Dry Hobbing Process Technology Road Map

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Introduction

Recent trends in gear cutting technology have left process engineers searching for direction about which combination of cutting tool material, coating, and process technology will afford the best quality at the lowest total cost. Applying the new technologies can have associated risks that may override the potential cost savings. The many interrelated variables to be considered and evaluated tend to cloud the issue and make hobbing process development more difficult.

Considerable work has been done cooperatively between the tool manufacturers and material vendors to improve the capabilities of the substrates being used. Efforts by both high-speed steel and carbide manufacturers are yielding materials that allow a continuous expansion of the envelope of productivity gains in gear production.

With today's advances in gear manufacturing equipment, there is a necessity to advance the capabilities of tools. In order to exploit new machine potential, extensive tool developments have taken place in recent years. Building on the successes (and failures) of earlier efforts, there has been an explosion of new technology with both new coatings and new materials.

The days of having one broad-range coating and limited material selection are long gone. The difficulty now is to determine the best combination possible for a given application, taking into consideration the specific gear manufacturer's expectations.

The purpose of this paper is to:

- Describe current technologies of gear cutting tool materials, specifically the relative properties of high-speed steels (HSS) and carbide grades.
- Describe thin-film coating technologies used for both wet (water-soluble or oil) and dry cutting processes, and discuss the properties and merits of those coatings.
- Discuss tool configuration requirements necessary for higher material removal rates and for dry cutting.
- Present application parameters for the use of tools under dry cutting conditions and results of successful and failed applications.
- Discuss the evaluation of the failure modes most common to dry cutting processes.
- Present a systematic approach to aid in the application of the technologies. By evaluating costs and risks associated with various processes for applications, the process engineer can implement new technologies where the savings/risk factor is most favorable.

The scope of this paper is limited to applications of tools in the 10–20 NDP range. However, the concepts presented can be modified and applied to other applications.

Systematic Approach

1. The first step, before making any changes to optimize an existing process, is to fully understand the current process parameters, costs and failure modes. Define the variables, such as part data, material, hardness, machinability, machine capacity and restrictions, tooling rigidity, chip removal issues, speed, feed, number of cuts, and shift strategy. Tool design characteristics, material properties and coatings must be defined. Define the measurables of the present process, such as cycle time, part change time, parts per hour, and downtime for hob change. Costs, such as tool price, sharpening costs and recoating costs, should be known. How much wear is generated for the current number of parts produced? Is the failure mode pure flank wear, or is chipping

Table 1—High Speed Steel Compositions.

Alloy Type	C Carbon	Cr Chromium	W Tungsten	Mo Molybdenum	V Vanadium	Co Cobalt	Total Alloy
M4	1.4	4.3	5.8	4.5	3.6	—	19.6
Rex 54	1.45	4.3	5.8	4.5	3.6	5.0	24.7
Rex 45	1.3	4.1	6.3	5.0	3.1	8.3	28.1
T15	1.6	4.0	12.3	—	5.0	5.0	27.9
Rex 76	1.5	3.8	10.0	5.3	3.1	9.0	32.7
Rex 121	3.4	4.0	10.0	5.0	9.5	9.0	40.9

Table 2—Cemented Carbide Compositions.

Grade	% WC Tungsten Carbide	%Cobalt	%Alloy carbides	Transverse Rupture Strength
C2	90	10	0	500 ksi
C4	94	6	0	360 ksi
C5	71	13	12% TaC, 4% TiC	380 ksi
C6	73.5	10	8.5% TaC, 8% TiC	325 ksi

or cratering also causing tooth damage? Without a firm understanding of present costs, how can an organization identify the best potential option offering the greatest chance for improvement with the least risk?

2. Perform theoretical evaluations of cycle time possibilities at various hob diameters and numbers of threads and gashes. Hob speed, chip load and feed scallop size will be the limiting factors, within the constraints of machine speed and horsepower capacity.

3. Look at material options, such as carbide, high speed steel and traditional materials, for wet and dry cutting applications.

4. Look at coating options for wet versus dry applications.

5. Look at cost per part (CPP) evaluations of the best options from the above choices.

6. Develop a test matrix to try one or two of the choices that show the best cost predictions.

7. Test tools for initial use and throughout sharpening and recoating, evaluating wear performance, part quality, performance through subsequent operations, etc.

8. Compare actual results to estimates.

Tool Materials

The following paragraphs provide a brief summary of commercially available substrate materials and coatings commonly used in the gear cutting industry. Although some of the information may seem academic, it is essential to have a good understanding of the characteristics of tool materials and coatings in order to maximize efficiency of the application.

Far from the days when conventional (cast) M2, M42 and T15 alloys were the predominant materials in gear cutting tools, the tool designer now has an extensive selection of quality high speed steel materials from which to select. In the United States, the newest generations of materials are manufactured by particle metallurgy (PM) for improved manufacturability, toughness and general cutting performance. Due to the prevalence of vacuum hardening and tempering, many of those alloys have evolved over recent years to optimize their heat treatment response.

Although there is a multitude of high speed steels available worldwide, such steels can be generally categorized into one of several groups based on their physical properties. In order to limit the scope of this discussion, only those materials readily available in the United States are covered.

The most common material in domestic gear cutting tools today is CPM M4 (Crucible particle metallurgy). Typically used in the hardness range of 64–66 HRc, it has very good wear resistance, has excellent edge toughness and is generally applied on a wide range of applications, cutting workpiece materials with hardnesses up to 38 HRc. Since M4 contains no cobalt (Co), it has a relatively low red (hot) hardness. Table 1 shows a comparison of some common gear cutting tool steels.

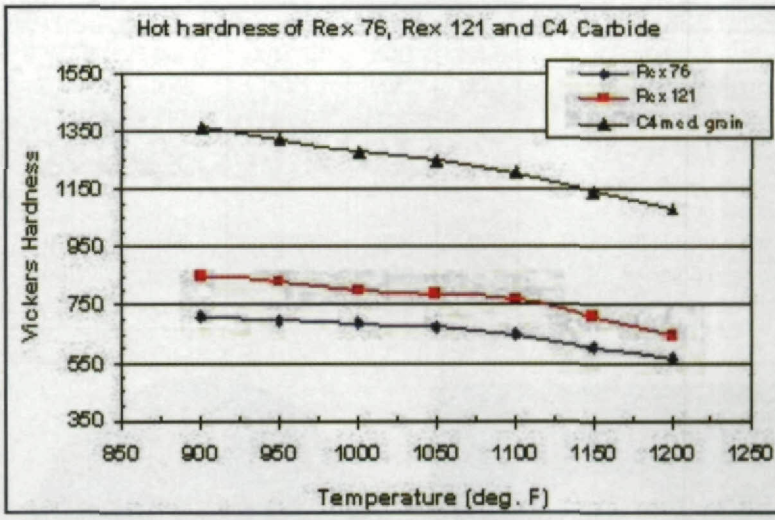

Figure 1—Hot Hardness of HSS and Carbide Materials.

Upgrade considerations to the base M4 material might be considered to take two paths, increased wear resistance or increased red hardness. CPM 54 is a fairly new alloy based on the M4 grade but with slightly higher carbon for higher hardness and with 5% cobalt for improved red hardness. At the high end of abrasion resistance is CPM T15 with an attainable hardness of 66–68 HRc and applicability to workpiece materials up to 48 HRc.

More aggressive applications (e.g. harder workpiece, faster cutting speeds) may require tools with even higher red hardness. CPM Rex 45, with 8% cobalt, is often recommended as an upgrade from CPM M4. Both Rex 54 and Rex 45 contain some amount of cobalt for red hardness, as shown in Table 1. Rex 45 might be selected where red hardness is more critical than wear resistance and Rex 54 where additional red hardness and high abrasion resistance are required.

Applications that generate high heat due to very hard or very abrasive workpiece materials can benefit from high performance steels, like Rex 76 and T15. Again, the selection criteria is based on whether wear resistance is most important (T15) or wear resistance and excellent red hardness are most important (Rex 76).

Cemented carbides are also good candidate materials for gear cutting applications, and as with the high speed steels, there are a wide variety of carbide grades from which to choose. Typical grades for hob manufacture, shown in

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Table 3—Properties of Common Physical Vapor Deposition (PVD) Coatings.

	TiN	TiCN	TiAlN-X	TiAlN-F	TiAlN-H
Hardness (HV 0.05)	2200	2800	2800	2600	2500
Coefficient of Friction (against steel, dry)	0.4	0.4	0.4	0.4	0.2
Compressive Stress (GPa)	−2.5	−3.5	−3.5	−2.5	−2.3
Oxidation onset temperature (°C)	600	400	800	800	800
Coating Color	Gold	Blue gray	Violet gray	Violet gray	Dark gray

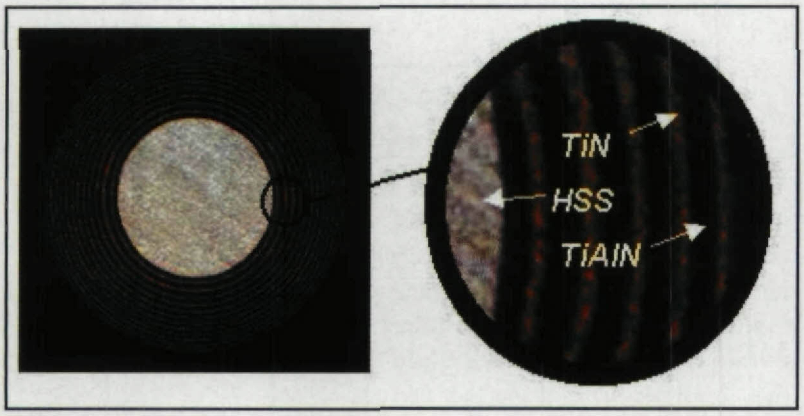

Figure 2—Magnification of ground spherical crater in high speed steel sample showing multi-layered coating.

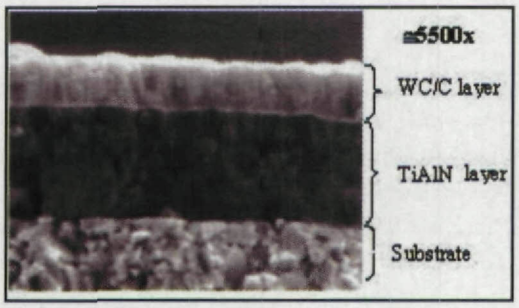

Figure 3—SEM photomicrograph of TiAlN-H.

Table 2, are mid-range in cobalt concentration and are often fine-grained or ultra-fine-grained for the highest possible toughness (transverse rupture strength).

In some cases, high speed steels are not wear resistant enough and carbides are too brittle to satisfy the application requirements. That chasm in the road of application development has led to the development of very specialized high speed steel "bridge" materials.

Rex 121, shown in Table 1, is a good example of that type of material. By comparing the total amount of alloy content (right column), it is clear that the alloy falls into a class of its own. Rex 121 is hardenable to more than 70 HRc and has wear resistance and red hardness levels unprecedented in the high speed steel family. Figure 1 compares Rex 121 hardness at elevated temperatures with Rex 76 and with C4 cemented carbide. Rex 121 is recommended in steel tool applications where Rex 76 is performing without chipping but with excessive wear, and in carbide tool applications where chipping is uncontrollable (perhaps due to workpiece material or design considerations).

Coating Technologies

The advent of commercial physical vapor deposition (PVD) coatings in the early 1980s had a tremendous impact on the gear cutting industry. Titanium nitride (TiN), the first and still most common tool coating, resulted in significant performance gains that allowed tools to run for two to 10 times their normal life. Soon applications were being designed around the expected performance from coated tools—that is, where a coated tool historically gave additional performance gains, the coating was now necessary for the application to work at all.

Today, there is a vast array of PVD coatings appropriate for gear cutting applications. Many of the coatings are unique in both composition and marketing name, but the most common tool coatings can generally be classified as titanium nitride (TiN), titanium carbo-nitride (TiCN), titanium aluminum nitride (TiAlN-X or TiAlN-F) and hard/soft combination coatings, like TiAlN-WC/C (TiAlN-H).

Table 3 shows some physical properties of those coatings. Oxidation onset is a measure of the thermal stability of the coating, which determines its ability to withstand the high temperatures encountered at the cutting edge. With the exception of TiAlN coatings, it is desirable to maintain a cutting edge temperature below the oxidation onset temperature in order to obtain the most benefit from the coating. See below for a more detailed explanation of the thermal characteristics of TiAlN coatings. The hardness value generally correlates with the abrasion resistance of the coating, with higher hardness providing better wear resistance.

Titanium nitride, a gold colored coating, accounts for the vast majority of coated gear cutting tools due to its proven performance base and its relatively low cost. TiN exhibits good thermal stability and can be used in a wide range of applications.

Titanium carbo-nitride (TiCN) is a specialized coating for cutting abrasive workpiece materials in applications that have a relatively low temperature at the cutting edge. Successful applications might include cast iron, alloy steels and fiber reinforced polymers.

Titanium aluminum nitride (TiAlN) coatings are typically used in high-heat generating applications, including dry cutting. Here the intent is to cause the aluminum component of the coating to oxidize, resulting in a thin layer of Al_2O_3 at the surface that is constantly replenished as it is worn away. The Al_2O_3 provides resistance to adhesive wear and also acts as an insulating layer to aid in keeping the frictional heat in the chip. In many cases, a decline in coating performance has been observed when the cutting edge temperature is not sufficient to oxidize the coating.

TiAlN-X is a single-layer coating with a very high hardness that is typically recommended in dry cutting or very high temperature applications.

The choice of coating material was much simpler before the advent of commercial multi-layer and hybrid coating combinations. Coatings can be applied in discrete or graded chemistries and in almost any combination of layers and layer thicknesses. By way of example, consider the TiAlN/TiN multiple-layer coating system TiAlN-F, shown in Figure 2. Here the two component layers, TiAlN and TiN, are deposited as discrete layers and the total layer thickness is on the order of 4–6 microns. There can be multiple advantages in such coating combination systems. First, the coating has a higher toughness due to the inhibition of crack propagation through the layers. Toughness is also enhanced by the distribution of internal compressive stresses due to the presence of the TiN interlayers. Finally, the range of applicability can be extended by the incorporation of the two dissimilar coating types.

Hard/soft coating combinations were of significant interest to many gear manufacturers when they were first introduced. Those coatings are designed to exploit the wear resistant properties of hard coatings as well as the low friction coefficient (high lubricity) features of coatings like tungsten carbide/carbon (WC/C) or molybdenum disulfide (MoS_2). It is well known that the MoS_2-type soft coatings perform poorly with aqueous coolants and can even be susceptible to ambient humidity. The WC/C coatings do not exhibit that behavior and also have the advantage of higher hardness.

Figure 3 shows a scanning electron microscope (SEM) photograph of Balzers Balinit® Hardlube (TiAlN-H), which is a good example of that type of coating system. Originally designed to aid in chip flow and evacuation in deep drilling and tapping applications, it was suggested that additional benefit could be gained in gear cutting by a reduction of frictional heat generated by chip flow on the rake cutting face.

Field testing has shown that the benefit of the coating systems in gear cutting is marginal, and that similar or better performance can generally be obtained by the use of more conventional TiAlN coatings. It is acknowledged that the coatings do have significant advantages for applications like deep-hole drilling, for which they were originally designed.

To round out the discussion on coatings and materials, consideration should be given to tool reconditioning requirements. Today, tool reconditioning often means recoating after resharpening, and that can lead to issues of declining tool performance from excessive coating buildup. Since every application is different, the point at which coating thickness begins to significantly affect cutting performance will vary. Table 4 shows guidelines for stripping and recoating based on experience with production applications, although it is generally agreed that the best performing reconditioned tools are stripped before recoating.

It should be noted, in the case of carbide substrates, that "conventional" chemical stripping is not a recommended option. Although it can be made to work, leaching of the cobalt binder from the cemented carbide by the stripping solution leads to degradation of the surface integrity, and recoating can be risky. Furthermore, tool markings and bore or shank diameters may be affected. Since regrinding of the tooth form to remove a coating can lead to large reconditioning costs, the use of non-recoatable coatings like TiAlN-H should be carefully considered.

Recently, a new chemical stripping technology was introduced that can safely strip most common PVD coatings from C2–C4 type (ISO K-grade) cemented carbides. That proprietary technology is still fairly new and is being scaled to production levels at Gleason Cutting Tools Corp.

All high speed steels are appropriate for stripping, and all of the noted coatings are strippable by chemical methods. Unlike carbide substrates, proper stripping techniques result in no leaching of alloy constituents or damage to the substrate.

Application Parameters

Speed recommendations for wet and dry hobbing are shown in Table 5. Cutting speed is a function of the part material, part hardness, hob material and hob hardness.

The axial feed rate is a function of the chip thickness, which depends on the edge toughness of the tool material, hob outer diameter, number of gashes, threads, depth of cut, etc. For that reason, Table 5 shows a recommended chip thickness rather than a straight feed recommendation.

The shift strategy for wet applications is generally a small, incremental shift amount after each part is cut. The hob is shifted one pass across its face width. The shift amount per part is determined based on the wear developed. A life factor in terms of lineal meters per hob tooth (LM/T) in

Table 4—Tool Reconditioning Guidelines.			
Coating Type	Strippable?	Recoatable?	Number of Recoatings
TiN	Yes	Yes	3–7
TiCN	Yes	Not recommended	—
TiAlN-X	Yes	Yes	2–4
TiAlN-F	Yes	Yes	2–4
TiAlN-H	Yes	No	—

Table 5—Application Parameters.			
	Wet cutting	Dry HSS	Dry Carbide
Speed (Surface meters/minute)	100 SMM	150–200 SMM	250–300 SMM
Chip Thickness (mm)	0.20–0.25 mm	0.25–0.30 mm	0.05–0.15 mm

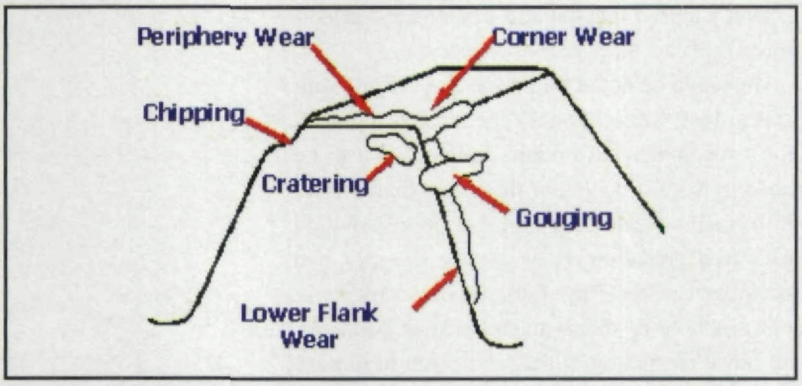

Figure 4—Six main types of tool wear.

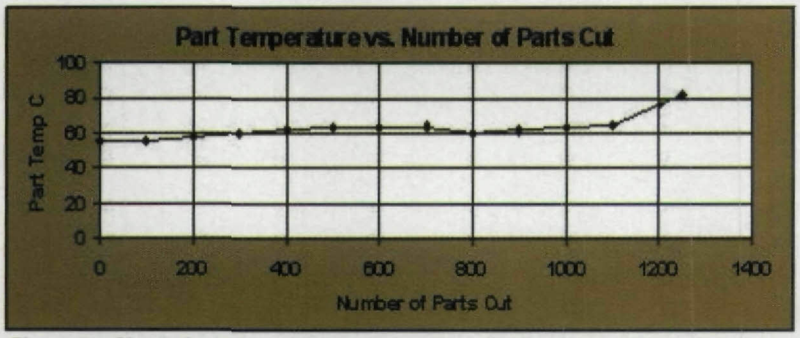

Figure 5—Chart of part temperature vs. number of parts.

the shiftable engagement zone can be determined. Conversely, a life factor developed empirically for one application can be applied to a similar application to determine the shift amount per part. If tool life is good, multiple parts are cut in each shift position to increase the lineal-meters-per-hob-tooth life factor for a desired amount of wear.

The shift strategy for dry applications is somewhat different. A larger shift amount equal to approximately one axial pitch should be used. The hob is shifted across the total usable face width and then returns to the initial shift position. An offset is used to more evenly distribute wear over the flanks of the teeth. The offset amount is equal to the axial pitch divided by the number of passes to be used. The hob is shifted at one axial pitch per part as before. The shift strategy provides time for the hob's built-up heat to dissipate when teeth are not in the cut.

Climb cutting is the preferred cutting method for a dry process versus the conventional cutting method. The thicker chip at the start has less tendency to weld to the cutting face. Chips welding to the cutting face can cause scuffing or tearing on the part flank, as the chips may get trapped and interfere with the finish cut. However, climb cutting produces slightly hotter part temperatures and has higher power consumption.

Tests of like hand, climb hobbing versus opposite hand, conventional hobbing on a dry cutting process revealed no significant difference in tool life or part quality.

Tool Configuration Changes

With dry carbide hobbing, generally high cutting speed and low feed is employed to achieve a fast cycle time, with good surface finish and small feed scallops on the part flanks. Since carbide is low in toughness, chip thickness is limited to a range of 0.050–0.150 mm. The hob can be made with low numbers of threads (one or two) to keep the chip load down. The hob diameter is kept small to maximize rpm. Gashes are maximized to reduce feed scallop and chip load. However, an adequate gash size is required to allow for the removal of chips from the cutting zone. The number of gashes, the gash size, and the sharpenable length of tooth are the trade-offs to be considered. Since the hob is generally recoated, and several layers of coating can begin to cause flaking or adherence issues, we generally recommend establishing a sharpenable tooth length that will result in six to eight uses.

Since cycle time is minimized, the volumetric rate (cubic inches per minute) of material being removed is maximized, and chip flow becomes critical. Too small of a gash size may allow chips to wedge into the bottom (chip packing) and lead to a catastrophic failure. A larger gash radius, back angle, and grinding the backs of gashes improves chip flow. With dry hobbing, no coolant is available to help flush chips out of the cut. A 5° hook sharpening on the face helps direct chip flow away from the cutting zone and reduces power consumption and heat generated. With carbide, gash sharpening is limited to straight gash due to manufacturing limitations. With high speed steel hobs, spiral gash angles can be used, even at low thread angles, to help equalize cutting chip curl angles and assist in chip flow away from the cutting zone.

Edge preparation of carbide hobs after sharpening and prior to coating helps reduce chipping tendency. A cutting edge radius of 0.0003–0.0005 in. is generally recommended. A larger "edge prep" amount causes the tool to act dull, increas-

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Table 6—Carbide vs. HSS dry cutting of pinions.				
Workpiece Data		**Results**	**Carbide TiAIN-X Dry**	**Rex121 TiAIN-X Dry**
Generating Module	1.40	Parts per hob use	3,360	6,700
Gen. NPA	15	Cutting Cycle time	0.16 minutes	0.10 minutes
HA	20° LH	Floor to Floor time	0.26 minutes	0.20 minutes
Face Width	29 mm	Tool cost per part	$0.19	$0.08
Number of Teeth	23	Machining CPP	$0.22	$0.17
LM/part	0.627	Total CPP	$0.41	$0.25
		LM/T	5.3	8.8

Table 7—TiAIN-H vs. TiAIN-F cutting automotive gear.				
Workpiece Data		**Results**	**Rex121 TiAIN-F**	**Rex121 TiAIN-H**
Generating Module	1.41	Parts per hob use	720	1,800
Gen. NPA	15°	Cutting Cycle time	0.17 minutes	0.20 minutes
HA	20° RH	Floor to Floor time	0.23 minutes	0.29 minutes
Face Width	30.8 mm	Tool cost per part	$0.47	$0.16
Number of Teeth	35	Machining CPP	$0.23	$0.25
LM/part	1.15	Total CPP	$0.70	$0.41
		LM/T	1.99	4.97

Table 8—Rex 121 vs. M35 dry cutting truck gear.				
Workpiece Data		**Results**	**Rex121 Dry TiAIN-FW**	**M35 Dry TiAIN, single layer**
Generating Module	3.02	Parts per hob use	980	686
Gen. NPA	20	Cutting Cycle time	1.3 minutes	1.3 minutes
HA	0	Floor to Floor time	1.5 minutes	1.5 minutes
Face Width	31.9	Tool cost per part	$0.40	$0.58
Number of Teeth	35	Machining CPP	$1.27	$1.28
LM/part	1.16	Total CPP	$1.67	$1.86
		LM/T	5.75	4.28

Table 9—Rex 76 TiAIN-F cutting spline part with oil coolant				
Workpiece Data		**Results**	**Rex 76 TiAIN Oil**	**Rex 76 TiAIN-F Oil**
NDP	8/16	Parts per hob use	74	216
NPA	30°	Cutting Cycle time	1.83 minutes	2.3 minutes
HA	0	Floor to Floor time	1.98 minutes	2.45 minutes
Face Width	292 mm	Tool cost per part	$3.69	$1.26
Number of Teeth	19	Machining CPP	$1.93	$2.13
LM/part	5.55	Total CPP	$5.62	$3.39
		LM/T	1.6	4.67
		Notes:	152 SMM, 1 pass @ 1.9 mm shift, hob peeled back 1.5 mm	122 SMM, 8 passes @ 5.0 mm shift, 0.15 mm wear

ing the heat generated and reducing the tool life factor. Edge preparation of high speed steel hobs is generally not required beyond the standard burr removal process in preparation for coating.

The static cutting clearance is a result of the outer diameter, cam clearance angle and a function of the steepness of the pressure angle. Relative velocity of the side of the tooth and the space of the gear material as yet uncut, moving toward the side of the tooth, creates a dynamic cutting clearance condition that also can affect the wear at various parts of the teeth. Static and dynamic cutting clearance evaluation must be considered in hob design. Tools that must be short-pitched to low pressure angles and low protuberance angles may not be ideal candidates for dry cutting.

Tools with low clearance angles also tend to cause "pressure welds," which are small particles of part material that are forced onto and adhere to the flank of the part under high heat and pressure. The welded particles are not troublesome for parts that are subsequently shaved, but are a problem for parts to be rolled. Part material may also adhere to the hob tooth face or flank near the lowest clearance area of the form. Commonly called "material pickup," that may cause tearing on the surface finish of the part due to the pickup material acting as a (dull) cutting edge. Material pickup can also be misinterpreted as hob wear.

Failure Mode Evaluation

A key to testing is evaluation of how the tool's cutting edge eventually fails. Figure 4 shows a schematic representation of the six main types of tool wear modes.

Abrasive Wear

Abrasive wear is the desired failure mode after cutting a substantial number of parts. Tool life wear criteria need to be established up front. The present application under wet conditions can be a source of valuable tool life information. Wear should be evaluated under a microscope at a magnification that can resolve the coating, substrate material, wear and material pickup. A 25X or higher magnification should suffice. Wear for carbide or dry high speed steels should be limited to 0.15–0.20 mm (0.006–0.008 in.), which will be fully cleaned up by 0.20–0.25 mm (0.008–0.010 in.) stock removal at sharpening. Use of a tool monitoring system, such as a tool card that tracks the number of parts cut for each use, number of passes, amount of measured wear, amount removed by sharpening, and tooth length remaining, is recommended. That helps track tool costs through the life of the tool. The life factor for each run can be expressed in terms of "lineal meters per tooth engaged for 0.XX mm amount of wear."

Cratering

Cratering as a failure mode generally indicates the feed rate being used is aggressive enough to erode coating and substrate material from the cutting face. The crater begins to form away from the edge, then progresses deeper and closer to the edge. Once the crater reaches the edge, the edge becomes weakened and a chip breaks away, resulting in an edge with no clearance and in eventual peel back failure. The feed rate should be balanced to allow both crater and abrasive flank wear to develop at a controlled rate.

Chipping

Chipping failures are caused by the cutting load exceeding the edge strength of the tool material. A chip leads to more catastrophic damage and therefore is to be avoided. The feed rate is the controlling factor for chip thickness and load on the cutting edge. Rigidity of the part as clamped can also contribute to chipping failures.

Thermal Degradation

The heat generated in dry cutting is dissipated into the chips, the hob and its holding system, the part, the part fixture and the air. Heat in the part causes thermal size changes to dimension over pins (DOP) and lead that must be compensated. Heat in the hob and its fixture may cause distortions that affect involute quality. Heat at the cutting edge interface can reach 900°C, causing oxidation of the coating. That is acceptable and even desirable in the case of TiAlN coatings, as the heat causes a microthin layer of Al_2O_3 that provides additional wear protection.

The feed rate can have a dramatic effect on part temperature. Using an aggressive enough feed rate to cause heat to go into the chip keeps part and hob temperature down. Too aggressive of a feed can cause a high chip thickness that overloads the edge strength of the tool, causing chipping. Too light of a feed rate at high cutting speeds will cause excessive enveloping cuts with thin chips, resulting in rapid tool wear and high part and hob temperatures.

For small parts, measuring part temperature can be an effective way of monitoring the hob's wear condition. As coating on the tool wears through to the substrate material, part temperatures elevate quickly and rapid edge failure follows. After monitoring of a process for "wear amount versus number of parts cut" and "part temperature versus number of parts cut," an empirical stop point temperature limit can be established. Figure 5 shows an application where the part temperature is monitored and the process is stopped at 80°C. Due to variability in sharpening, edge preparation, and reconditioning, the number of parts produced when the 80°C point is reached varies. By using part temperature rather than piece count, the maximum number of parts per use can be safely achieved each run, with less risk of catastrophic failure.

Machine Considerations

The trend toward dry cutting is led by changes in machine design with regard to chip evacuation, thermal stability, and high-speed, direct-drive hob head and work table capability. The entire machine design and construction has been re-engineered to be dry cutting capable. Dry cutting may be possible on existing equipment; however, modifications for chip evacuation may be required.

Application Results

Results of various applications are represented in Tables 6–9 to show comparisons of some successful and marginal results. (At the customer's request, part specifications were changed slightly to keep the application anonymous. But, all applications shown are based on actual test or field results. The tables' data can still be used for general comparison to similar applications.)

Conclusion

Implementation of a new hobbing process, such as dry cutting, requires a discipline of monitoring all process measurables, tracking tool wear, and documenting assignable causes of various wear modes under different parameters. The best method for gear processing is the result of a thorough evaluation of process parameters and costs associated with each of those parameters.

When properly applied and monitored, dry cutting process technologies can result in improved productivity and reduced total cost. A good working relationship with tool supplier, tool maintenance supplier, coating supplier and equipment supplier is required to assure consistency of results achieved.

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