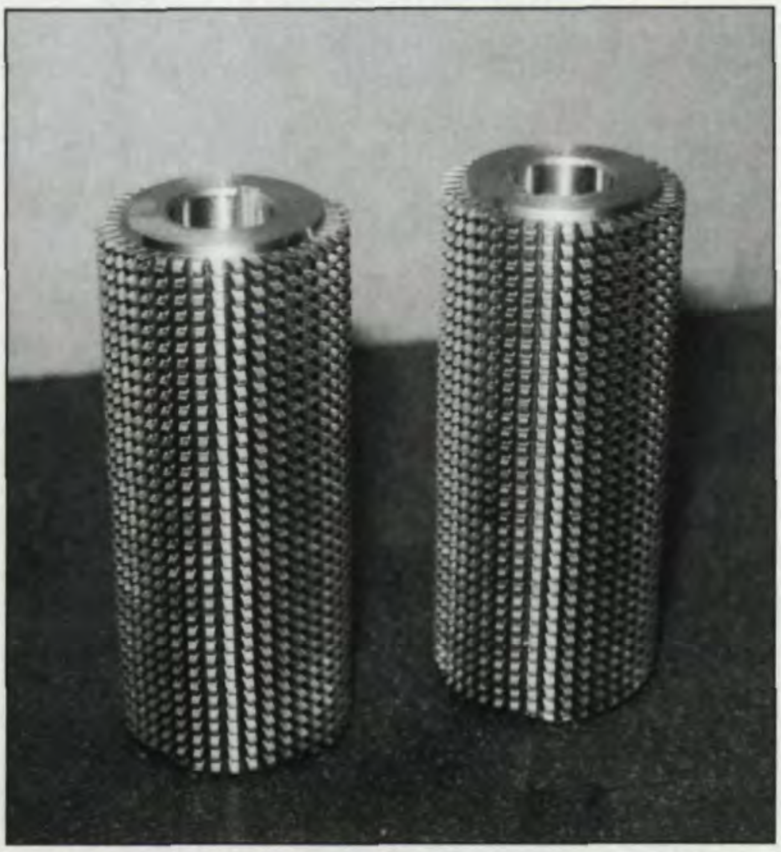

Fig. 10 - Illinite® Maintenance-Free hob made by ITW Components and Tools. (Courtesy ITW Components and Tools.)

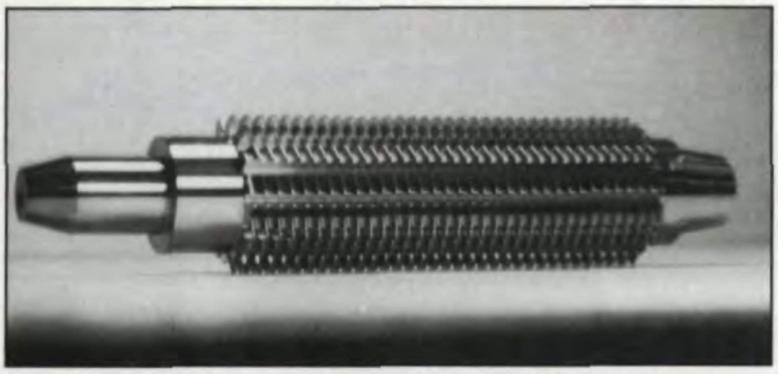

Fig. 11 - Star Cutter's small diameter hob with limited sharpenings. (Courtesy Star Cutter Company.)

signed with the same parameters and goals, but incurs the resharpening cycle.

ITW Components and Tools, an Illinois Tool Works Company, offers the Illinite® Maintenance-Free hob, a disposable hob with no resharpening, shown in Fig. 10. It is fully coated with a TiN or TiCN material and is constructed with a bore or as a solid integral unit.

Star Cutter offers its small diameter hob, a high-capacity hob, which is designed for a small number of resharpenings, with a solid integral drive shank or bore. It is shown in Fig. 11, and is fully coated with their Gold Star TiN.

There are some common general features regarding the super hobs, such as the Wafer,™ Gash-Master,™ and Illinite® Maintenance-Free designs. They have a long, useable face width, are as small on diameter as conditions allow, are coated, have many flutes, have multiple-starts, and are disposable and not resharpened. They always operate with a full coating on face and flank of the hob teeth and need no recoating. Their initial accuracy is intact for their duration, and no sharpening or qualification equipment or in-float inventory is needed.

The effectiveness of a super hob or any other hob can be measured by several factors. One is the number of pieces the hob can cut in its life, preferably measured by the lineal tooth inches cut. (This is the number of parts times the gear face width times the number of gear teeth. Some data for disposable hobs have reported 200,000 to 300,000 tooth-inches, and with the resharpenable hobs, even higher numbers.) Another measurement factor is the floor-to-floor time, and another is the cost of the tool. Probably none of these taken alone will represent the true picture, which is the net cost per piece. A complete gear cutting cost analysis, including tool cost, machine cost, setup and inspection cost, resharpening cost, recoating cost, tool inventory float cost, and perhaps a few additional factors, is needed to find the cost per piece.

Many times gears are cut under predetermined conditions with gear making and sharpening machinery already in place, and the Fette Heavy Duty and Star Small Diameter hobs, with limited sharpenings, could be more suitable for these circumstances. These "near" super hobs, because they are resharpenable, can produce more pieces per hob and might be the right choice when the manufacturing cost accounting is reviewed.■

Line of Action: Concepts & Calculations

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Bill McElroy,
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In the past gear manufacturers have had to rely on hob manufacturers' inspection of individual elements of a hob, such as lead, involute, spacing, and runout. These did not always guarantee correct gears, as contained elements may cause a hob to produce gears beyond tolerance limits.

A solution to the individual element inspection is to have a "line of action" inspection that is a composite of all individaul elements, giving absolute assurance that the hob will cut parts to print tolerances (negating machine errors).

The following technical presentation will describe "line of action" and its benefits to the gear producer.

Concepts and Calculations

It is understood that the line of action (generation) is the succession of points of contact between the hob flank and the gear flank during the generation process.

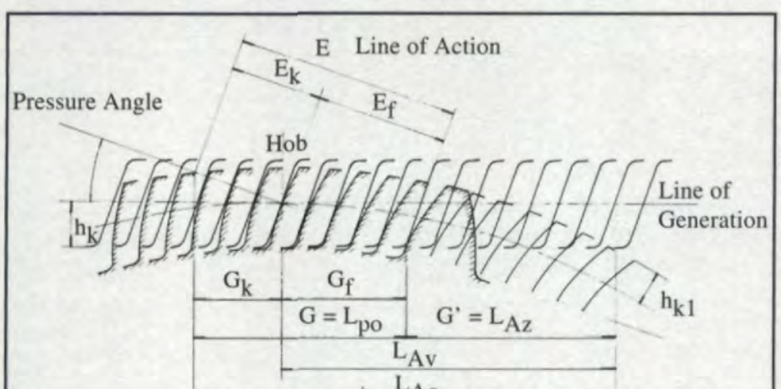

Fig. 1

This line, shown in Fig. 1., is normal (perpendicular) to the hob flank profile and forms with the horizontal line (line of generation), the pressure angle value.

The generation segment (length of action) is the necessary generation length to generate all the involute flank of a gear profile.

According to Fig. 1, we will detail all the values:

Ek = Generation segment of the gear addendum.
Ef = Generation segment of the gear dedendum.
E = Generation segment of the gear tooth involute profile.
Gk = Addendum generation length.
Gf = Dedendum generation length.
G = Profile generation length.
G^1 = Roughing length of the tooth profile.

Calculation formulae:

$$Ek = \sqrt{((d0_v / 2 + h_{kl})^2 - (d0_v / 2 * \cos \alpha n)^2)} - d0_v / 2 * \sin \alpha n$$

$$Ef = \frac{hk}{\sin \alpha n}$$

$$E = Ek + Ef$$

$$Gk = Ek * \cos \alpha n$$

$$Gf = Ef * \cos \alpha n$$

$$G = Gk + Gf$$

$G' = \sqrt{((d0_v / 2 + h_{kl})^2 - (d0_v / 2 - hk)^2)} - Gf$

being:

hk = hob addendum.

h_{kl} = gear addendum

$d0_v$ = normal pitch diameter.

$$d0_v = mn * zv = mn * \frac{Z1}{\cos \beta 01}$$

Z_1 = number of gear teeth

β01 = gear helix angle at the pitch diameter

αn = normal pressure angle

So, in this way for a rack limit case ($Z_1 = \infty$):

$$E = \frac{h_{k1}}{\sin \alpha n} + \frac{hk}{\sin \alpha n}$$

$$G = E * \cos \alpha n$$

For a module mn = 1

hk = 1.25

$h_{k1} = 1$

we will have:

αn = 20° ——> E = 2.9238 + 2.6548 = 6.5786
G = 6.1989

αn = 30° ——> E = 2 + 2.5 = 4.5
G = 4.2286

αn = 15° ——> E = 3.8637 + 4.8296 = 8.6933
G = 8.1690

If we divide the length G by the normal lead (tn), we will obtain the necessary hob turns (revolutions) to generate the gear tooth profile.

$$\text{Number of revolutions} = \frac{G}{t_n * Z}$$

being: Z = number of hob threads,

t_n = nominal pitch

So we have:

αn = 14° 30' ———> 2.86 revolutions.
αn = 15° ———> 2.6 revolutions.
αn = 20° ———> 1.97 revolutions.
αn = 30° ———> 1.346 revolutions.

However, we can say that if we make three revolutions, we will cover all the possibilities for any normal pressure angle.

Checking and Standards

In order to check a hob line of action (generation), we must see the difference between mechanical checking machines and CNC checking machines.

The mechanical checking machines, i.e. Klingelnberg models PWF 250 and 300, have

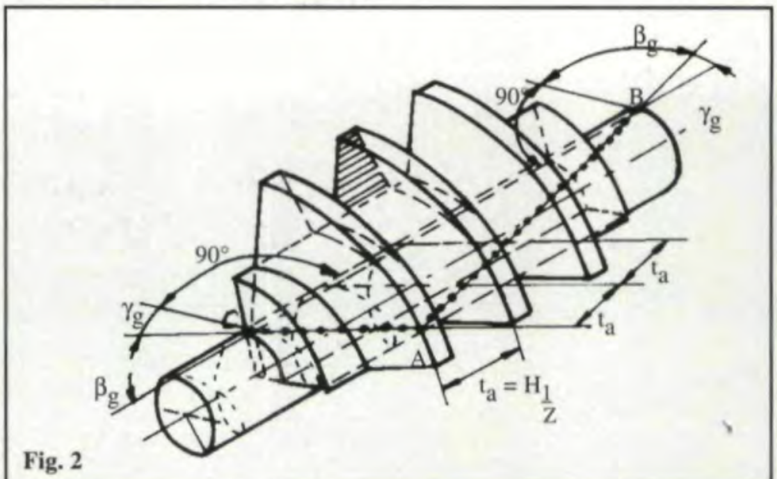

Fig. 2

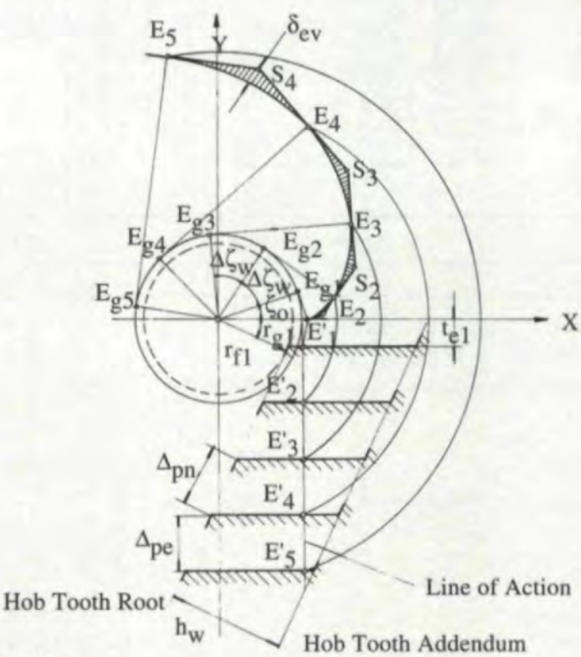

Fig. 3

this capability. In the CNC checking machines, it is only a matter of software.

The checking of the line of action or generation is made according to the graphic in Fig. 2, following the line AB. This line is held in a plane tangent to the base circle (radius rg) of the hob, because a hob for its involute profile, is equivalent to a worm or to a gear with a number of teeth equal to the number of starts.

Accordingly, this criterion in the graphic of Fig. 3 represents the hob's different cutting flanks and its correspondent positions in the gear tooth involute flank during the generation. The points we measure in the line of action, E1', E2', E3' .....etc., generate the involute in the points E1, E2, E3, ...etc., placed on the theoretical involute.

On the other hand, accordingly, the number of cuts, i.e., the number of the hob gashes and

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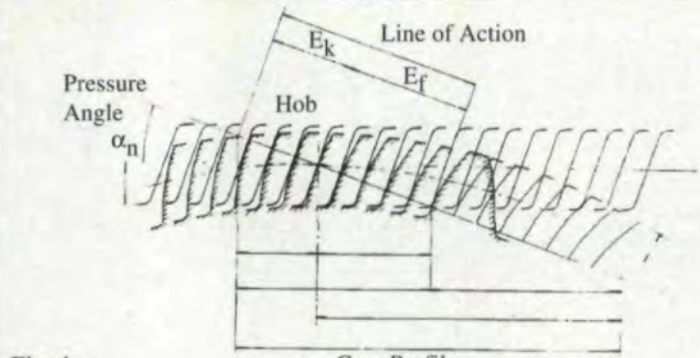

Fig. 4a

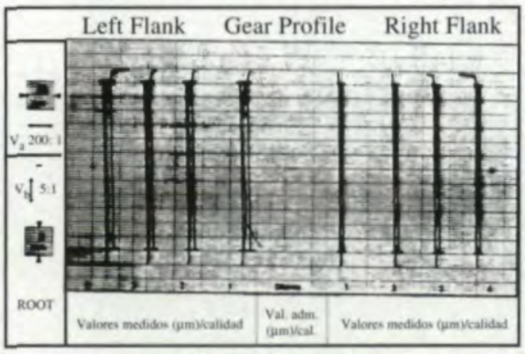

Fig. 4b Gear Profile Tooth Chart

Table I
Individual Hob Errors
(Numbered in accordance with DIN 3968)

	F_e*
6 - Addendum eccentricity diameter runout	0%
7 - Cutting face error	7%
8 - No adjacent flute spacing error 9 - Adjacent flute spacing error 10 - Adjacent flute spacing error }	7%
11 - Direction of blades (function of the module)	0.6%
12 - Deformation profile	100%
13 - Chordal thickness	94%
14 - Axial lead between consecutive cutting edges 15 - Axial lead in one turn }	94%

$$F_e = F_e^* \cdot f$$

F_e = Error in one turn
F_e^* = Percentage of individual errors on error F_e.

Table II

Module range		from to	0.63 1	1 1.6	1.6 2.5	2.5 4	4 6.3	6.3 10	10 16	16 25
16	Variation along line of action from tooth to tooth measured at cutting edge.	AA DIN	± 4	± 4	± 4	± 5	± 6	± 8	± 10	± 12
		ISO	± 4	± 4	± 4	± 5	± 5	± 6	± 8	± 11
		A DIN	± 6	± 7	± 8	± 9	± 10	± 12	± 16	± 20
		ISO	± 6	± 6	± 6	± 8	± 8	± 10	± 12	± 18
		B DIN	± 12	±14	±16	±18	±20	±25	±32	±40
		ISO	± 10	±10	±11	±13	±13	±17	±22	±32
		C DIN	± 25	± 28	±32	±36	±40	±50	±63	±80
		ISO	± 20	± 20	±22	±26	±26	±34	±45	±63
17	Cumulative variation of involute helicoid over active length.	AA DIN	8	8		10	12	16	20	25
		ISO	12	9	8	12	12	15	20	28
					10					
		A DIN	12	14		18	20	25	32	40
		ISO	14	14	16	19	19	24	32	45
					16					
		B DIN	25	28		36	40	50	63	80
		ISO	25	25	32	34	34	42	55	80
					28					
		C DIN	50	56		71	80	100	125	160
		ISO	50	50	63	70	70	85	110	160

the number of hob threads (starts), the error δev can be variable.

Finally, we can consider that the line of action errors are the result of the hob errors in the hob's lead, profile, index, and run-out.

Interpretation of the Line of Action Check

If we do not consider any kind of additional errors beyond the hob error, the involute profile generated by this hob should be identical to the hob line of action checked.

In Fig. 4a we show a typical checked hob line of action graphic, and in Fig. 4b, we show the gear profile obtained with this hob without machine errors, hob workholding errors, and without machine flexing.

Advantages. The check is independent of the number of hob starts because we are checking the final result of the generated gear.

We know what the gear's profile will be, and what will be affected by the hob on the gear profile quality. This will give the end user absolute assurance of the hob quality and generated gear profile.

In Table 1 we can see the percentage of the individual hob errors, which will have an influence on the line of action checked. As we can see, the main factors are lead and profile.

Control (Check) Standards. The only standards which include the hob line of action inspection are DIN 3968 and the ISO. All the other standards (AGMA, BS, MCTI, etc.) only have as an equivalent the checking of the lead in three revolutions (the maximum number of revolutions to generate an involute profile), but they do not include the hob profile errors. In Table 2 we show the inspection values according to DIN and ISO standards.

The standards, which include the inspection of the hob lead in three revolutions depends on the number of starts. So, for example a $\alpha n = 14° 30'$, the number of revolutions to be checked will be:

Z = 1 ———> 3 revolutions
Z = 2 ———> 1.5 revolutions
Z = 3 ———> 1 revolutions
Z = 4 ———> 0.75 revolutions

Conclusion. The checking of the line of action (generation) is the only one which guarantees the quality of the gear profile obtained by generation with the hob. We consider the line of action control as the most important for hobs in the complete inspection criteria of DIN and ISO standards. ■

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Environmentally Safe Fluids for Industrial Cutting, Lubrication, & Cleaning

Neal Vandewalle
ITW Fluid Products Group,
Norcross, GA

Not long ago, many manufacturing managers thought sensitivity to environmental protection standards meant additional expenses, decreased productivity, and a plethora of headaches and hassles.

But today, thanks to new technology and products, helping to save the environment can actually help manufacturing companies save money, time, and wear on equipment and improve the workplace for employees.

Sometimes it might seem hard to switch to a new product after growing comfortable with or accustomed to an old one, but it's becoming important that everyone does his or her part to better protect the environment. And, as in many cases, when affordable technology is available that will help, and when the initial cost is the same as what many companies are paying for older, environmentally hazardous products, there's no reason for not switching.

Notably, vast improvements have been made in the formulation of industrial cutting fluids for tapping, machining, grinding, and other metalworking tasks. These fluids are required to extend the life of tools that are subjected to heat, stress, and friction in their normal operation.

For example, most current, popular tapping fluids pose an environmental risk because they contain 1,1,1-trichloroethane (methylchloroform) as a primary active ingredient. The substance evaporates readily, and this family of solvents has been identified as a leading cause of decay in the earth's ozone layer, which protects living matter from overexposure to ultraviolet rays from the sun. Recent findings indicate serious ozone depletion over the most densely populated portions of the Northern Hemisphere. Previously, damage primarily affected the unpopulated South Polar Region.

Additionally, 1,1,1-trichloroethane can find its way into and contaminate groundwater systems. Moreover, plant employees who inhale the vapor by-products can suffer adverse effects.

As a result, 1,1,1-trichloroethane is scheduled to be banned by international agreement by the year 2002. In the United States that deadline has been moved up considerably. President George Bush recently announced that the U.S. firms are required to phase out production of chloroflurocarbons, halons, carbon tetrachloride, and 1,1,1-trichloroethane by December 31, 1995. According to the HSIA (Halogenated Solvents Industry Alliance), the only exception to the ban will be "essential uses and the servicing of existing equipment."

That's a strong message. What it means is that companies have three, not 10 years to convert to other tapping fluids, free of such hazardous ingredients as 1,1,1-trichloroethane. The pressure is on.

Besides Tapping Fluids...

Other commonly used metalworking fluids pose environmental threats. In most cases, these are oil-based fluids that need to be applied generously to surfaces for metalworking. Every year users dispose of thousands of gallons of spent product classified as hazardous waste.

In addition to disposal problems, flood coolants create health hazards, such as skin irritations, slippery floors, and smoke/mist in the air.

To combat such hazards safer metalworking lubrication systems, comprised of a high-performance, vegetable-based fluid and application system, have been developed. Tests show that these systems pose no health risks to workers or the environment.

Because of a higher lubricity factor, they also require only a thin molecular coating on the cutting edge of a tool to dramatically reduce heat build-up during operation. When properly applied with an applicator, the lubricant is consumed in the machining process, thus eliminating the need for maintenance of flood or water-diluted coolants, sumps, and other elaborate drainage systems and waste disposal.

Previously, on one machining line, 280,000 gallons per year of diluted oil-based coolant were used. There was a constant need to dispose of the coolant as it became contaminated and rancid. With the new system, each nozzle uses only one-and-a-half ounces of lubricant daily, and the whole operation uses only about 200 gallons per month or 2,400 gallons per year.

The resulting savings are substantial, and there is virtually no mess to clean. Previously, oil-based fluids had to be collected and disposed of at a waste dump. They also might have been incinerated. Furthermore, the floor and other surfaces at plants that have switched to the vegetable-based lubricant systems are no longer covered with oil.

The natural lubricants also offer other benefits. Metal chips, which result from machining, remain dry and fall away cleanly from operations. When traditional coolants are used, the chips and oil remain on the finished parts and can require an additional cleaning process - and can create more contaminated run-off. If the metal shavings aren't completely removed from a part, they can impair the operation of a final assembly.

The superior lubricity of the new vegetable-oil based products increases tool life because reduced friction on the cutting surfaces eliminates the heat that causes the tool to quickly wear out.

For instance, a steel fabricator began using a vegetable-based oil and application system for its sawing operation and maintained detailed records for a 30-day period. By the end of the span, saw-blade life had almost doubled from a previous average of 28-32 hours to as much as 52 hours. Additionally, there was no longer a need for cleanup after sawing. The firm now sends parts directly to layout, punching, and end preparation, resulting in time and labor savings.

Moreover, because such systems are free of hazardous substances, their use isn't governed by the myriad of federal, state, and local regulations that apply to most other industrial lubricant and tapping fluids. So firms that switch to the newer, environmentally safe products can avoid compliance, disposal, and administrative hassles.

Industrial Cleaners Can Be A Problem

Another problem area toward which to cast an environmentally attuned eye is that of heavy duty industrial cleaners. Butyl Cellosolve, a substance that reportedly causes a variety of severe health problems in laboratory animals and humans, is found in some prominent industrial cleaners that call themselves "safe." However, the American Conference of Governmental Industrial Hygienists has established a maximum exposure level of 25 parts per million for the substance, and the use of Butyl Cellosolve has been condemned by the Registry of Toxic Effects of Chemicals.

New non-toxic, biodegradable products are available which contain no hazardous ingredients or solvents and which, with minor equipment modifications, can replace vapor degreasing systems currently utilizing 1,1,1-trichloroethane as a primary cleaning agent.

The environment is everyone's business. Utilizing today's new technology not only helps protect the environment, but also makes good business sense because the products are affordable, readily available, and easy to use. ■

Neal Vandewalle
is the Vice-President of the ITW Fluid Products Group. He has over a decade of experience in the metalworking industry.

Classification of Types of Gear Tooth Wear - Part II

Louis Faure
CMD Transmissions,
Cambrai, France

Introduction

The first part of this article included abrasive wear with two bodies, streaks and scoring, polishing, and hot and cold scuffing. This part will deal with three-body wear, scratches or grooves, and interference wear. Normal, moderate, and excessive wear will be defined, and a descriptive chart will be presented.

Wear With Three Bodies

This type of wear is characterized by the presence of a third body (in general abrasive) between the two surfaces in contact.

Scratches, Grooves (Scratching). This type of wear appears as isolated cavities and more or less deep streaks on the teeth flanks oriented in the direction of sliding motion. (See Fig. 1.) The intervals separating these scratches, their length, and their distribution on the teeth are very irregular. These scratches are generally caused by the introduction of foreign bodies of variable sizes in the gearing, particularly large dust particles, metallic particles, pieces of rust or calamine, molding sand, etc.

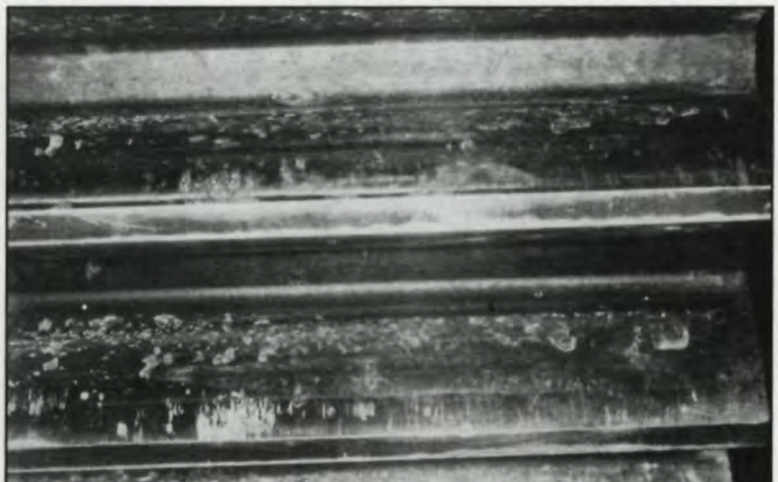


Fig. 1 - Scratches which can be seen on the uppermost part of the teeth profiles of a dryer wheel.

This type of wear can often be seen just after start-up, after the repair of an installation, or before the filter has had a chance to remove impurities from the lubricant.

Open gears lubricated with grease are, because of insufficient protection, very often susceptible to this type of deterioration. Scratches on the profiles are a sign of the presence of foreign bodies in the teeth. To avoid the development of abrasive wear, one should

- assure the structural integrity of the gear housing to prevent possible exterior pollution,
- check the state of the filters,
- filter the lubricant or change it,
- assure that no particles originating at the foundry may detach from the housing,
- lightly polish the scratched zones and assure that no hard particles are still embedded in the teeth surfaces.

This type of degradation, whose cause is to be looked for in the vicinity of the gear, is of little concern to the teeth if discovered in time, and if appropriate necessary measures are taken to stop its development.

We note a fundamental difference with the metal pull-off or adhesion phenomena, which are much more cause for concern, for they jeopardize the gearing conditions.

Abrasive Wear. This wear phenomon is caused by the presence of fine abrasive particles in the lubricant.

These particles may have come from the exterior environment of the gearing (dust, sand, miscellaneous impurities) and may have been introduced in the lubricant because of insufficient protection of the teeth. They may also have come from the inside of the gearbox (foundry sand particles, particles from metal burrs or pit holes, oil impurities).

The appearance of abrasive wear depends on the size and nature of the contaminating particles; for example, a fine abrasive dust will form a mixture with the lubricant, which will polish the teeth, giving them a dull, soft surface.

The presence of sand in the oil or grease (in the case of open gears) will generate a surface aspect rougher towards the tooth tip with a few scratches in the sliding direction and a polished zone below the pitch line.

On case-hardened gears, the presence of carbide near the surface may induce abrasive wear, especially if the load on the teeth is heavy, and if the sliding is high (as with hypoid gears).

When bigger particles are found in the lubricant, we may see the formation of a few scratches on the profiles (Cf. preceding paragraph.) They are generally present in the middle of the polished surfaces.

In the case of abrasive wear, the particles are constantly swept from the contact surfaces (in general by lubricant), and we never encounter local adhesions or micro-weldings.

Abrasive wear is thus totally different from scuffing phenomena because the scratches and the material removal seen are not the results of faulty lubrication or inadequate service conditions. The lubricant is often the vehicle which contains the abrasive particles and transports them throughout the system, causing pollution of the seals, bearings, bushings, the pumps, and all the meshings.

Abrasive wear is generally a phenomenon progressing very quickly and resulting in an increase of gear backlash in service, which may bring about modifications in dynamic behavior, and/or a distortion in the profile form which is the source of noises and vibrations.

If it is not detected, the erosion mechanism will continue and result in pointed teeth. It is not rare to discover worn teeth as shown in Fig. 2. Most of the time, when we attain a critical evolution as represented there, the tooth section has reduced greatly, and we often observe shearing effects in the zone BB.

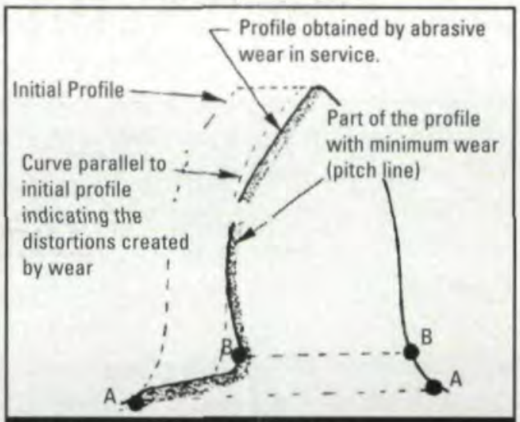


Fig. 2 - Abrasive wear mechanism.

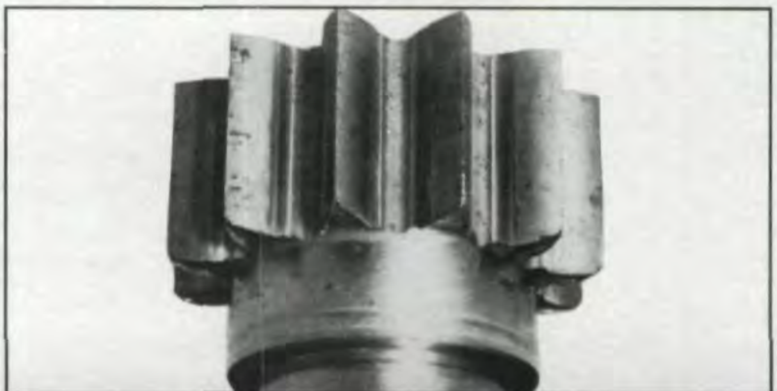


Fig. 3 - Abrasive wear of a pinion tooth. We can see on this figure the dull aspect of eroded flanks with the presence of a few scratches, the appearance of shouldering at the bottom of the active profile, and the tooth tips in knife-blade shape.

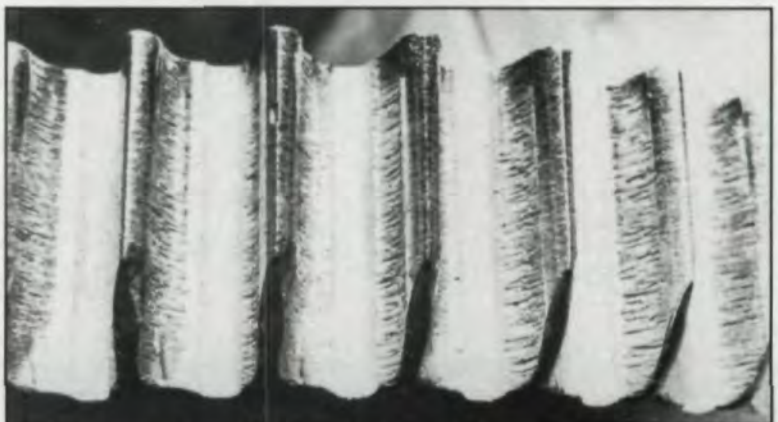


Fig. 4 - Abrasive wear with important loss of material.

In case-hardened gears, if the abrasive wear is intense, it will result in a rapid reduction of the thickness in the hardened surface on the teeth. This will bring about the formation of another type of deterioration (spalling), which will generally be fatal to the teeth, for the thickness of the hardened layer will no longer be sufficient to support the load to be transmitted. (See Figs. 3-4.) If the abrasive wear is detected in time, before its effect has caused a modification of the profiles and an increase of backlash incompatible

Louis Faure

is the Technical Manager at CMD Transmissions of Cambrai, France. He is an active member of ISO and AFNOR (Association Francais de Normalisation and the Union de Normalisation de la Mécanique. He has also taught gear theory and gear failure analysis.

with the gearing function, and if its causes are perfectly established so that efficient remedies can be undertaken, we will observe a durable stabilization of the state of the teeth.

Interference Wear

This type of wear occurs when contact between teeth happens in bad geometric conditions at the beginning or the end of meshing. This is the case mainly when the contact occurs outside of the action segment. The two profiles in contact are no longer tangent, and their faulty mating during this period of the meshing generates an overload or shock in the teeth zones concerned.

We observe during the beginning of meshing a concentration of the load on the low point of the driving element. At the end of the recession, we encounter the concentration of the load at the tip of the driving element profile.

This interface mechanism is illustrated on the sketch in Fig. 5. We have represented on each side of the segment of action *T1T2* two pairs of teeth meshing in interference position. In general, an interference wear appears at the low point of the profile in a narrow wear zone (sometimes with the presence of pitting or scratches), and at the tooth tip in the form of streaks prone to evolving into scratches and, in extreme cases, metal pull-off.

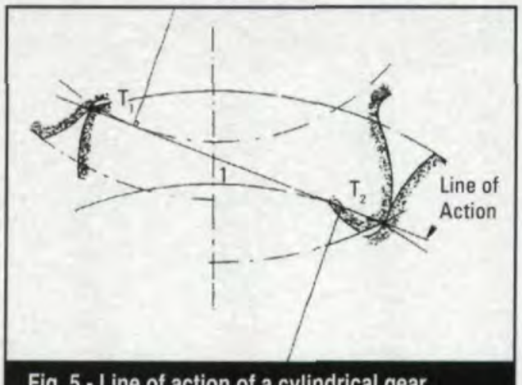


Fig. 5 - Line of action of a cylindrical gear.


Fig. 6 - Interference wear recorded on the base of a driven gear wheel profile.

In general, since we will detect shocks at extreme points of the meshing, this type of wear will result in an increase in gearing noise. In the case of through-hardened gears we observe a hollow in the lower parts of the profile, as well as a light flow on the high parts of the profile, which will result in the formation of a burr on the active ridge at the tooth tip. In general, interference wear is not dangerous, for as the gear wears off, we will observe a reduction of shocks and overloads at the extreme points of the meshing. The degradation which may be observed on the flanks will end up by running in and disappearing, and the noise level will reduce.

In general, interference wear is not influenced by the lubrication quality. We encounter this type of wear:

• When the design of the teeth was bad (primary interferences),

• When the teeth have undergone overloads which have brought about exaggerated deflections of the teeth in service,

• When the gear contains, in the critical zones of the profiles, excess material which results from cutting defects.

• When one or more teeth have been distorted, cracked, or broken in service. In this case, the meshing of the following tooth and perhaps a few other following teeth is no longer assured, and we observe shocks at the base of the profile which generally are extremely severe and can cause the formation of deep hollows. Fig. 6 gives an example of interference wear recorded on the flanks of a gear wheel.

Normal Wear

This is a slow, progressive wear which is not prejudicial to keeping the gear in service for the normal expected life.

In this class of wear we generally place common wear abrasion with two bodies in all its different possible manifestations. In the case of normal wear, we are not in the presence of damage, but of a normal appearance which shows proper operation of the teeth.

In general, this type of wear requires no special inspection or any systematic follow-up if we do not see any notable evolution after a certain time of gear operation. This type of wear appears very slowly in surface-hardened teeth. The same is true for lightly loaded gears.

For gears of moderate hardness, the wear will develop on each side of the pitch line where sliding is null by modifying the shape of the profile as indicated in Fig. 7. As long as the wear remains low, this type of profile form evolution of the teeth is beneficial at the meshing level, for it allows better absorption of the teeth impacts during their engagement.

We will thus often observe the disappearance in time of the streaks at the tooth tip or at the root of the teeth, which sometimes appear soon after first start-up of a gear (in the general case of gear teeth loaded at low speed or medium speed).

As wear progresses, the profile deviations will increase with such consequences as an increase of dynamic efforts during meshing, as revealed by the increase in noise and vibration levels or an increase in backlash.

We can fix a limit to normal wear by considering the following:

• The maximum value of backlash authorized in service by the designer of the gear. This tolerated value will be very much different whether the load direction changes or remains always applied to the same series of flanks during the rotation of one of the gear wheels.

• The vibration level or noise level, which should not surpass a certain preset value.

• The dynamic effects during meshing due to deviations of profile caused by wear. In fact, these deviations generate overloads on the teeth for which the gearing has not necessarily been sufficiently dimensioned when designed. They are generally difficult to estimate, but the appearance or the progression of pitting on the teeth can be a useable criterion to set the end of normal wear.

We will consider the criteria defined above each time that the mechanism in which the gear is placed transmits alternate effects or is subject to important torsional vibrations. They should also be considered in the case of gears used for driving alternative machines or machines of high inertia having long drive shafts or with low rigidity, or in the case of mechanisms with backlash compensation or gears used to carry out precise displacements.

To follow the evolution of backlash in service, we can periodically record the distance between the profiles, either with thickness gauges inserted between the teeth or by "rotating" the teeth and measuring with a comparator the relative movement of one element of the gear in relation to another near the pitch line.

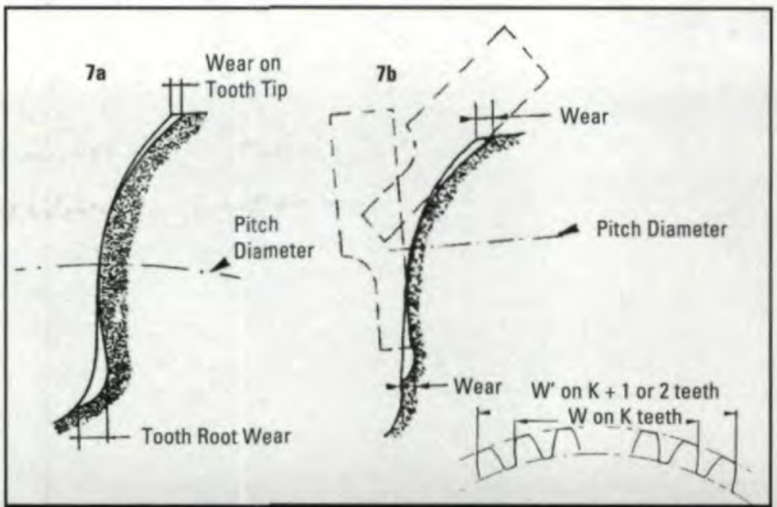


Fig. 7a - Distinctive aspect of distortion of gear teeth profiles under wear action. 7b - Principle of direct wear measurement.

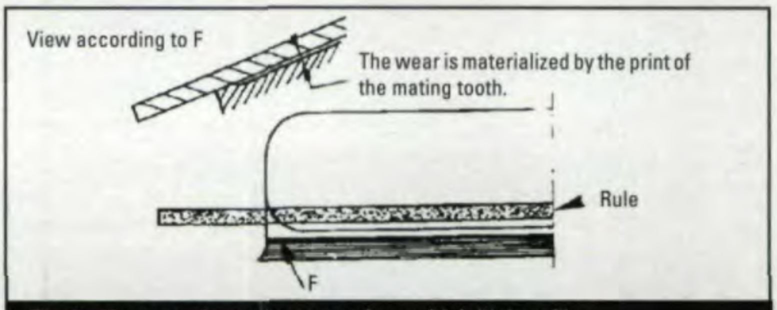


Fig. 8 - Measure of wear by comparison with initial profile.

We can also make a direct evaluation of wear on the teeth by using the following method:

• Check the value of *Wk* over *K* teeth, which gives the distance near the pitch line measured on the *K* teeth. At this point on the teeth, the wear is lowest. (Cf. Fig. 7b.)

• Check the value of the distance over the $K + n$ teeth ($n = 1$ or 2) in such a manner as to tangent to profiles near the tip circle.

• Check the value of the distance over the $K - n$ ($n = 1$ or 2) in such a manner as to tangent the profiles near the dedendum in the place where the teeth show the greatest wear (Cf. Fig. 8).

• Determine the wear value using the following formula:

wear on tooth addendum:

$$\frac{(W_K + n \cdot p_b - W_{K+n})}{2}$$

wear on tooth dedendum:

$$\frac{(W_K - n \cdot p_b - W_{K-n})}{2}$$

with p_b = base pitch

The wear values obtained (reduced from tip relief if need be) will be used for maximum

Fig. 9 - Normal wear. Aspect of a large gear wheel flank lubricated with grease.

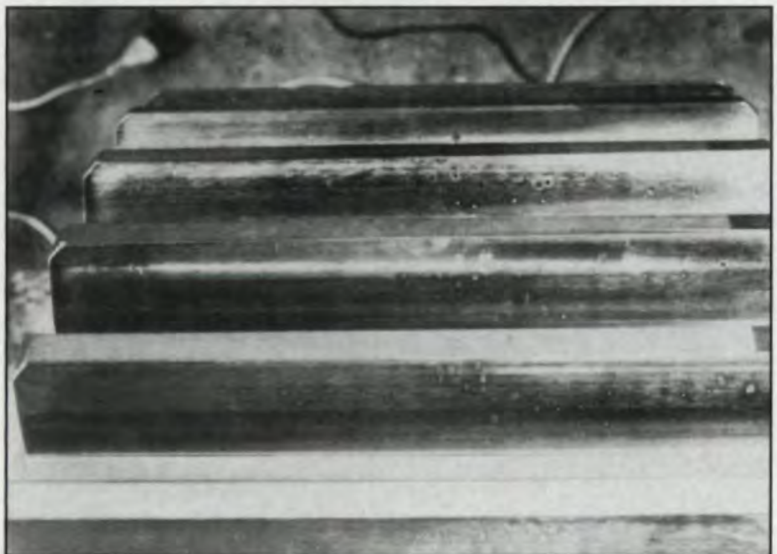


Fig. 10 - Normal wear. Normal aspect of gearing teeth flanks. We note a few traces of the passage of foreign particles between the teeth and some unimportant small pitting.

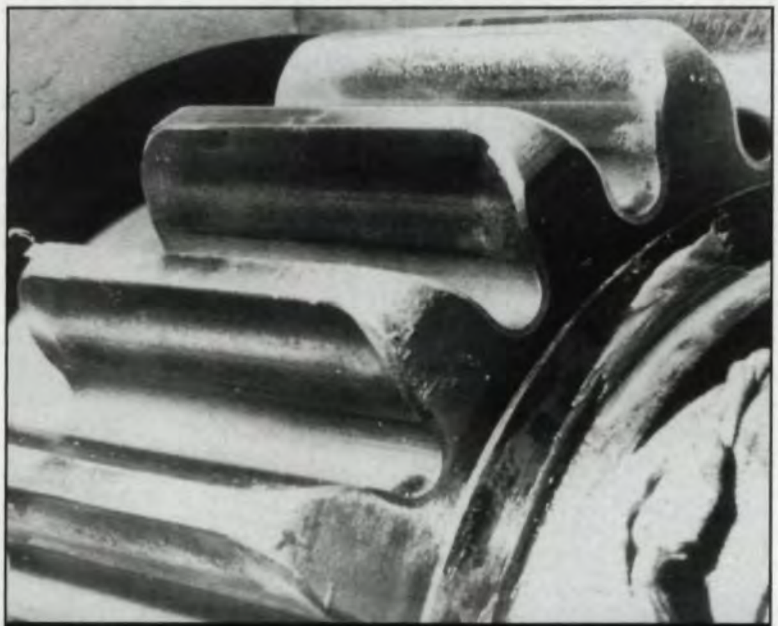


Fig. 11 - Moderate wear. We will note the trace of the operating pitch line on the teeth flanks and the presence of fine streaks indicating that the teeth operate near the limit rate of lubrication.

backlash calculation of the gear in operation. In certain cases, the wear on the flank dedendum may be obtained from the print left by the mating wheel by direct measurement with gauges (See Fig. 8). Generally we can classify as normal wear the following surface aspects:

• Streaks or scratches on the teeth surface, providing that they do not evolve while in service,

• Polishing, providing that its surface does not show localized traces of metal pull-off or scuffing,

• Abrasive wear, providing that its progression is slow or has become stabilized. This type of wear is often beneficial at the beginning of a gear life for it encourages the establishing of good contact surfaces.

• Interference wear when it is slightly marked on the teeth. In the case of through-hardened teeth, we can admit that normal wear is often accompanied by the formation of pitting in the heavy loaded zones of the gear. (See Figs. 9-10.)

Moderate Wear

At this stage of wear development, the teeth appearance is such that we can easily notice that material removal has occurred during operation near the tip of the teeth and on tooth flank dedendum. In general the trace on the operating pitch line becomes apparent and appears as a continuous line of low thickness on the whole width of the teeth. On this line we do not notice any wear or material removal.

Moderate wear is characterized by loss of material along the profiles which is more rapid than that obtained in the case of normal wear. This wear appears most often when the gears operate near their limit rate of lubrication. Many gears, because of voluntary oil viscosity limits rendered mandatory by use conditions (cold starting without preheating, for example), operate under such conditions.

This type of wear appears almost systematically in the case of highly loaded gears made of through-hardened steel and running at low speed. In this case, we often see the appearance of pitting, which is more or less dense on the teeth profiles. (See Figs. 11-12.)

The presence of particles in the lubricant or the pollution of the lubrication device can also lead to the generation of this type of wear. The moderate wear seen on the teeth is not in most applications an abnormal phenomenon and may be considered non-destructive.

It can generally be tolerated, but can be reduced by increasing the oil film thickness, mainly by assuring a better cooling of the oil (reducing gearing operating temperature), or by increasing the oil viscosity. We can also possibly reduce the load on the teeth (for example by improving the dynamic conditions).

If the gearing is operating with lubrication by splashing, we will often obtain good results by installing an injection lubrication system with a filter to retain the metallic particles in suspension in the oil.

In the case of gear wheels lubricated with grease, we obtain a noticeable improvement by replacing this lubricant by oil whenever possible. This implies that the sealing conditions in relation to the environment, the conditions of exterior pollution by the oil, or the safety conditions (installation temperature) will allow such replacement.

A moderate wear can lead to an increasing the noise and vibrations of the gear which sometimes result in a reduction of anticipated gear life.

Excessive and Destructive Wear

This type of wear is considered an anomaly which often leads to rejecting the gear or anticipating its replacement.

The result is an important change of teeth shape and in most cases in a great reduction of their thickness. This deterioration of teeth can result from separate or joint action of one or more wear phenomena described in the preceding paragraphs. We can, for example, find teeth whose general appearance is comparable to that of moderate wear, but the volume of material removal is very large. We note the appearance of a step near the tooth root, the very low residual tooth thickness, and the destruction of the overall shape of the profile. This type of deterioration is generally generated by abrasive wear, which can in certain cases, when the residual thickness of the teeth becomes weak, end up in the total breakage of whole teeth by shearing.

We can also find destructive wear which is the result of adhesive wear and is due to direct contact between teeth flanks because the load transmitted was too large for the lubricant used. It is often the case for highly loaded gearing running slowly, where we observe the development of cold scuffing or of deep scratches.

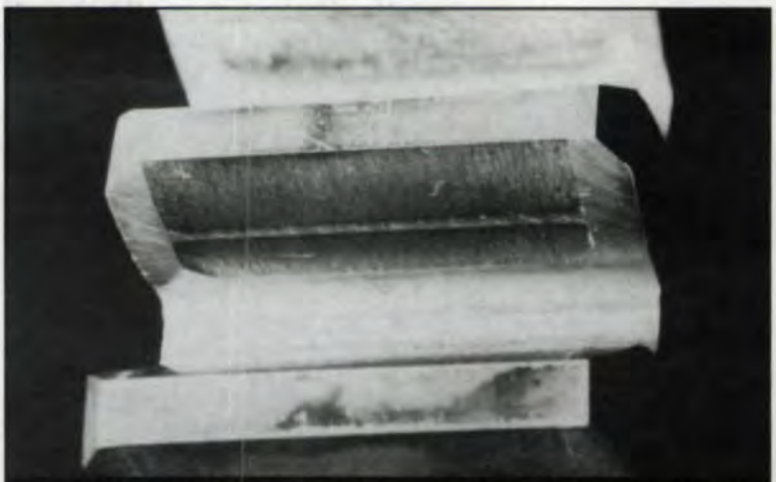


Fig. 12 - Moderate wear. This moderate wear has been caused by hot scuffing, which was stopped in time. We clearly note the traces of material pull-off near the tooth tip and root. The operating pitch surface is not altered.

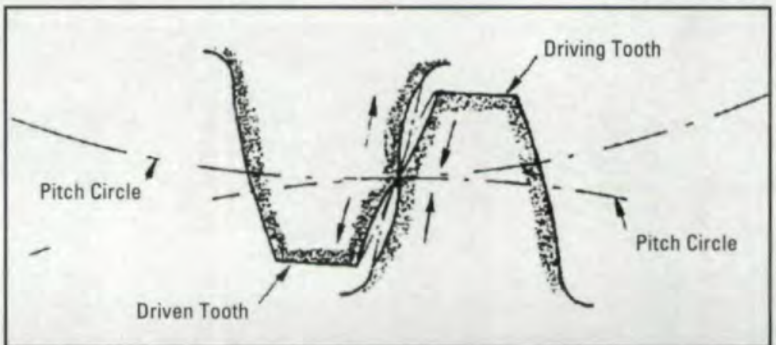


Fig. 13- Mechanism of destructive wear.

Fig. 14 - Excessive wear of a spiral pinion. We note the presence of steps in the profile root and pointed tooth tips. This pinion is near the end of its life.

The sketch in Fig. 13 shows how the destruction occurs on teeth profiles.

In the case of through-hardened gearing, undetected hot scuffing can most of the time result in destructive wear which will take the gear out of service.

Destructive wear can also be caused by the development of severe pitting, which most of the time is localized below the pitch line, and which is caused by multiplying the falling in of the teeth surface in the region affected, thus destroying the general profile shape. (See Figs. 14-16.)

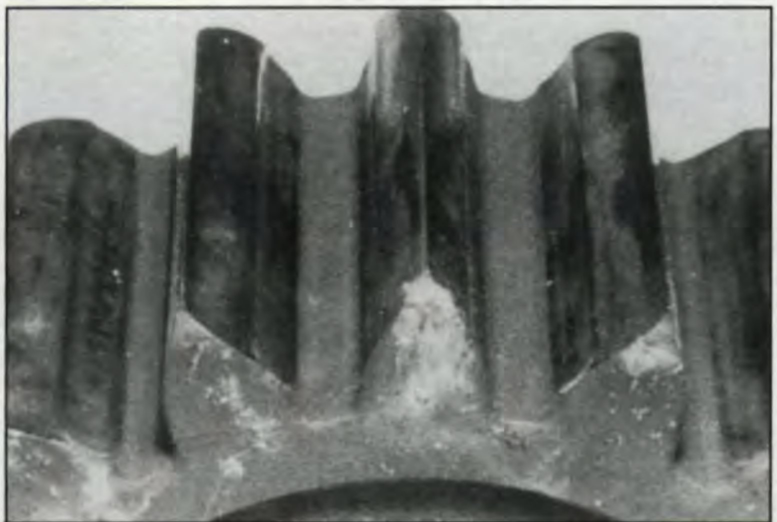


Fig. 15 - Excessive wear of a pinion. We note the presence of pointed teeth and important distortion of the profile in the dedendum.

Fig. 16 - Excessive wear of a pinion. This wear, which has been caused by extended scuffing, has brought about a spectacular reduction of tooth thickness in the meshing zones. We note the presence of deep grooves in the direction of slippage motion, the presence of a line at the pitch diameter, and the presence of pointed teeth. This pinion is out of service.

Table I

	Abrasive wear with 2 bodies		Adhesive wear				Wear with 3 bodies		
	Wear with 2 bodies	Scoring Streaks	Polising	Adhesions or metal pull-off	Hot scuffing	Cold scuffing	Scratches Grooves	Abrasive wear	Interface wear
Normal wear with slow progression	⊗	⊗	⊗					⊗	⊗
Moderate wear can be tolerated Progression to be surveyed		⊗		⊗			⊗	⊗	⊗
Excessive wear can be considered as gear limit use.		⊗			⊗	⊗	⊗	⊗	
					Breakage				

Before trying to find a remedy for excessive wear to save the gear, the underlying cause (or causes) must be determined.

• In the case where the lubricant is responsible, its performance must be increased (viscosity choice), or the load to be transmitted must be reduced. If the profiles are deeply distorted, this remedy will be efficient only if a run-in or a re-machining of the teeth is performed to re-establish a good conformity of the contact surfaces (in the case of through-hardened gears).

• In the case of excessive wear caused by abrasion, an improvement of the housing sealant or lubricant filtration will quite often solve the problem. However, we must be certain that the excessive wear demonstrated by increase of backlash between the teeth is compatible with the full safety operation of the driven element. When there is a doubt, a gear replacement must be performed.

• When we see excessive wear caused by the multiplying of pitting on the teeth and often accompanied by an increase of noise and gear vibration, (in the case of through-hardened teeth) we can proceed to a re-machining of the teeth or a grinding of upper parts of flanks which are too thick, to try to re-establish a good conformity of the geometry of the teeth in contact. We can also increase the lubricant viscosity, which would effect a reduction in pitting development.

If despite this treatment, such wear continues to develop, it means that the load transmitted is excessive for the material performance and the causes have to be looked for in the unforeseen overloads which happen in service, or in the insufficient hardness of the teeth flanks (in the case of through-hardened teeth). The entire design of the gear has to be re-examined.

Conclusion

To complete this article, we propose a classification of wear phenomena which has been established as follows: We have recorded in a double chart different wear forms on one side, and on the other side, different characteristic wear levels. (See Table I.)We have placed with references and arrows arranged in chart boxes each type of wear at its initial development stage (which we can usually ascertain), and possible evolution which we may ascertain for each phenomenon previously described. ■

Acknowledgements: *Published as AGMA documents 88 FTM 4 and in Europower Transmission, April, 1992. Reprinted with permission.*

Our Readers Discuss Gear Rattle, Gear Books, and *Gear Tech*

Investigation of Gear Rattle Phenomena

The article by Messrs. Rust, Brandl and Thien was very interesting in its description of the problem and of some of the interactions which occur.

The authors have concentrated exclusively on the excitiation due to torsional vibrations from the engine, but in general this is only part of the problem. As they correctly deduce, it is angular acceleration that is critical, but in many cases, the angular acceleration is due to a combination of engine torsionals and gear transmission errors.

At 1,500 rpm with 0.5% speed fluctuation twice per revolution the angular acceleration due to the engine is 250 rad/s^2. A transmission error of 1 µm at 30 mm radius on a gear at a frequency of 30 times per revolution (once per tooth) gives an angular acceleration of 740 rad/s^2 at this speed, and so can greatly assist rattling.

The effects of gear transmission errors on rattle can normally only be neglected if the gears are quite exceptionally accurate. However, the gear errors tend to give impacts on the drive flank only, rather than the leading and idling flank impacts associated with engine torsionals.

J.D. Smith
Cambridge University
Cambridge, England

Good Gear Books Revisited

I believe you will still find *Wire Measurement of Screws, Gears, Splines, and Worms* by W. F. Vogel available from Joseph Silvagi, Camdale Precision, Inc., 15900 Common Road, P. O. Box 295, Roseville, MI 48066. He also has copies of Vogel's *Involutometry & Trigonometry*.

Robert E. Smith,
R. E. Smith & Co., Inc.
Rochester, NY

Rave Reviews

An addendum to one of the responses to our Readers' Survey in our last issue...

I realize that a cover sheet was not required for this faxed response, but I felt duty bound to elaborate on my impressions of *Gear Technology*.

...I have been on the mailing list since the first issue of the magazine. Since then I have saved every issue. EVERY issue. Information gleaned from its pages has provided me technical material with which to solve problems, spectacular covers to grace the appearance of my office, and historical commentary that added color and content to lectures I have given on the subject of gears.

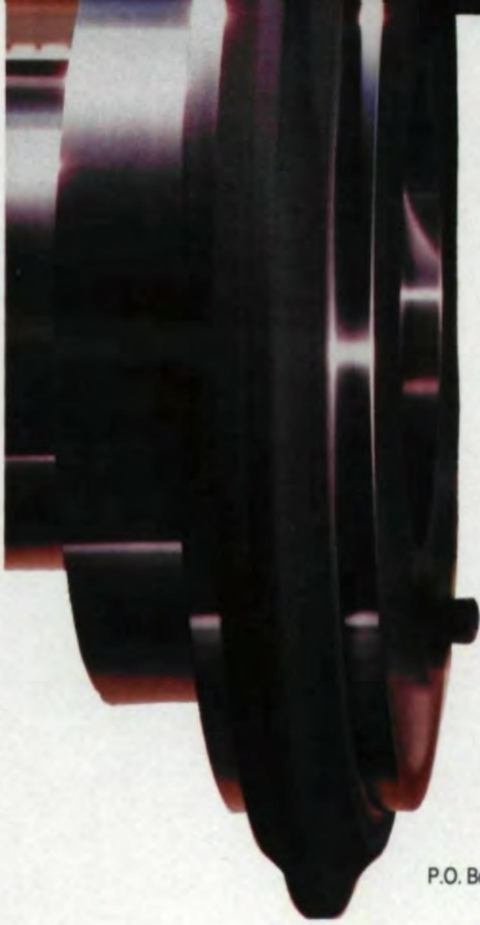
The series of drawings by DaVinci on the early issues, the photo of the "South Pointing Chariot," and articles on everything from the basics to the arcane make this magazine nothing less than a collection of superlatives.

Keep up the excellent work!

Raymond E. Shaw
Executive VP/Gear Engineer
Maddox Metal Works, Inc.
Dallas, TX

VIEWPOINT

We welcome your opinion. Share your viewpoint with the rest of our readers. Address your letters to The Editor, Gear Technology, P. O. Box 1426, Elk Grove Village, IL 60009. We reserve the right to edit letters when space requirements demand it.



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CIRCLE A-41 on READER REPLY CARD

Hiring & Firing the Older Employee

Be wary of the reasons you give either verbally or in writing.

Howard J. Rubin
Ellen C. Auwarter

MANAGEMENT MATTERS

Given the current economic and legal climate, matters of hiring and firing are cause for considerable concern among managers. In addition to all the other factors to be considered, employers must be wary of exactly how these procedures should be carried out, so that the company is not left open to lawsuits based on charges of discrimination of one kind or another. The reasons given for a particular employment decision may be as crucial to determining liability as the decision itself.

Employers need to be especially wary in the case of employees over 40, who may have cause for litigation under the Age Discrimination in Employment Act ("ADEA"). Several recent cases illustrate the fine line an employer must walk when terminating or refusing to hire an older employee. While these cases relate to industries other than gear manufacturing, the issues they raise can affect any company and are, therefore, instructive.

A recent decision from the U. S. Court of Appeals for the Second Circuit, in New York, *Bay v. Times Mirror Magazines, Inc.*, provides vital clarification of two legal principles that are often litigated whenever an employee or job applicant sues for age discrimination. Both principles relate to the reasons given by the employer for the termination of the current employee or its refusal to hire a prospective employee. The *Bay* decision illustrates how the way in which an employment decision is justified can be critical to the employer's defense to an age discrimination claim.

Beware of "Overqualified"

The *Bay* case arose because of Times Mirror's acquisition of *Field & Stream* magazine, after which Times Mirror implemented a reorganization. As a result of the reorganization, plaintiff's position - a publisher of *Field & Stream* - was downgraded to one with less responsibility and a reduction in salary. The downgrade also required that Bay report to a second-level manager (a group publisher) instead of to the president of the company, as he did before the reorganization. Times Mirror interviewed Bay and others for the position of group publisher. But because Bay would not accept the demotion or the concept of group publisher, he was terminated. In his age discrimination lawsuit, Bay argued that he had been rejected for the posi-

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Howard J. Rubin
is a partner with the law firm of Davis & Gilbert, New York City, which specializes in advertising, marketing, and business law.

Ellen C. Auwarter
is an associate with the same firm.

tion of group publisher because he was overqualified.

In so arguing, Bay sought to take advantage of the relatively new case law in the Second Circuit that an employer who refuses to hire a job applicant or fires an older worker because that person is "overqualified" for the position, may be guilty of age discrimination. This principle was established in *Taggart v. Time, Inc.* and *Binder v. Long Island Lighting Co. ("LILCO")*. The Second Circuit panels in these cases reasoned that, in general, the older a person gets, the more qualified he or she becomes. The Court's decisions reflected its concern that employers might use the excuse that a person is "overqualified" as a coverup for age discrimination. If employers could fire or refuse to hire "overqualified" applicants, it would essentially be providing employers with a pretext, i.e., a way of disguising the fact that age discrimination played a part in that decision.

MANAGEMENT MATTERS

A *conclusory statement* that a person is "overqualified" may easily serve as a mask for age discrimination.

In *Taggart*, a prospective employee had applied for 32 positions at Time Inc. and was not placed in any of them solely because he was said to be overqualified for some positions and underqualified for others. The Court held that *Time's* refusal to hire Taggart solely because he was overqualified constituted circumstances from which a reasonable juror could infer discrimination by *Time* by concluding that the reason given was not believable and therefore a pretext.

In the *Binder* case, an employee had been forced into early retirement after his position was eliminated. Plaintiff argued that positions had been available, but had been filled by younger people. LILCO did not contest that fact and instead defended its decision by stating that no available position was "suitable" or "appropriate" for Binder's level of skill and salary. Consequently, LILCO believed that Binder might become frustrated if a position made little use of his experience. In response to that contention, the Court noted that although a jury could conclude that LILCO was acting out of a genuine concern for Binder's job satisfaction, it could also conclude that

LILCO's explanation was a pretext for age discrimination. The Court noted that the Age Discrimination in Employment Act "does not forbid employers from adopting policies against 'underemploying persons in certain positions so long as those policies are adopted in good faith and are applied evenhandedly.'" With that, the Court reversed the District Court's grant of summary judgment in favor of the employer.

The concurring opinion in *Binder* is instructive, for its warning led to the ruling in *Bay*. The occurrence suggested that *Taggart* and *Binder* may lead employers to believe that they can never hire or fire a person based upon whether that person is overqualified and that, if they do so, an age discrimination lawsuit will automatically go to trial. The concurring judge opined that an employer may actually have legitimate reasons for declining to employ overqualified individuals and should not be prohibited from declining to do so.

The *Bay* case responded to the call for clarification when it held that:

"Neither [*Taggart* nor *Binder*] forbids employers from deciding to place employees in positions for which they are overqualified on the ground that overqualification may affect performance negatively....The problem addressed in those cases is that *a conclusory statement* that a person is overqualified may easily serve as a mask for age discrimination."

Thus, the *Bay* court held that employers had to give an explanation whenever they failed to hire or terminated an employee on the grounds of overqualification. With respect to the decision to terminate Bay, Times Mirror had provided sufficient explanation in that there was more than a conclusory statement that Bay would have been overqualified. Indeed, Bay himself conceded at his deposition that he was dissatisfied with his downgraded position both because of his diminished responsibilities and because he would be required to report to a second-level manager. This was the very concept with which he disagreed. Given those facts, the Court held: "Dissatisfaction in a downgraded position is a legitimate reason for an employer to replace an employee with someone not distracted by such dissatisfaction."

When making hiring decisions, companies should carefully evaluate the applicant's qualifications against the duties of the job, and, if it is determined that a person is not appropriate for the job, or is not the best applicant available, be specific in the company's records about why the applicant is being rejected, rather than merely saying that he or she is "overqualified" for the job. Remember that companies are not required to tell applicants why they are not being hired. This is probably the best course to follow.

With respect to reorganizations, a similar course of action should be adhered to. Be specific about the reasons for the "overqualification." In addition, be mindful of the fact that the employee being asked to take a demotion is still on the premises. Communication is critical. Indeed, a key factor supporting the decision in *Binder* is that the plaintiff was never given any opportunity to say whether he would be content in a downgraded position. In contrast, Bay's opinion was clear: he "chafed at the diminution of his responsibilities," both while still employed and at his deposition. That fact was instrumental in the Court's decision that he in fact was "overqualified" for the position and that the employer's decision to terminate him was justified by a nondiscriminatory reason. Therefore, it is wise to give the employee every opportunity to show that he or she would or would not be dissatisfied with the demotion.

Salary and Length of Service as Factors

The *Bay* decision is instructive in another thorny, oft-litigated area - namely, the issue of whether an employer can make employment decisions based on a person's salary or length of service. Prior to *Bay*, consideration of either factor had been held impermissible under the ADEA. *Bay*, however, reached the opposite conclusion. In support of his claim that the most senior, highly compensated employees were eliminated after the reorganization, plaintiff urged the Court to consider an inter-office memorandum written by the Chairman of Times Mirror and circulated to James Kopper, the Executive Vice President to whom Bay had to report in the downgraded position. The memorandum noted that Bay's salary was well above the salaries of Times Mirror's other publishers and was more than Times Mirror would have to pay for a group publisher, the title just above plaintiff's. Plaintiff argued that these references to salary established that "high salary was a critical factor in the decision not to retain [him]."

The Court held that nothing in the ADEA prohibited an employer from making employment decisions that "relate an employee's salary to contemporaneous market conditions and the responsibilities entailed in particular positions in concluding that a particular employee's salary is too high. *To be sure, high salary and age may be related, but, so long as the employer's decisions view each employee individually on the merits, do not impose a general rule that has a disparate impact on older workers...and are based solely on financial considerations, its actions are not barred by the ADEA.*"

Despite this seemingly clear direction from the Second Circuit, decisions since *Bay* continue to grapple with the fine line between whether considerations of salary and length of service are in fact "based solely on financial considerations" or whether they provide evidence of age discrimination. In a decision from the Western District of New York, *Wolf v. Ferro Corp.*, plaintiff introduced two pieces of direct evidence in support of his age discrimination claim. First, he cited a statement from defendant, a manufacturer of speciality ceramics, that he was let go instead of a younger employee "because it was expected that [plaintiff] would retire soon, whereas [the other employee] was much younger and would continue to develop." The second piece of evidence was a statement regarding the standards the employer used to decide who should be laid off during the reduction-in-force: "We talked in terms of dollars...."

In deciding that Wolf's case had to proceed to trial, the Court noted that the first comment indicated that the comparative ages of the two employees factored into defendant's decision to discharge plaintiff, and the second comment indicated a "desire to 'replace an older employee with a young one for the sole purpose of economizing on salary costs.' "

Bay stands out as the notable exception to the general rule that salary and length of service are impermissible factors. If this split in the appellate courts continues, it is likely that this issue will head to the U.S. Supreme Court for resolution.

In the meantime, companies would be wise to assess each termination of employees over 40 using the criteria outlined in the *Bay* case; justify such terminations by evaluating the employee as to the substance of his or her performance, and relate the termination solely to the financial performance of the company and its need to save a certain sum of money - not to the salary of a younger employee. ■

MANAGEMENT MATTERS

Companies should justify the termination of over-40 employees based on the substance of their performance and on the need of the company to save a certain number of dollars, not on the smaller salaries of younger employees.

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Custom-made high precision ATA -spiral bevel gears with two months' delivery!

Spiral Bevel Gears

Our basic product is spiral bevel gears. Our experience in handling highly classified materials, our high precision hard cutting method, as well as our own heat treatment spotlight us as a gear producer for demanding customers, such as the off-shore and mining industries, as well as machine tool and car manufacturers. Furthermore, we have equipment especially developed for shot peening spiral bevel gears. Our latest achievements are being chosen as suppliers to Indy CART, F1, C1, drag racing, off-road, rally, and truck racing teams on a world championship level.

Special Gear Boxes

In addition to spiral bevel gears, ATA also manufactures custom tailored complete gear units for marine and heavy duty applications.

Hydro Power Plants

The ATA product development work is remarkably represented by propeller-turbine operated small electric power plants. "Turnkey" service-free hydro-electric power plants produce with falls of 2-30 meters, power capacity of 20-2400 kW.

ATA

Professional experience over half a century

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CIRCLE A-8 on READER REPLY CARD

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