# GEAR TECHNOLOGY

NOVEMBER/DECEMBER 2002

*The Journal of Gear Manufacturing*

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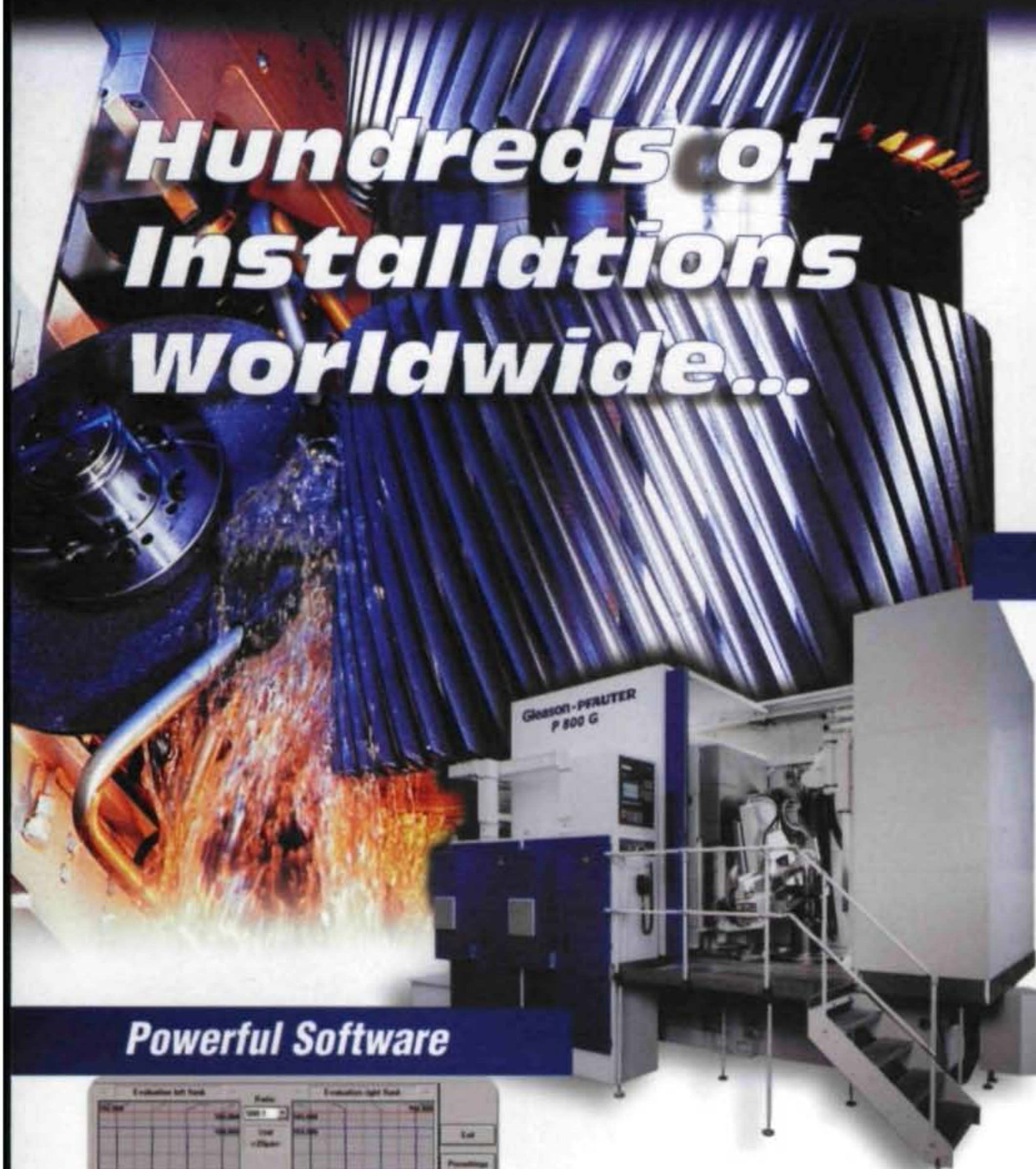


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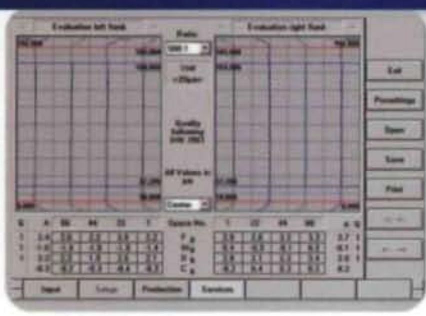

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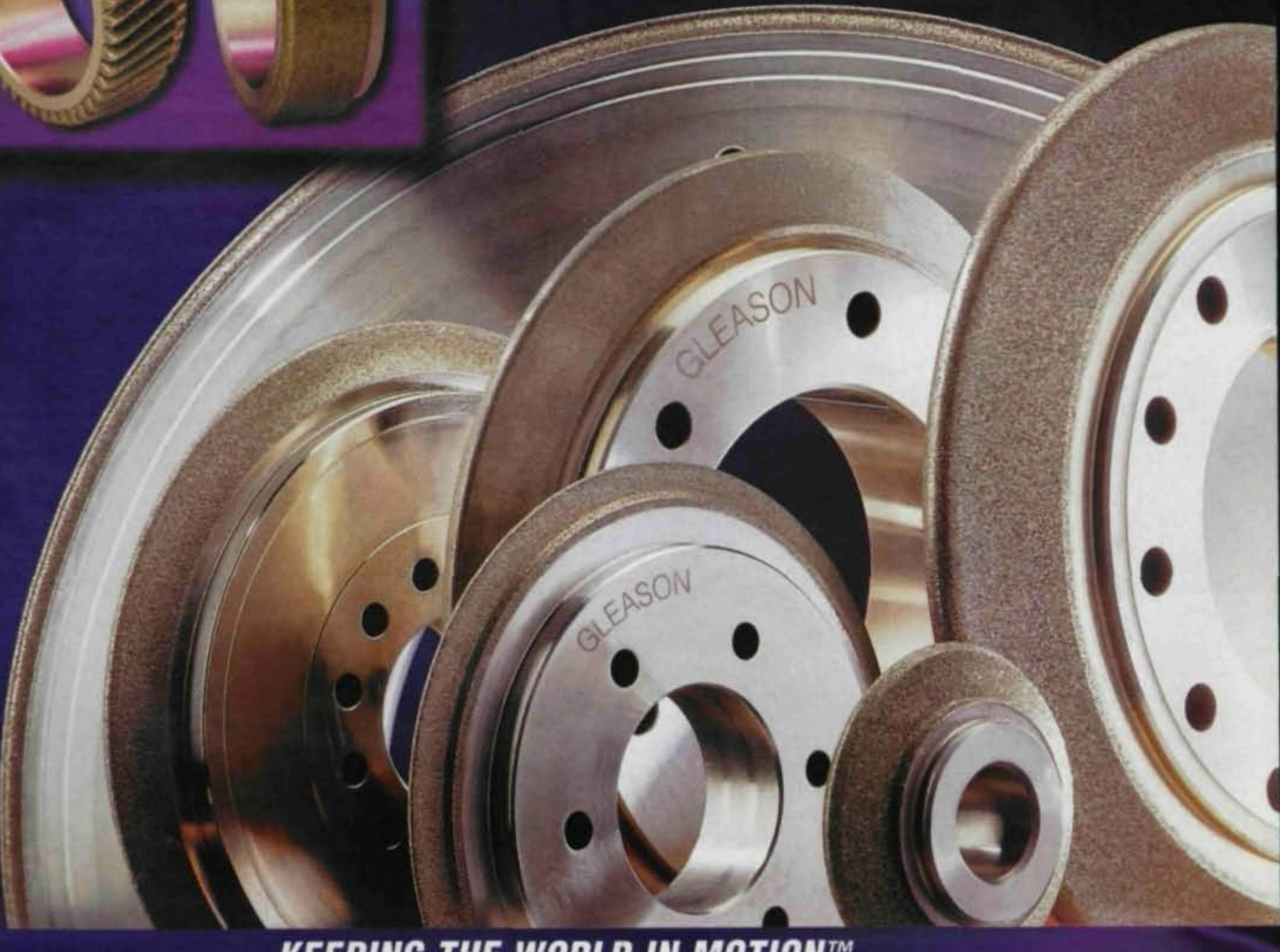


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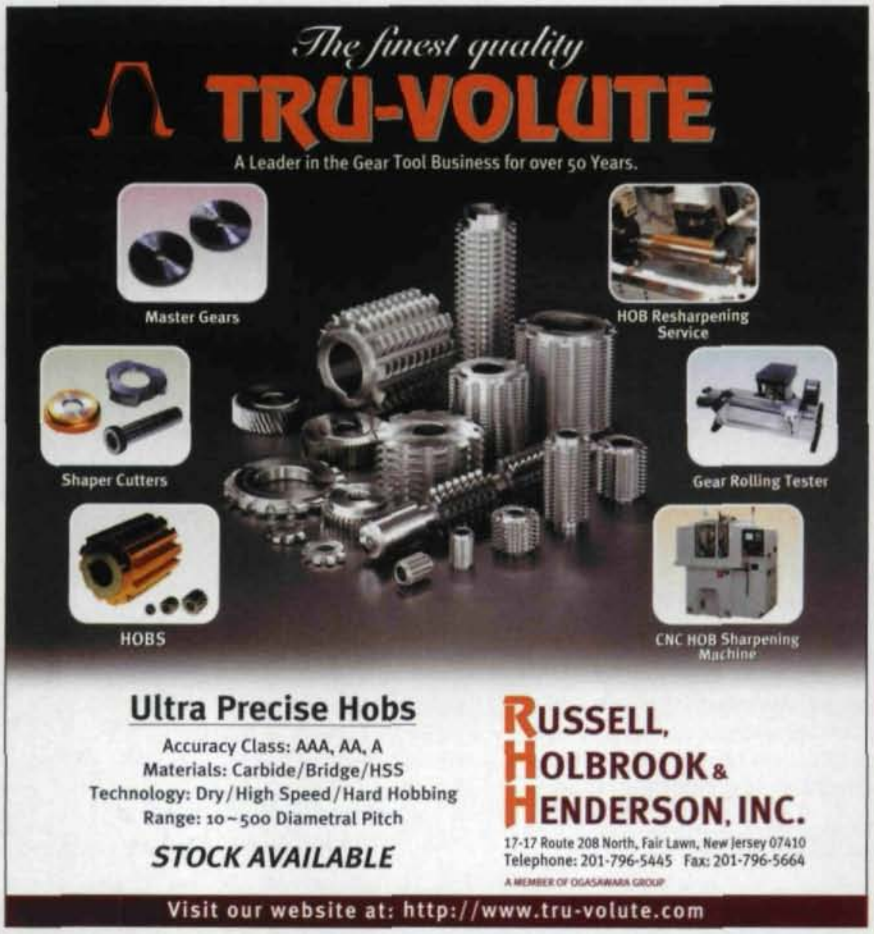



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Cover photo by Jennifer M. Flam, taken at SU America Inc. booth at IMTS 2002.

# The Gear Industry on Your Desktop

With this issue, we're proud to present our latest milestone. The *Gear Technology Buyers Guide 2003* on CD-ROM—a comprehensive snapshot of nearly 400 of the industry's suppliers—is the best directory of the gear industry available.

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But the *Gear Technology Buyers Guide 2003* is more than just a milestone. It's also a stepping stone. It's a product that bridges the gap between the printed directories we used to produce and the comprehensive, dynamic directories we're building at *The Gear Industry Home Page*™ and *powertransmission.com*™. Those websites are increasingly becoming the way people look for information on the gear industry.

The strength of the websites is that they're able to provide much more than a snapshot of the industry. Instead, what they offer is a full-motion, constantly updated, multidimensional universe of activity, which you can tap into just by logging on. The potential amount of information that can be put and found online is infinite.

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Both websites are extremely intuitive and easy to navigate. They allow keyword searches, and they include types of information not available in any other format. Some of the companies have complete brochures and even video clips on our websites. In addition, you can use hyperlinks to visit the websites of hundreds of companies. You can easily request a quotation from one company or a dozen companies, all at one time.

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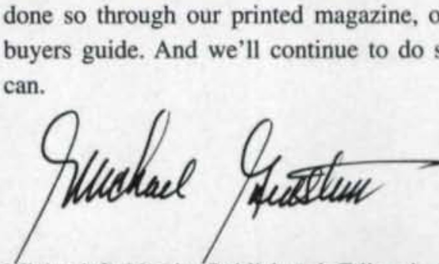

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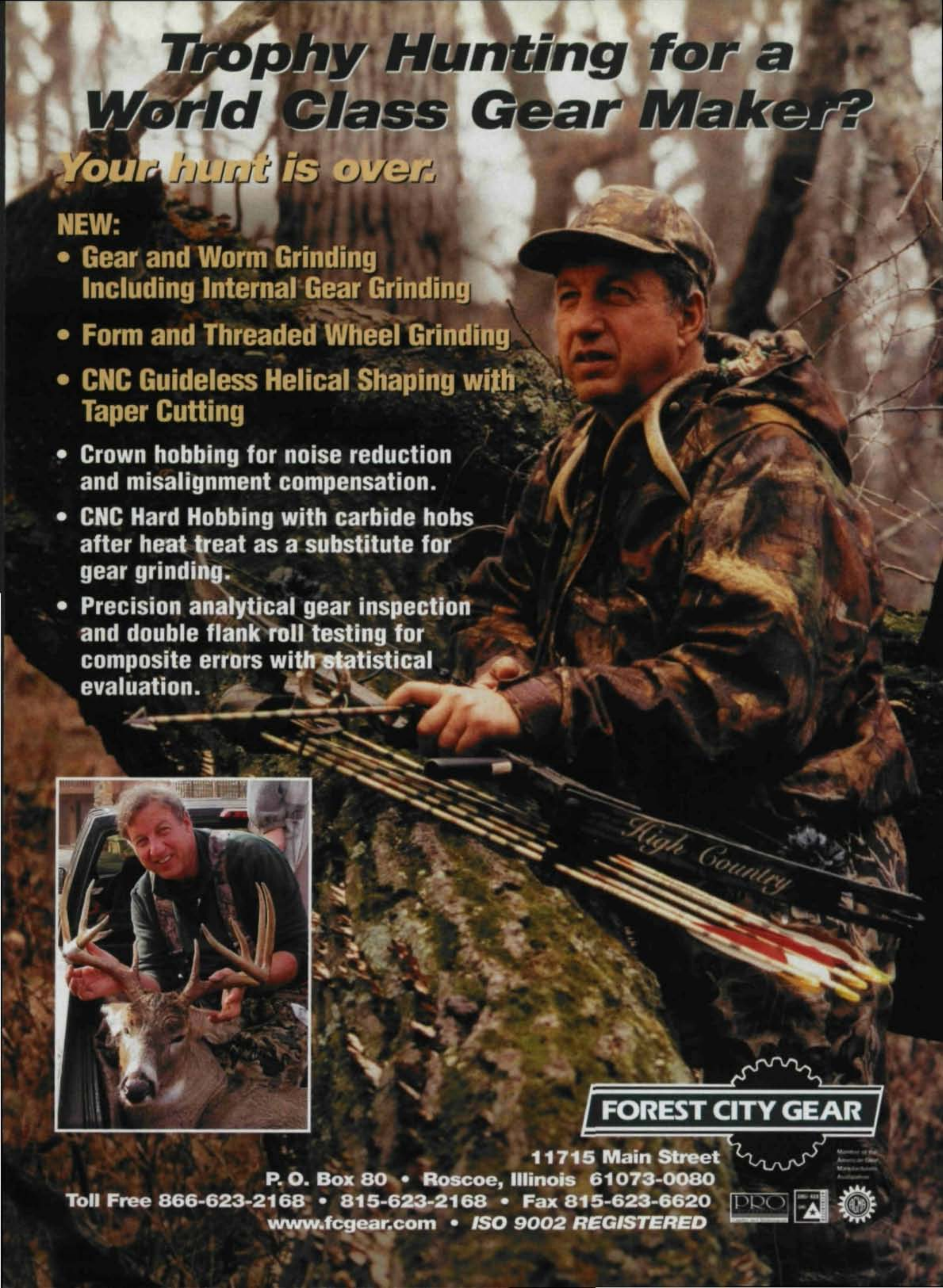
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## Gear Coating Raises Scuffing Resistance to Raise Torque Capacity

A gear manufacturer has an order for 1,000 spur pinions for use in small planetary reducers, but his customer means to use them with marginal lubrication and at a pitch-line velocity and torque that are so high they will cause scuffing and premature failure.

Also, the customer wants a single lubricant of one viscosity for this and other slower speed reducers in his machines, and he doesn't want the manufacturer to add antiscuffing agents to the oil because of concern about damaging other parts.

Faced with this problem, the manufacturer could do one of three things. He could curse his customer's unreasonable demands—privately, then try publicly to explain to him the physical limits of his imagined gears. He could redesign the pinions, planets and rings to make his customer's reducers perform at their specified speed and under their expected conditions.

Or, he could raise the gears' scuffing resistance—and consequently their torque capacity—by coating them with an amorphous hydrocarbon-based matrix embedded with metal-containing nanocrystallites.

The third option is what The Timken Co. of Canton, OH, is offering to gear manufacturers. Applied by PVD, the coating is called ES200.

In lab tests, the coating increased a gear's scuffing torque. Scuffing torque is the torque at which scuffing appears at a particular pitch-line velocity with a particular lubricant. Consequently, ES200 significantly increased a gear's torque capacity, letting it operate at combinations of pitch-line velocities and torques that otherwise would cause scuffing.

The tests were conducted by Design Unit, a technical consulting business located at the University of Newcastle upon Tyne, in England. Design Unit tested 31 pairs of helical gears from Timken for scuffing resistance. The gears included ground gears; superfinished gears; and superfinished, coated gears.

According to the tests, a gear set consisting of a ground gear and a superfinished gear coated with ES200 had a scuffing torque 42% greater than a gear set consisting of two superfinished gears, and 70% greater than a gear set consisting of two ground gears.

The increase could be even greater than 70% among nonground gears, says Ken Krummrich, director of Timken's Engineered Surfaces Business.

Scuffing can limit the torque capacity of spur, helical, bevel, hypoid and worm gears. But, scuffing is most likely to occur in gears operating at very high pitch-line velocities with high sliding velocities, says Carl Ribaudo, technical leader of gear-application development and testing in Timken's Engineered Surfaces Business.

ES200 is available for all gears, including internal and external spurs, internal and external helicals, single- and double-enveloping worms, bevels and hypoids. The coating is meant for industrial applications, such as speed reducers and planetary gear sets.

Besides scuffing resistance, Timken tested ES200's effect on gears' pitting resistance. According to those initial tests, the coating increased pitting resistance so a gear's torque capacity could be increased 33% or its pitting life extended by about 10 times, given operation at a constant torque.

Assuming a standard gear steel, the coating is applied without affecting gear dimensions or microstructure and without causing gear distortion. The coating is about 2 μm (80 μin.) thick and is applied at temperatures less than 150°C (300°F).

The coating itself is applied by Timken as a service through its Engineered Surfaces Business. It receives customers' gears and coats them via batch processing with specialized physical-vapor-deposition equipment.

Also, Timken can increase a gear set's torque capacity with ES200 applied to only one gear per mesh. Thus, a customer with gear sets of two gears each has Timken apply its coating to only one gear from each set. In Design Unit's tests, the coating didn't cause increased abrasion on adjoining noncoated gears.

Besides prototypes for lab tests, Timken has created prototypes for customers to field test in applications and coated gears in low-volume production for customers as steps in proving ES200 to those people.

ES200's hardness can be difficult to compare with a gear's hardness because the thin coating can't be measured with conventional hardness scales, like Rockwell and Brinell. Still, Ribaudo says the coating is about 40% harder than a carburized steel based on nanohardness measurement.

Other companies, such as Balzers Inc., make coatings for gears. Comparing those coatings' effects on gear performance with ES200's effects can be difficult, though. The effects may be covered by confidentiality agreements between the companies and their gear customers. Or customers may be unwilling to reveal how their gears are affected by their coatings.

As with other coatings, ES200 can let gear manufacturers develop a higher-duty product line or increase life ratings.

That ability could be the best option to the gear manufacturer trying to create 1,000 spur pinions that meet his customers's needs.

As Krummrich says, the manufacturer could have Timken apply ES200 to the pinions for less than the cost to redesign the reducers. Also, coating could be done in less time than redesigning. Also, a coating that makes the reducers work has to be better for the manufacturer than private cursing of and attempted explanations to his customer.



## CMM Gear Checking Software

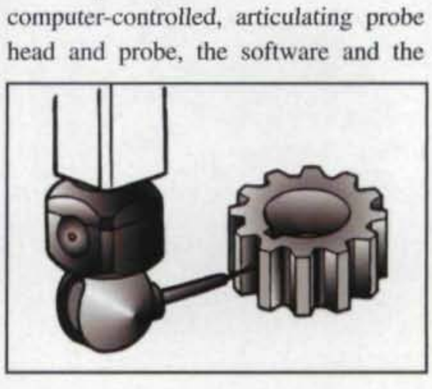
Anyone who ordered coordinate measuring machinery from Giddings & Lewis L.L.C. in the last few months found a free surprise in his package—an upgraded gear checker.

Sheffield CMM MeasureMax+ version 6.4 software can inspect spur and helical gears, both internal and external. Additionally, it can perform calibration, lead, profile, spacing/runout and topography checks, set reference frames and output plots on all Giddings & Lewis CMMs.

The gear checking capacity in MeasureMax+ is not as robust as a dedicated gear inspection system, such as those sold by Gleason Mahr, Klingelnberg GmbH or M&M Precision Systems Corp. Those systems typically can also inspect worms, bevels, hobs and other parts.

However, it may be an inexpensive way for some shops to inspect gears—especially those whose gear manufacturing is only in small quantities or occasional.

The package, which consists of a computer-controlled, articulating probe head and probe, the software and the



CMM, costs $53,000. This cost is for the basic and smallest machine package.

Another key difference between this and dedicated gear checkers is that the new software can also measure a variety of non-gear features, according to Joe Zink, manager of software development for Giddings & Lewis of Fond du Lac, WI.

"With a dedicated gear checker, you can only measure dedicated gear parameters. With MeasureMax+, if a gear is on a shaft and you want to look at cylindricity, it is possible," Zink says. "You can look at all kinds of geometric features."

The MeasureMax+ gear checking procedure is relatively simple. To begin the process, the operator inputs the gear parameters from a selectable toolbar. The instrument measures lead, profile topography and tooth spacing in a gear by using a touch probe to collect data points. Points are collected along one face of the tooth, and the parameters are computerized. Studies can be started, interrupted, cancelled or resumed any number of times.

The software was designed to make life a little easier for machine shops as well. Bill Fetter, CMM marketing manager at Giddings & Lewis, noted that an advantage of the system is that it can make use of existing equipment at machine shops.

"For example, a shop will want to check different components of its inventory," he says, "they can use our equipment to check machine covers and housings as well as gears."

Although the MeasureMax+ software can be a good solution for some shops, it's not intended for everyone. There are still advantages to traditional gear inspection systems.

Gleason Mahr sells checkers to gear manufacturers, but doesn't deal so much with geometric measurement. Its inspection equipment generates an involute profile from the base circle, the same principle that's used in manufacturing. By contrast, says Bruce W. Cowley, Gleason product manager, CMM gear inspection equipment must add rotary axes to correlate with a generative gear tester.

CMMs won't handle every job, Cowley says. "They're good for prismatic inspection. But for making measurements for a generative purpose, there are still correlation issues associated with that type of equipment."

Prismatic inspections involve checking factors like points, circles, lines and features that aren't contoured.

Knowing specifically what the software can check goes a long way in solving this very complicated purchasing decision for buyers of gear checkers. Gear checking software from M&M Precision Systems, for example, can check for things that the user doesn't have prints for and can generate parameters from which to manufacture new parts, according to M&M Precision's sales department.

## AGMA to Introduce New Quality Rating System

AGMA is preparing to release a new cylindrical gear accuracy tolerance rating standard, to replace AGMA 2000-A88. The new standard was discussed at the AGMA Gear Industry Regional Meeting, held in August in Rosemont, IL.

AGMA 2015-1-A01 is a complete revision of the old standard, according to Edward Lawson, chairman of the AGMA Inspection and Handbook Committee and director of metrology for M&M Precision Systems Corp. He gave a presentation on the new standard at the meeting.

Users of AGMA 2015-1-A01 will have to adjust to quality grades that are the opposite of what they may be used to. The new standard's tolerancing system is based on ISO 1328-1. Like that standard and the world's other major gear standards, AGMA 2015-1-A01 will use lower-numbered grades to represent the smallest tolerances, while the higher-numbered grades will represent the largest tolerances. The highest quality gears will be grade 2 under the new standard.

To distinguish between gears rated according to the new standard and those rated according to the old standard, a new quality prefix has been introduced with AGMA 2015-1-A01. The new standard requires the letter "A," whereas the old standard required the letter "Q." So, a quality grade of 7 under the new system would be expressed as "A7" instead of "Q7."

In addition to the new numbering system, AGMA 2015-1-A01 will include new methods for analyzing profile and tooth alignment. Instead of the K-band system of charting profile deviations, the new standard incorporates a "line fit" method, which is similar to the methods included in other gear standards around the world. The new standard will also include information on instrument verification, master gears, composite testing and measurement process calibration.

Other major changes from AGMA 2000-A88 include tighter tooth alignment (lead) tolerances and the introduction of tolerances for total index (cumulative pitch) variation.

AGMA 2015-1-A01 is expected to be released toward the end of 2002. Additional information is available from AGMA by calling (703) 684-0211.



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# Cutting Hardened Gears

**Dennis Gimpert**

**This paper was presented at the Basic Gear Manufacturing & Design 2002 Technical Program, in Nashville, TN, in January 2002. The program was organized by the Society of Manufacturing Engineers.**

### Introduction

The need for improved power transmissions that use gears and gearboxes with smaller overall dimensions and with lower noise generation has left manufacturing engineers searching for different methods of gear processing. This search has led to the requirement of hardened gears.

During the heat-treatment process, changes in the structure of the material and modifications of the tensions present in these hardened gears will normally cause unacceptable distortion. The most frequent distortion errors that occur will be in the lead, involute and pitch. These errors will cause the active tooth profile to mesh inaccurately during operation, increasing load and generally causing unacceptable gear noise. For these reasons, hardened gears normally require an additional finishing operation after heat treatment.

We can distinguish between two different types of hard gear finishing operations: one with an undefined cutting edge, such as gear grinding, and the second with a defined cutting edge, such as hard hobbing.

This paper will focus on the defined edge process of hard hobbing using carbide tools. Current carbide materials, tool coatings and gear hobbing machine technology have all led to significant improvements in hard hobbing. This is especially true in the fine- to medium-pitch gear range, i.e. 12 DP and finer. The primary advantage of carbide hobs, with proper coating, is the ability to withstand the extreme forces that occur during hard cutting.

**Table 1–Several Carbide Grades for Gear Cutting Tools.**

| ISO grade | C code approximate | Grain size, µm | Bending stress, N/mm² | Compressive stress, N/mm² | Hardness, HV30 | ISO application | Gear application |
|---|---|---|---|---|---|---|---|
| K30-40 | C-1 | medium, 2 | 3,000 | 5,000 | 1,300 | metal forming | rolling |
| K10-20 | C-2 & C-3 | fine, 1 | 2,300 | 5,400 | 1,700 | universal | standard cutting |
| K10-15 | C-3 | extra fine, < 1 | 2,500 | 6,000 | 1,720 | micrograin | skiving |
| K15-30 | C-1 | ultrafine, < 0.5 | 3,000 | 6,000 | 1,620 | high performance | dry cutting |
| P20-30 | C-5 & C-6 | medium, 4 | 2,200 | 5,300 | 1,560 | high temperature | dry cutting |

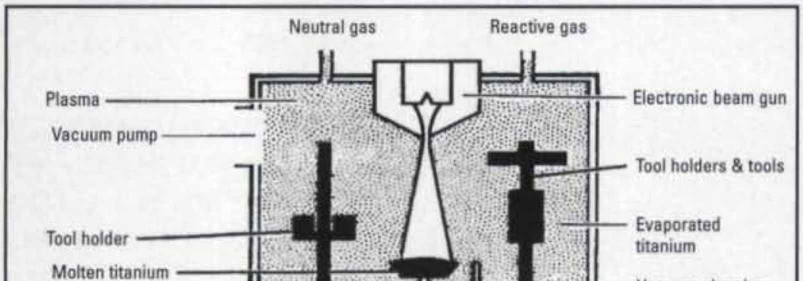


*Figure 1—Titanium nitride coating schematic, courtesy of Balzers Tool Coating Inc. of Tonawanda, NY.*

### Carbide Hobs

Advances in carbide hobs have been in the material grades. Ultrafine, fine, medium and large grained carbides are all available today. In addition, technical advances in the process of forming the carbide hob blank have occurred, such as in the hot isostatic pressing (HIP) process. This process provides an additional "coining" of the carbide blank under extreme pressure and temperature to increase the internal adhesion and to promote the deflection strength of the carbide grains. According to ISO, solid carbide materials can be broken down into several application groups. Gear cutting tools are divided into the "K" and "P" groups. The "K" group provides higher resistance to abrasion. The "P" group provides higher resistance to temperature. Table 1 shows characteristics of four "K" grades and one "P" grade.

Each grade in Table 1 is different due to the grain structure, which ranges from medium to ultrafine. Each grade has its applications, which are associated with the grain structure. To generalize, current results have shown that the "K" grades perform better than "P" grades for soft hobbing. The "K" grades also can have a micrograin structure (grain size < 0.5 µm) which is not possible with the "P" grades. Also, the "K" grades have shown a longer life under abrasive conditions due to their toughness.

### Coatings

For nearly 30 years, various companies have offered coatings for cutting tools to improve their performance and life. This process began with a single-layer TiN (titanium nitride) coating and now includes several other advanced performance coatings. A quick review of the basic coating process will be informative.

Tools are first physically and chemically cleaned and then placed on a fixture that will become the cathode of a high voltage circuit in a vacuum chamber. The chamber is evacuated and charged with the inert gas argon. The argon gas is used to further clean the tool surfaces using a process called sputter cleaning, in which the argon gas ions are propelled by a high voltage field to blast the tool.

An electronic beam, or high voltage arc, is next used to heat a pure titanium ingot until it evaporates. At this time, nitrogen gas is introduced into the vacuum chamber and the titanium ions are electrically accelerated towards the tools. See Figure 1. The titanium ion bombardment combines with the nitrogen gas to form the coating of titanium nitride, TiN. This coating is allowed to plate the tools to a thickness between 1 µm and 4 µm, 0.00004" and 0.00016". A tight bond is established between the TiN and the tool that will not crack or delaminate due to any physical distortion of the tool during use.

This process is called physical vapor deposition, PVD, and operates at a temperature in the 900°F range. This temperature is much less than the tempering temperature of high speed steels. Thus, the tools will not be softened, which would require them to be rehardened with resulting distortion of the original tool geometry. Another important advantage of the PVD process is that edge embrittlement of solid carbide tools is minimized. This ultrathin PVD coating also helps maintain a sharp cutting edge, which is essential for extended tool life.

Another process developed at the same time as PVD was the chemical-vapor-deposition (CVD) process. This process has the disadvantage of operating in the 1,750–1,950°F range. At this temperature, tool steels will be softened.

In addition to TiN, there are several other coatings available under different marketing names that use the PVD process. One is TiCN, titanium carbonitride, and a second is TiAlN, titanium aluminum nitride. Table 2 presents characteristics of these three types of coatings.

There are also multilayer hybrid coatings that offer advantages based upon specific applications.

**Sharpening and Reconditioning of the Hob**

After a certain number of workpieces are produced, the tool will become dull and must be resharpened. It is absolutely critical to sharpen hobbing tools correctly. The original geometry of the cutter must be maintained and the cutting edge of the tool must be sharpened with a fine edge. The tool metallurgy must not be damaged due to excessive heat during grinding. For this reason, an oil-based coolant that is inactive both for chlorine and sulfur should be utilized when sharpening carbide hobs. For skiving hobs, recoating after sharpening is not as essential as it is for hobs used when hard hobbing from the solid. As a side note for carbide hobs, edge preparation (removal of grinding burrs) after sharpening—but prior to recoating—is recommended.

**Table 2–Characteristics of Three Coating Types.**

| | TiN | TiCN | TiAlN |
|---|---|---|---|
| Microhardness (HV 0.05) | 2,300 | 3,000 | 3,000 |
| Coefficient of friction | 0.4 | 0.4 | 0.4 |
| Maximum temperature | 600°C | 400°C | 800°C |
| Thermosetting resistance | ++* | + | +++ |
| Thermal insulation | ++ | + | +++ |
| Color of coating | Gold | Blue gray | Purple gray |

*Plus signs indicate general heat resistance of the coating, with more plus signs indicating more resistance.

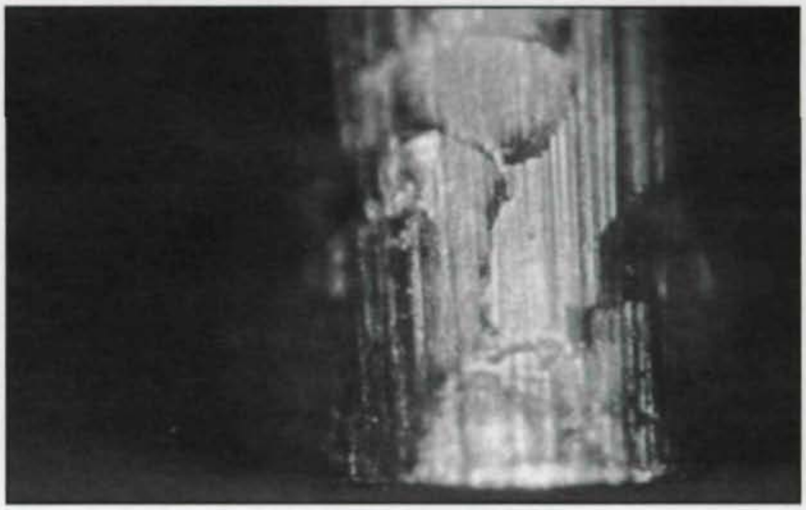

*Figure 2—Microphotograph of delaminating TiN coating.*

The resharpening of the hob will remove the original coating on the cutting face. This removal will in turn reduce the life of the tool or, in the case of hard hobbing, make the process uneconomical. It is possible to recoat the tool and this can normally be done 3–4 times with the TiN process. With TiCN and TiAlN, the coatings are difficult to apply across the cutting edge due to the high internal tension of the coating itself. After several coatings of TiN, an uneven buildup will occur and a delaminating tendency will develop so the coating layers must be removed (see Figure 2).

There are currently two methods available to remove the tool coatings, chemical and physical stripping. Chemical stripping of the coating layer on carbide tools is a sensitive process and must be done with a degree of skill. Excessive chemical stripping will not only remove the coating, but will leach the cobalt binders and degrade the

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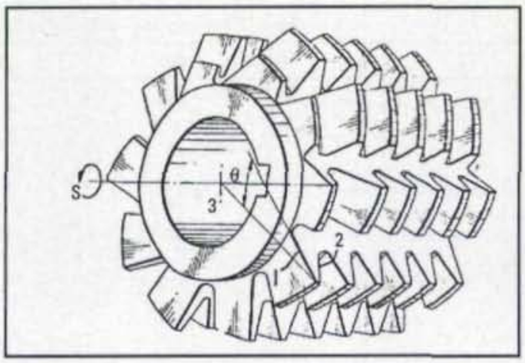



*Figure 3—Drawing from Azumi skiving patent.*

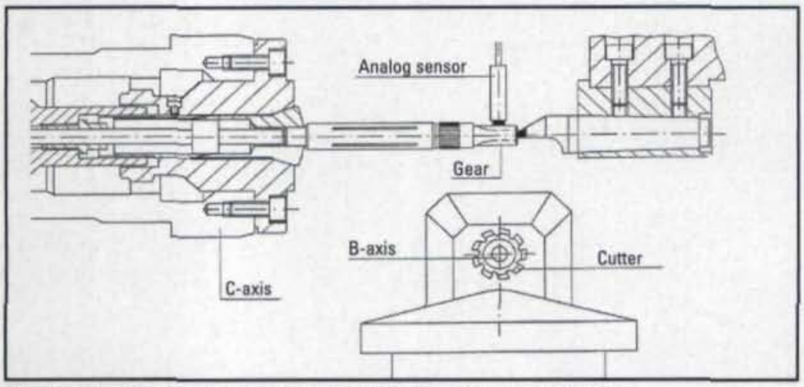



*Figure 4—Electronic gear-to-hob alignment and stock dividing.*

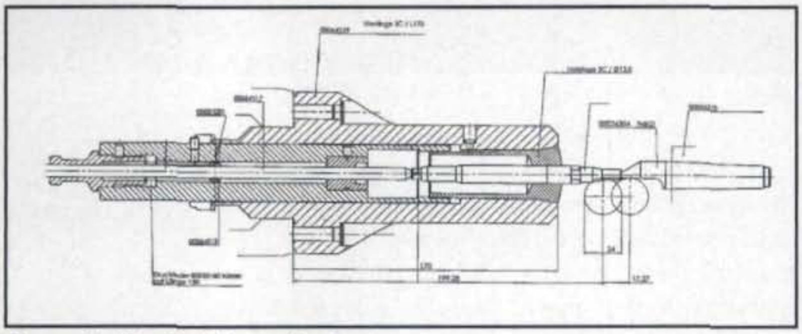


*Figure 5—Hard hobbing collet fixture.*

microstructure of the carbide material. This microdegradation of the cutting edge will produce a sawtooth-like surface. In addition, the hubs, tool bore and tool markings must be protected to prevent degradation.

Physical stripping of the coating layer must be done by the original tool manufacturer and involves reprofiling of the entire hob. Although this is quite expensive compared with chemical stripping, the tool is virtually a new cutter with guaranteed quality and tool life.

**The Hobbing Machine and Fixture System**

To match the advances in both carbide materials and coating technology, the hobbing machine has seen advances as well. Today, all modern hobbing machines are designed for high-speed hobbing. These machines have hob speeds in excess of 3,000 rpm, with 5,000 rpm typical and with work spindle speeds to match that of the cutter. In addition, these machines are designed to be extremely rigid both dynamically and thermally. Some current design characteristics of modern hobbing machines include:

- Composite epoxy beds for improved static and dynamic conditions,
- High-speed hobhead with temperature stabilization,
- High-speed work spindle,
- The ability to use both wet and dry hobbing techniques,
- Digital drives with optically coupled circuits,
- Linear guideway systems,
- High-speed automatic loading, i.e. 2–3 seconds,
- Compact footprint,
- Ergonomic design for operator, and
- Ease of maintenance.

**History of Skiving**

Although skiving has been utilized in the United States for more than 30 years, it has only recently become practical to use an involute gear generating hob for skiving fine- and medium-pitch gears. The first of the technical developments was from the Azumi Mfg. Co. Ltd. of Japan, which received United States Patent Number 3,786,719, issued Jan. 22, 1974. This patent covered several areas, but of commercial importance, we quote from the patent:

"Further object of the present invention is to provide a hobbing cutter which enables to finish a previously hardened blank with roughly formed teeth. … A hobbing cutter characterized in that the leading surfaces of blades including both side cutting edges of each blade are inclined backwardly in an amount ranging from 15° to 60°."

Figure 3 shows a drawing of the hobbing cutter from the Azumi skiving patent.

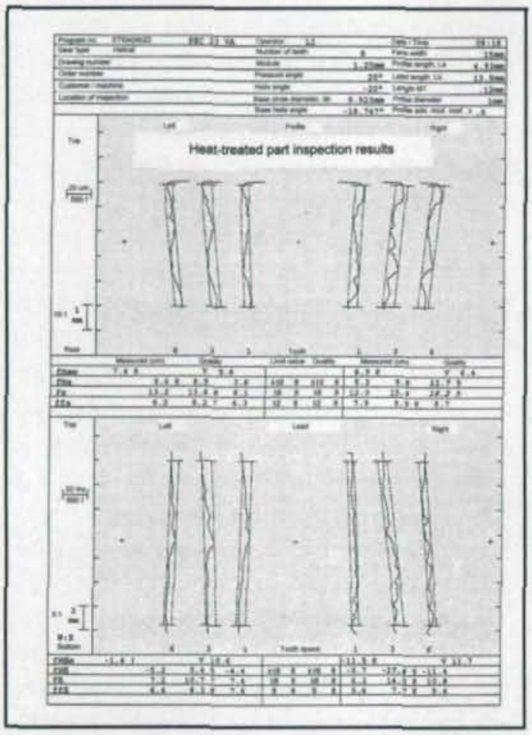
That patent covered the use of all practical negative rake hobs for the finish skiving (recutting) of previously hobbed and hardened workpieces. It was used on medium- to coarse-pitch workpieces as a pregrind or as a finishing operation. Nearly 30 different companies in the United States have used the process for coarse-pitch work. In the past, the success of this coarse-pitch application has been limited to the achievable gear quality, the expense of the cutting tools, complex tool sharpening, alignment of the hobbed workpiece with the cutter, and a "single-source" tool supplier. The Azumi patent expired on Jan. 22, 1991.

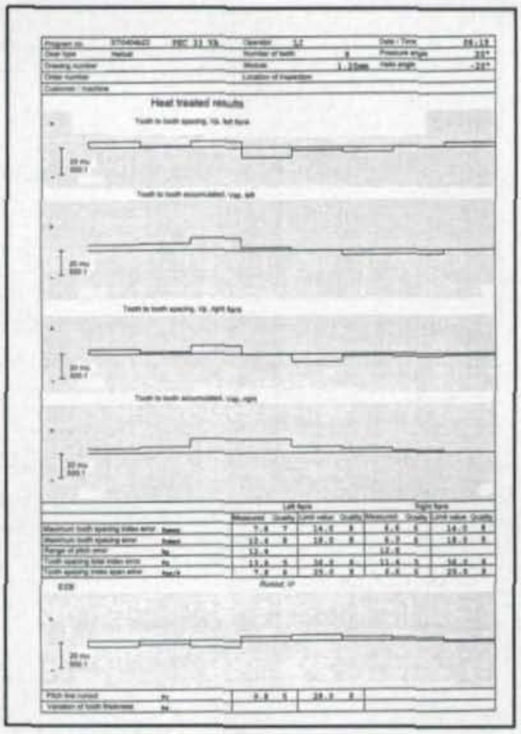
**Skiving Hobs**

The carbide hobs used in skiving fall into two distinct categories. For coarse-pitch workpieces of 10 DP or coarser, the cutters normally have a negative rake cutting face design; this reduces the cut-

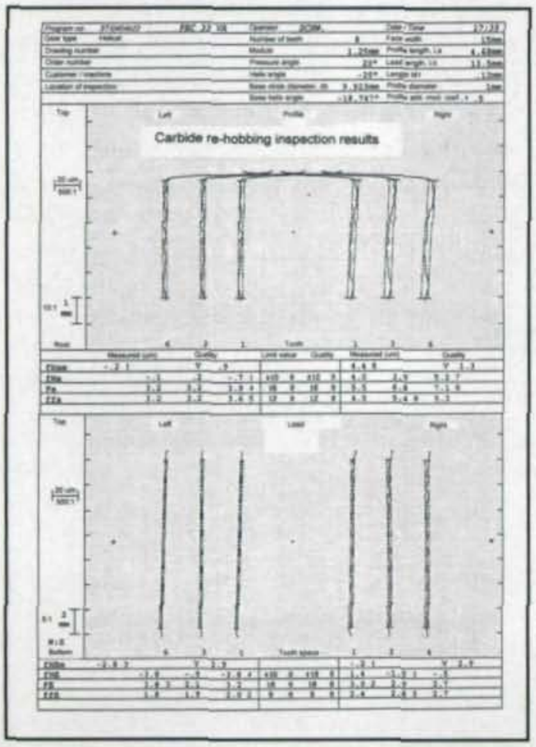
**Table 3—Example of Carbide Rehobbing.**

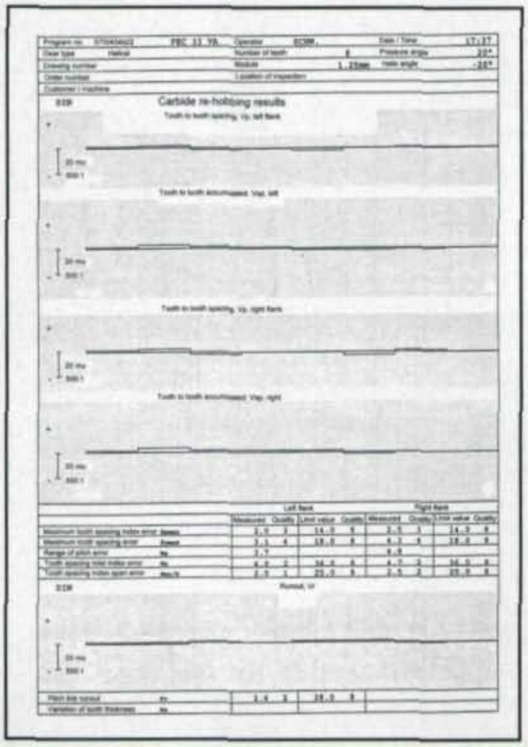
| Workpiece data | | Cutter data | | Cutting data | |
|---|---|---|---|---|---|
| Workpiece | Hand tool armature shaft | Cutter type | Carbide hob, class AA | Coolant | Yes |
| Material | 4140 | Coating | TiN | Number of cuts | 1 |
| Hardness at rehobbing | 57 HRc | Outside diameter | 1.250" | Hob speed | 325 sfm |
| Normal diametral pitch | 20.32 (1.25 module) | Threads | 1 | Hob rpm | 993 |
| Number of teeth | 8 | | | Axial feed | 0.02"/rev. |
| Pressure angle | 20° | | | Stock removal | 0.003"/flank |
| Helix angle | 20° | | | | |
| Face width | 0.591" | | | Hob-to-work alignment | 4 seconds |
| Outside diameter | 0.557" | | | Cutting | 22 seconds |
| Whole depth | 0.110" | | | Load and unload | 3 seconds |
| | | | | | |
| | | | | Total floor-to-floor time | 29 seconds |



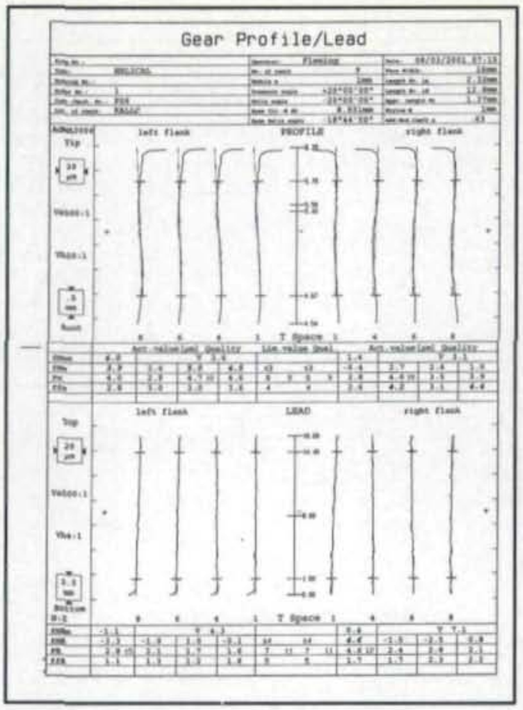




*The two charts at left show a typical helical pinion gear after heat treatment.*




*These two charts show the same helical pinion after hard rehobbing with a carbide hob. The gear quality has been improved and is approximately AGMA 10 on profile and exceeds AGMA 12 on lead and spacing.*





*These two charts (above and right) show a helical pinion after hobbing from the through-hardened blank. The accuracy is of very high quality with AGMA 10 on profile and AGMA 12 on lead and spacing.*

ting shock on the carbide material as the cutting edge contacts the hardened tooth flank. For finer-pitch work, this negative rake is not required. One disadvantage of negative rake hobs is the difficulty in sharpening them. As the hob is sharpened, the outside diameter decreases, which changes the required grinding wheel offset to produce the correct negative rake.

When skiving medium- to coarse-pitch gears, the tip, outside diameter, and root are normally not hobbed. In addition, a smooth transition into the root area of the tooth is desired. For these reasons, the ideal hob for coarse-pitch preskiving would be a hob with protuberance to provide undercut and full fillet radius that improves the blending of the root into the active profile.

For fine-pitch gear applications, it is more practical to use a standard cutter, as the profile problems will be of minor significance and the minor increase in tool wear during root cutting is not important. With the use of a standard radial rake carbide hob, the correct term for the process should be "carbide rehobbing" and not "skiving," which refers to the use of a negative rake hob.

An example of carbide rehobbing appears in Table 3. Also shown are analytical gear inspection charts of the profile, lead and spacing after heat treatment and after carbide rehobbing.

### Skiving Process

Both mechanical and CNC machines are capable of skiving, but the machine should be equipped with an automatic workpiece-to-cutter synchronization system. This feature makes the skiving operation economical and is essential with automatic loading systems. An electronic noncontact system is shown in Figure 4. This system measures position impulses at the cutter spindle (B), the work spindle (C), and the gear using an analog sensor. These impulses are then processed by the machine's CNC control, which modifies the relative position of the work spindle

**Table 4—Example of Carbide Hard Hobbing.**

| Workpiece data | | Cutter data | | Cutting data | |
|---|---|---|---|---|---|
| Workpiece | Hand tool armature shaft | Cutter type | Carbide hob, class AA | Coolant | Yes |
| Material | 4140 | Coating | TiN | Number of cuts | 2 |
| Hardness at rehobbing | 52 HRc | Outside diameter | 0.945" | Hob speed | 722 sfm |
| Normal diametral pitch | 25.4 (1.0 module) | Threads | 1 | Hob rpm | 2,887 |
| Number of teeth | 9 | | | Axial feed, first cut | 0.016"/rev. |
| Pressure angle | 20° | | | Axial feed, second cut | 0.016"/rev. |
| Helix angle | 20° | | | | |
| Face width | 0.630" | | | Cutting | 29 seconds |
| Outside diameter | 0.456" | | | Load and unload | 3 seconds |
| Whole depth | 0.089" | | | | |
| | | | | Total floor-to-floor time | 32 seconds |

to the cutter to align the gear teeth of the workpiece with the teeth of the hob.

Coolant offers many advantages during skiving. First, coolant provides lubricity during cutting. Second, it controls the temperature of the cutter, workpiece, and machine system. Temperature control is very important as the skiving process does not produce a normal chip. The chips are smaller, and do not absorb the heat as well as a normal chip. Third, it flushes the chips away from the cutter and workpiece. Fourth, it improves the surface finish. And lastly, it increases tool life.

During green hobbing, the selection of correct tooth thickness is important so that all tooth flanks will be completely hobbed during skiving. The allowance of tooth flank stock can be calculated or determined through practical experience. Typically, 0.002"–0.004" per flank is used for gears of 12 DP or finer.

Also of significance are the cutting methods, speeds, and feeds. Climb hobbing is recommended because it will produce the most distinct cutting chip. This helps to control the dynamic condition of the cutting process and improve the cutter life. Our experience has shown that cutting speeds in excess of 600 sfm are possible. The selection of a feed rate depends on the required surface finish. Typical feed rates range from 0.020"–0.050" per revolution. The shifting method is also important because during skiving, only the finishing section of the cutting edge is subjected to wear. In contrast, during green cutting, the roughing portion of the tool does most of the work. This means that larger shift increments should be used when skiving. Typically, for gears of 12–48 DP, shift steps of 0.012"–0.016" per shift are used.

### History of Hard Hobbing

Machining parts in the through-hardened condition has been the desire of most manufacturing engineers. Hard turning has been successful for some time, but only recently have carbide materials with advanced coatings and rigid hobbing machines allowed for hard hobbing. This portion of the paper defines hard hobbing as a part with a through-hardness of between 48 and 52 HRc.

### Technical Requirements

The requirements for hard hobbing are nearly identical to those of skiving or carbide rehobbing.

One major difference is in the shifting strategy used. During hard hobbing, a large amount of energy is required for chip removal. That energy eventually becomes heat. It is essential to help dissipate this heat, and we recommend that a full pitch of the hob be shifted after every workpiece.

When the hob has been shifted across the face, the shifting program should return the hob to the initial start position minus an offset based upon the hob design and application. The purpose of this offset is to help evenly distribute wear on the hob.

A second difference is in the fixture system used. Again, due to the extreme cutting forces, the fixture must clamp the workpiece securely (see Figure 5).

Table 4 shows an example of carbide hard hobbing. The analytical gear inspection results, including profile, lead and spacing, are also shown.

### Conclusions

The need for higher quality, hardened gears has become universal. Engineers have explored various methods to manufacture hardened gears economically, including material selection, soft machining methods, heat-treatment processes and hard finishing. Each of these has additional costs.

The process of hard hobbing from a solid through-hardened workpiece blank is an emerging technology. It has become a practical method because of the higher machine rigidity as well as improved carbide materials and tool coatings. Data from several high production installations confirms that the hard hobbing process is viable.

# Predicting the Heat-Treat Response of a Carburized Helical Gear

**B. Lynn Ferguson, Andrew M. Freborg, Greg Petrus and Melvin L. Callabresi**

**Abstract**

Using the DANTE software, a finite element simulation was developed and executed to study the response of a carburized 5120 steel helical gear to quenching in molten salt. The computer simulation included heat-up, carburization, transfer and immersion in a molten salt bath, quenching, and air cooling. The results of the simulation included carbon distribution, volume fractions and distribution of phases, dimensional change, hardness, and residual stress throughout the process. The predicted results were compared against measured results for hardness, dimensions and residual stress. The excellent agreement between predictions and measured values for this carburized 5120 steel gear provides a basis for assessing the various process parameters and their respective importance in the characteristics of not only these heat-treated parts, but of other compositions and shapes.

**Introduction**

Distortion of steel parts due to heat treatment is a widely known but poorly understood problem. While the general causes of part distortion are well known, in most cases the specific cause-effect relationship has not been established. The main reasons behind the lack of understanding of distortion include the many sources of distortion, the breadth of engineering disciplines that must be brought to bear on the problem, the lack of analytical tools to help dissect the problem, and the willingness of heat treaters to solve distortion problems by trial and error.

Recognizing that developing an engineering tool to address the distortion problem would require more effort and resources than any one company could devote, a collaborative project was defined that involved national laboratories, industry and academia. The project was managed by the National Center for Manufacturing Sciences, and the project team members are identified in Table 1. Besides the breadth and depth of expertise included within the project team, it is important to note that the collaborative nature of the project helped provide the substantial resources necessary to allow model development, material characterization, actual heat-treat trials, and model validation to be addressed.

A result of this collaborative effort was the development of a software tool named DANTE, which is an acronym for Distortion ANalysis for Thermal Engineering.

**The DANTE Software**

The DANTE software consists of a set of subroutines that describe the thermal, mechanical and metallurgical response of steel to heating and cooling. These subroutines include the Bammann-Chiesa-Johnson (BCJ) material model developed at Sandia National Laboratories in Livermore, CA; models for both diffusive and martensitic phase transformation developed at the Colorado School of Mines; and a heating-carburizing-quenching model description and methodology. These subroutines have been interfaced with the finite element solvers ABAQUS (a product of HKS Inc. of Pawtucket, RI) and KIVA (a product of Sierra Vista Technology of Albuquerque, NM).

The BCJ material model, an RD 100 award winner (Ref. 11), is based on the use of internal state variables to describe the mechanical behav-

**Table 1—Heat Treat Distortion Program Participants**

| Industrial | Department of Energy | University |
|---|---|---|
| Dr. M.L. Callabresi (Consultant) | Lawrence Livermore National Laboratory | Colorado School of Mines |
| Deformation Control Technology Inc. | Los Alamos National Laboratory | IIT Research Institute |
| Eaton Corp. | Oak Ridge National Laboratory | |
| Ford Motor Co. | Sandia National Laboratories | |
| General Motors Corp. | | |
| Torrington Co. | | |
| The National Center for Manufacturing Sciences | | |

ior of individual metallurgical phases over wide ranges of temperatures, deformation levels and deformation rates. The state variables link the microscopic mechanisms active during deformation to the observed macroscopic behavior. For heat-treatment processes, where mixtures of phases are ever changing during the process, the model has been enhanced to include the effects of phase transformations, transformation-induced plasticity (TRIP), and a mixture theory that predicts the mechanical behavior of the phase mixture from the behavior of the individual phases. For details on the BCJ model as applied to heat-treat processes, see References 3 and 7.

The phase transformation predictive models have been interfaced with the BCJ material model so that the evolution of metallurgical phases is continually updated during the simulation. The phase transformation behavior of carbon and low-alloy steels has been mathematically described using a state variable method that is compatible with the BCJ model. These transformation models track the volume fraction of each metallurgical phase as functions of time and temperature. Details concerning the phase transformation models are found in References 3, 9 and 10.

Specific material data used by these models in the simulation are determined from well known, but not often practiced, mechanical and thermal tests. The data for the BCJ material model are fit from temperature- and rate-controlled tension and compression tests. Using software developed at Sandia specifically for generation of data sets in the BCJ format (Ref. 12), true stress/true strain data for different temperatures and strain rates are determined for each material phase. The phase transformation data are derived from heating and cooling dilatometer experiments. Elastic properties and thermal properties, including latent heats of formation, were extracted from published literature and implemented within the model as functions of temperature and carbon level.

**Heat-Treat Process Simulation**

A 21-toothed helical gear, shown in Figure 1, was selected for simulation. This gear, made from 5120 steel, is typically machined from a forged blank, carburized, quenched in molten salt, washed and tempered. To simulate the response of any part, several major assumptions must first be made. For this helical gear, the assumption was made that heating and cooling conditions in the actual process were uniform around individual gears and neighboring gears did not influence the heating and cooling. This assumption allowed

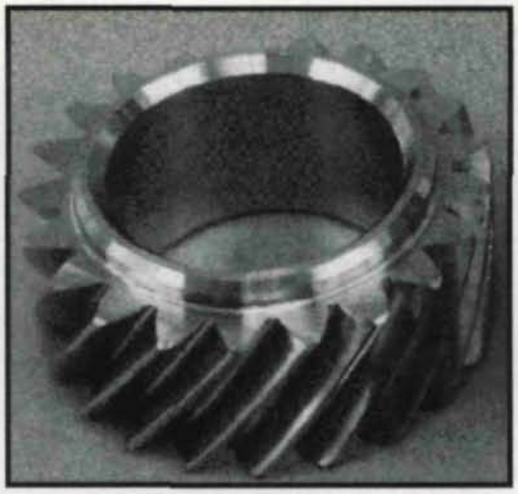


*Figure 1—Carburized helical gear.*

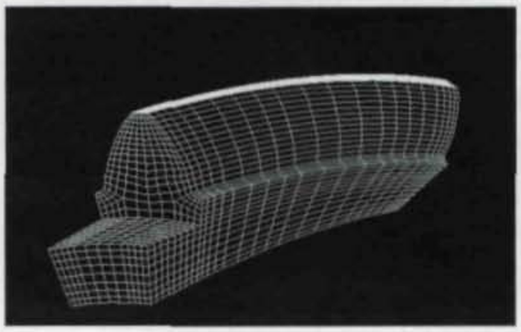


*Figure 2—Mesh of single tooth.*

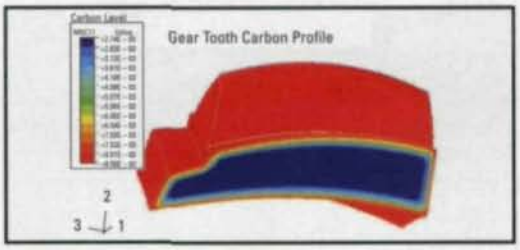



*Figure 3—Carbon profile in carburized and quenched helical gear (units are weight fractions).*

us to focus on a single gear tooth, as shown in Figure 2. Cyclic symmetry conditions were applied to the cut faces of the model.

The heat-treat schedule employed in the model is shown in Table 2. Heating was accomplished by applying a temperature-dependent surface heat transfer coefficient representative of typical gas-fired, continuous-throughput furnaces. A constant carbon potential of 0.85% was applied uniformly to all exterior part surfaces to provide the boundary condition for the carbon diffusion model. Quenching involved transferring the gear through air to the quench tank, immersing the gear in molten salt at a speed of 96.8 mm/s, and holding for the remainder of the time. The gear was then removed from the salt and air cooled to ambient temperature before washing. The washing step and tempering are not considered in this paper, largely because austenite

**Melvin Callabresi**

*is a technical consultant for advanced material model development, numerical simulations and manufacturing process modeling. He worked at Sandia National Laboratories of Albuquerque, NM, for 27 years and has development experience in finite element code, nonlinear numerical simulations, advanced material model development and manufacturing process modeling.*

**Andrew M. Freborg**

*works for Deformation Control Technology Inc. in Cleveland, OH, adapting finite element analysis to address quality/processing areas in the ferrous metals industry. Prior to joining DCT, he was senior process engineer with LTV/Republic Engineered Steels of Massillon, OH, from 1989–1995.*

**Greg Petrus**

*is vice president of Deformation Control Technology. He has been working with numerous metalworking and manufacturing companies to solve their production problems. Specifically, he has concentrated on applying analytical methods to their deformation and thermal processes.*

**B. Lynn Ferguson**

*is founder and president of Deformation Control Technology. He is a member of the editorial review committee for the* International Journal of Powder Metallurgy. *Before forming DCT, he was employed at TRW Inc. of Cleveland, OH, and Republic Steel Corp. Ferguson holds a doctorate in materials engineering.*

| Table 2—5120 Carburization & Salt-Quench Cycle | | | |
|---|---|---|---|
| Step | Temperature | Time | Carbon Potential |
| Heat-Up | 20–850°C | 10 mins. | – |
| Carburize | 850–900°C, 900°C, 900–843°C, 843°C | 30 mins., 3.75 hrs., 15 mins., 45 mins. | 0.85%, 0.85%, 0.85% |
| Transfer to Quench | Air | 12 secs. | – |
| Salt Quench | 230°C | 4 mins. (includes 96.8 mm/s immersion) | – |
| Air Cool | 20°C | 10 mins. | – |

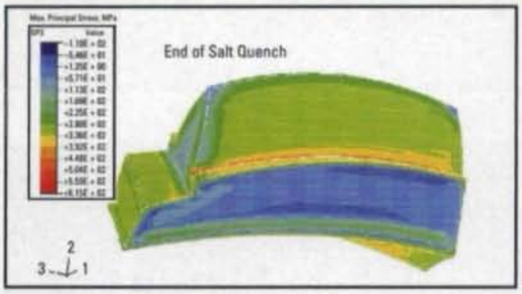



*Figure 4—Maximum principal stress contour map at the end of the salt quench. Part temperature is 230°C.*

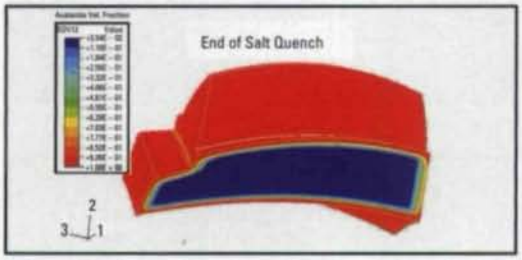



*Figure 5—Austenite volume fraction at the end of the salt quench. Part temperature is 230°C.*

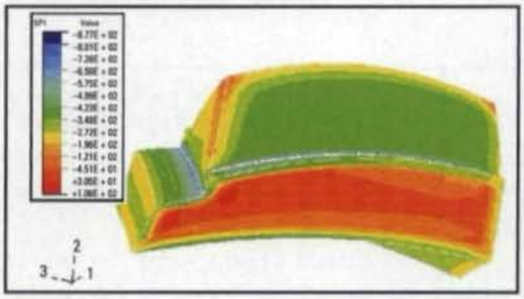


*Figure 6—Minimum principal stress after salt quench and air cool. Part temperature is now 20°C.*

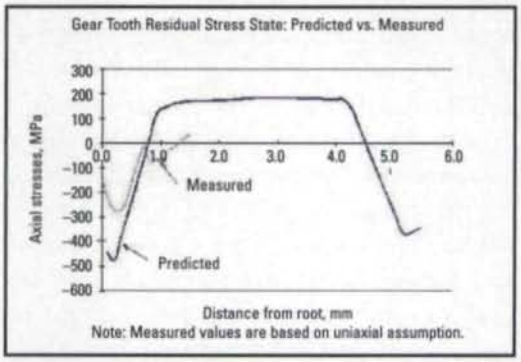



*Figure 7—Comparison of predicted stress vs. stress computed from X-ray measurements.*

decomposition is completed prior to washing, and the tempering process model had not been fully implemented when the demonstration model was developed.

Model results illustrating the carburized tooth are shown in Figure 3. The main assumption in the carburizing boundary conditions was that the carbon potential was uniform around the tooth exterior and bore. The final case depth was 0.64 mm, defined as the depth at 0.4%C. Note, the carbon profile of the carburized gear was not measured; the carbon diffusion model had been validated previously where predicted profiles were found to agree with profiles determined directly by electron-beam microprobe or indirectly by microhardness measurements (Refs. 6 and 8).

Figure 4 shows a contour map of maximum principal stress at the end of the salt quench. The case is in residual tension of approximately 300 MPa, with the direction of this stress being along the length of the tooth. The part temperature at this point in the process is 230°C, which is above the martensitic temperature of the carburized case. As indicated in Figure 5, the high carbon case is still fully austenitic at this point, while the low carbon core of the part has transformed to a mixture of ferrite-pearlite (up to 7%), bainite (up to 35%) and martensite (remainder).

Figure 6 shows a contour map of minimum principal stress after cooling the quenched gear to room temperature. The case now exhibits residual compression of approximately 400 MPa along the tooth face and 500 MPa in the root. For comparison, Figure 7 illustrates the predicted versus measured surface and near-surface stresses, with the measured values determined from X-ray diffraction patterns taken along the direction of the root valley. These values were measured for martensite and were not corrected for multiaxial effects. Qualitative agreement between the measured and predicted values seems reasonable, but the differences between the two still require further examination. At this time, there is not sufficient basis to comment definitively on the accuracy of the measurements derived from X-ray analysis and the comparison with predicted values.

Previous validation studies that focused on simpler ring shapes have shown a similar difference between predicted and measured surface stresses but virtually identical values for stress through the case and into the core (Ref. 8). A slight amount of surface decarburization and oxidation may have a significant impact on the localized measured surface stress state.

The helical gear model indicates that at the end of the final air cool, the case is transformed to martensite with about 25% retained austenite, as shown in Figure 8. The retained austenite level in the model matches the amount observed in the carburized case of gears at this point in the process. The volume fractions for the phases were also corroborated by qualitative matches of predicted phase volume fractions versus metallographic observations.

The hardness model in DANTE is based on a simple rule of mixtures, where the hardness of each individual phase is calculated and the combined hardness is then based on the summation of the phase fraction times its respective hardness. Martensite hardness is based on carbon level, and the hardness of the diffusive phases of ferrite, pearlite and bainite are functions of the temperature of phase formation in addition to carbon level. Martensite and lower bainite therefore are dominant phases in parts with high hardness, while retained austenite, ferrite and pearlite reduce hardness. The predicted hardness of the gear tooth model is plotted in Figure 9, with the high carbon case being the high hardness region as expected.

Figure 10 shows a bar graph describing the radial displacements of the four corner bore nodes for the evaluated gear tooth section at the end of each process step. After heat-up, the part expansion is evident by the radial expansion of all four bore points. As carburization progresses during the next process step, the bore shrinks slightly as carbon diffuses into the austenitic lattice. The part then thermally contracts as it slightly cools during transfer to the quench. The bar marked "Immerse" is actually at 5 seconds into the salt quench after immersion has been accomplished during the first 0.3 seconds. Transformation of the austenite is still negligible at this time, while thermal contraction is pronounced. After completion of the salt quench, the core of the tooth has now transformed to martensite and bainite, with the result being a reversal in radial movement as the bore grows with the formation of these phases. The final air cooling produces a thermal shrinkage, with the bottom radius being approximately 12 microns smaller and the top radius being 10 microns larger than original size.

The chart shown in Figure 11 is similar to Figure 10, except that Figure 11 tracks the radial movement of the tooth tip. The tooth tip moves outward during heating and carburizing. However, more significant is radial growth and barreling of

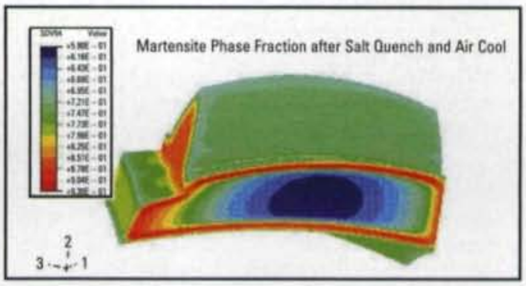


***Figure 8—Volume fraction of martensite after salt quench and air cooling to 20°C.***

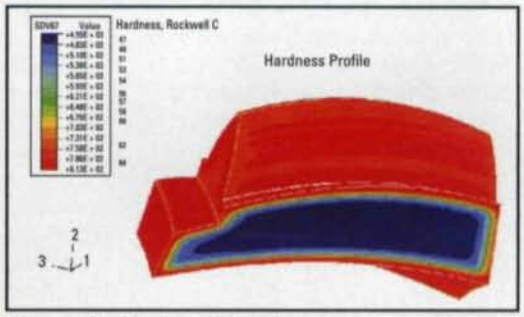


***Figure 9—Predicted hardness contours in gear tooth after quenching and air cooling to room temperature.***

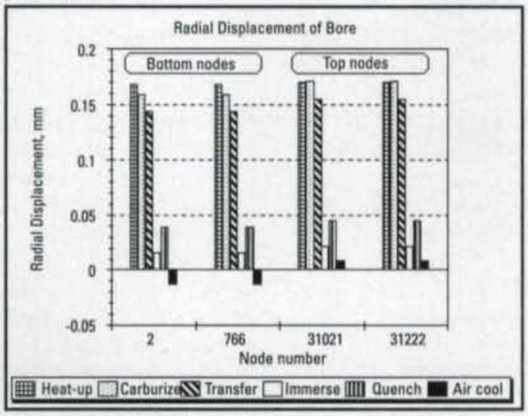


***Figure 10—Predicted bore displacement during heat treatment.***

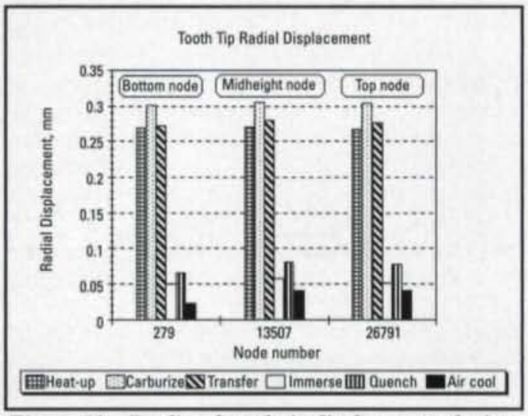


***Figure 11—Predicted tooth tip displacement during heat treatment.***

the tooth that is shown at the end of the final air cool. The bottom node has grown the least at approximately 25 microns, the midheight node has grown more than 40 microns, and the top node of the tooth has grown just less than 40 microns. While these radial growths may seem small, they

# ABOUT DANTE

A software tool called Distortion ANalysis for Thermal Engineering (DANTE) was recently developed by a team of specialists to analyze part-distortion problems. Because of the many sources of distortion, the variety of engineering disciplines required to analyze the problem, the lack of analytical tools to solve the problem and the tendency of heat treaters to use trial and error for distortion problems, the DANTE tool was created to look deeper into the issue.

**Benefits**

The immediate benefit from using DANTE is prediction of dimensional change, residual stress state, and part hardness. These predictions provide direct insight into the effects of steel chemistry, part shape and process on these values; and a method for comparing processes, green shapes and steel grades can therefore be achieved. This knowledge, when applied, provides a means of reducing costs and time associated with distortion-corrective steps, through reduced straightening, reduced machining of hardened parts, and possible substitution of free quenching for press- or fixtured-quenching processes.

As an example, high-pressure gas quenching following vacuum carburizing is becoming a popular process substitution for conventional gas carburizing followed by immersion quenching in oil. The DANTE simulation tool provides a valuable means of comparing these processes. Also, processes such as induction hardening, which is done as an in-line process on individual parts, can be compared against batch-quenching processes. Thus DANTE provides a powerful means of assessing potential process developments prior to initiating potentially expensive plant trials.

Simulation using DANTE can improve part quality through:

- More uniform carburized case, which can minimize machining after hardening;
- Achievement of deeper levels of surface compression and improved fatigue life through improved understanding and control of the heat-treat process;
- Optimal design of part geometry and required fixturing to maximize heat-treatment response and minimize undesirable distortion.

DANTE provides technical insight into the heat-treat process, which is a benefit by itself; but when skillfully applied, it can result in design- and production-cost reduction and improved part quality.

**Theory**

*During heat treatment, dimensional changes occur due to* thermal expansion and contraction, phase transformation, and internal stress. Dimensional change cannot be prohibited during heat treatment, but it can be taken into account during design. However, unanticipated dimensional change, termed distortion, is a major problem in heat-treat processes and costs the industry millions of dollars each year. DANTE predicts the phases and distribution of phases, internal stress state, and final hardness of the steel part.

**DANTE's Material Model:** DANTE includes a multiphase material model based on the Bammann-Chiesa-Johnson (BCJ) *internal state variable model to address heat treatment of steel.* This material model was recognized as a RD 100 award winner in 2000.

The internal state variable model characterizes the internal state of a phase, where the state variable relates to the microscale physical state of the phase. Evolution equations describe how the state variables change with temperature, rate of deformation, and deformation level. State variables included in the BCJ model are static- and rate-dependent, yielding as functions of temperature and alloy content, and hardening balanced by recovery mechanisms. The constants that define the state variables are derived from conventional temperature- and rate-controlled tension and compression tests.

**DANTE's Phase Transformation Kinetics Models:** The steel transformation models in DANTE include austenite formation during heating, and austenite decomposition to ferrite/pearlite, bainite and/or martensite during quenching. At present, low-temperature tempering of martensite is also addressed. The kinetics model is driven by phase transformation data obtained from dilatometry.

**DANTE's Carburizing Model:** DANTE includes carburization as a mass diffusion model where the diffusivity of carbon in iron is controlled as a function of carbon content and temperature. The effects of selected alloy elements, such as chromium, on carbon diffusivity are also included. The surface carbon potential may be specified as a constant value, or it may be defined as a function of time and temperature based on particular furnace performance data. The carburization model can be used to simulate conventional gas carburizing, as well as vacuum carburizing.

**Material Data:** During the initial collaborative project, the mechanical, thermal and phase transformation behavior of the 5100 series of low alloy steel was developed in detail. Phase transformation kinetics data and mechanical behavior data were later developed for some other grades of alloy steels, including 8620, 9310, and 4320 steel. During a subsequent U.S. Army-sponsored Small Business Innovative Research (SBIR) program, comprehensive material data were developed for the high alloy gear steel Pyrowear 53 (a trademarked and patented alloy produced by Carpenter Technology Inc.), which is used in gear transmission applications for military helicopters.

**Quench Media Data:** Part of the processing data available with DANTE are heat-transfer tables for selected oils, salts, water (immersion and spray), and gases.

**Software Packages**

DANTE exists in two versions. The DANTE/ABAQUS version requires that users have a valid license for ABAQUS/Standard and ABAQUS CAE for pre- and post-processing of results. The DANTE subroutines are distributed as object code that is linked to ABAQUS at run time. This version of DANTE runs on any platform on which ABAQUS runs, including Windows NT and UNIX workstations. Models may be either 2-D or 3-D in nature and element types include quadrilateral, hexahedron, wedge, and tetrahedron elements.

The second version of DANTE is called DANTE/KIVA and has the same capabilities as the ABAQUS version, but instead the *software couples with the KIVA special purpose finite element* solver. KIVA solves coupled mechanics problems involving carbon diffusion and transient thermal-stress process steps, but is limited to hexahedral elements at this time. KIVA's primary advantage over the DANTE/ABAQUS package is much faster solution times for 3-D problems. KIVA relies on existing pre- and post-processing software such as ABAQUS CAE or PATRAN for model-building and graphical display of results.

**About DANTE**

The DANTE software package is available for licensing from Deformation Control Technology Inc. A product of a collaborative *industry-government laboratory-university consortium,* DANTE consists of several components, each with separate ownership but covered by commercial licensing of the software. The material model was developed by Sandia National Laboratories of Livermore, CA, and is owned by Sandia. The phase transformation kinetics models were developed by the Colorado School of Mines under contract to the National Center for Manufacturing Sciences, and NCMS is the owner. DCT is responsible for maintaining, marketing, distributing and training. For more information, contact DCT at (440) 234-8477. ○

are highly significant from a design and application standpoint because they use up most of the allowable dimensional variation in the gear tooth.

### Summary

A simulation of the carburizing and quench hardening of a 5120 helical gear has been conducted using the DANTE heat-treatment simulation software package. Agreement between predicted values and measurements for phase volume fractions and distribution of phases, and residual stress state was excellent. The predicted dimensional changes associated with the heat treatment of this type of gear were also in agreement with experience. However, a more robust system for accurately comparing model results with typical gear measurements and properties (such as surface residual stress) is still required for a realistic judgement of model performance and accuracy. This work is in progress.

Additional work also continues in refining the experimentally measured phase transformation kinetics, characterization of additional steels, and characterization of other quench processes.

### Acknowledgments

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#### References

1. Dowling, W., et al. "Development of a Carburizing and Quenching Simulation Tool: Program Overview," *2nd International Conference on Quenching and Control of Distortion*, edited by G.E. Totten, M. Howes, S. Sjostrom, K. Funatani, ASMI, Cleveland, pp. 349–355, November 1996.

2. Shick, D., et al. "Development of a Carburizing and Quenching Simulation Tool: Determination of Heat Transfer Boundary Conditions in Salt," *2nd International Conference on Quenching and Control of Distortion*, edited by G.E. Totten, M. Howes, S. Sjostrom, K. Funatani, ASMI, Cleveland, pp. 357–366, November 1996.

3. Bammann, D., et al. "Development of a Carburizing and Quenching Simulation Tool: A Material Model for Carburizing Steels Undergoing Phase Transformations," *2nd International Conference on Quenching and Control of Distortion*, edited by G.E. Totten, M. Howes, S. Sjostrom, K. Funatani, ASMI, Cleveland, pp. 367–375, November 1996.

4. Anderson, C. "Development of a Carburizing and Quenching Simulation Tool: Numerical Simulations of the Rings and Gears," *2nd International Conference on Quenching and Control of Distortion*, edited by G.E. Totten, M. Howes, S. Sjostrom, K. Funatani, ASMI, Cleveland, pp. 377–383, November 1996.

5. Mgbokwere, C., et al. "Modeling the Heat Treatment Behavior of a Transmission Ring Gear Blank," *3rd International Conference on Quenching and Control of Distortion*, edited by G.E. Totten, B. Liscic, H.M. Tensi, ASMI, Prague, pp. 355–364, March 1999.

6. Ferguson, B.L., G.J. Petrus, and T. Pattok, "A Software Tool to Simulate Quenching of Alloy Steels," *3rd International Conference on Quenching and Control of Distortion*, edited by G.E. Totten, B. Liscic, H.M. Tensi, ASMI, Prague, pp. 188–200, March 1999.

7. Prantil, V.C., et al. "Simulating Distortion and Residual Stresses in Carburized Thin Strips," submitted to *ASME Journal of Engineering Materials and Technology*.

8. Ferguson, B.L., A.M. Freborg and G.J. Petrus, "Software Simulates Quenching," *Advanced Materials & Processes*, pp. H31–H36, August 2000.

9. Lusk, M.T., and Y-K Lee, "A Global Material Model for Simulating the Transformation Kinetics of Low Alloy Steels," *7th International Seminar on Heat Treatment and Surface Engineering of Light Alloys*, IFHT, Budapest, pp. 273–282, September 1999.

10. Lusk, M.T., et al. "An Internal State Variable Model for the Low Temperature Tempering of Low Alloy Steels," *1st International Conference on Thermal Process Modeling and Computer Simulation*, Shanghai Jiaotong University, 2000.

11. "Material Modeling Predicts Failures," *Research & Development*, September 2000.

12. J.F. Lathrop, "BFIT—A Program to Analyze and Fit the Sandia Plasticity (BAMMANN) Model Parameters to Experimental Data," SNL Report, September 1995.

# The Barkhausen Noise Inspection Method for Detecting Grinding Damage in Gears

Jeffrey S. Ceurter, Chad Smith and Roy Ott



### Introduction

When hardened steel components are ground, there is always the possibility of damage to the steel in the form of residual stress or microstructural changes. Methods for detecting this sort of damage have always had one or more drawbacks, such as cost, time, complexity, subjectivity, or the use of hazardous chemicals.

A relatively new method, known as Barkhausen noise analysis, meets the demand for measuring defects in ground steels in a very reliable, standardized and cost-effective manner (Refs. 1 and 5). Use of this technique is simple and can reduce product failures to 0%. Semiautomated gear inspection systems have been employed by gear manufacturers to take advantage of the capabilities of Barkhausen instrumentation.

Combined with dimensional inspection, hardness tests and periodic metallographic analysis, the Barkhausen noise analysis method can help close the loop on insuring product quality. Barkhausen noise analysis can be a strong link in the chain that ultimately leads to a long and reliable gear life.

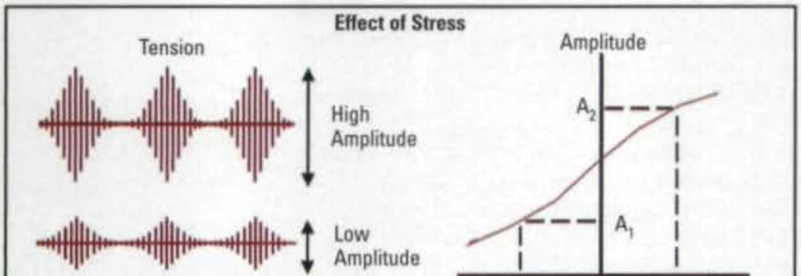


*Figure 1—Barkhausen noise amplitude vs. stress.*

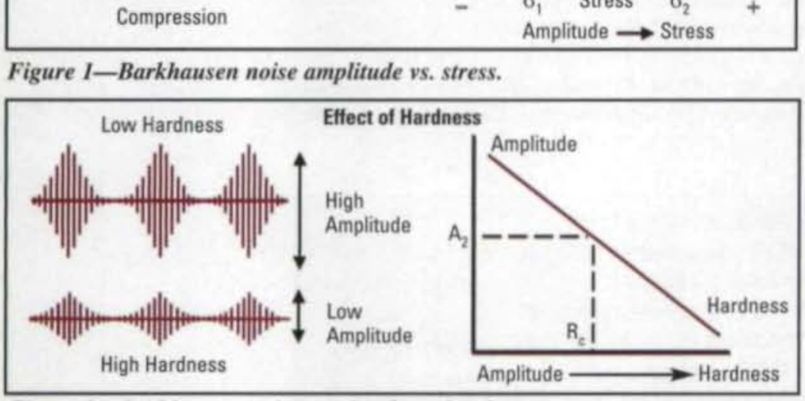


*Figure 2—Barkhausen noise amplitude vs. hardness.*

### Measurement Techniques and Instrumentation

Barkhausen noise analysis is a technique based around a relatively simple concept involving ferromagnetic materials and a magnetizing field. When a magnetizing field is placed near a ferromagnetic material, the material undergoes a net magnetization change. This change is a result of the microscopic motion of magnetic domain walls within the material.

When a domain wall moves, it emits an electrical pulse that can be detected by a coil of conducting wire placed near the material. These discrete pulses are measured in a bulk manner, resulting in a compilation of thousands of electrical pulses referred to as Barkhausen noise (Refs. 3, 6, 7 and 9). The amplitude of this signal is sometimes referred to as the magnetoelastic parameter (MP). The amplitude is affected by anything that impedes the motion of domain walls. Some factors to consider are inclusions, precipitates, dislocations, grain boundaries, and residual stresses.

In the sense of macrometallurgy, we may sum up these factors in two categories, hardness and residual stress. In general, Barkhausen noise is increased with decreasing hardness and increasing tensile stress, and conversely, Barkhausen noise is decreased with increasing hardness and increasing compressive stress. This principle is illustrated in Figures 1 and 2.

The instrumentation required to detect Barkhausen signals is illustrated in Figure 3. A magnetizing field is created and applied to a ferromagnetic material through the use of an electromagnet. The material reacts to the magnetic field as described above and emits Barkhausen bursts, which are captured by a sensor consisting of a coil of conducting wire. The signal is then amplified and filtered. The amplitude is calculated using an RMS equation, and the data is digitized for display and output to a computer.

### The Nature of Material Defects Caused by Grinding

Grinding damage is the result of energy being converted to heat. This heat is concentrated in the surface layers and may cause undesirable effects if not properly managed. Some of the factors affecting the rise in temperature in the surface layer include the coolant type, coolant concentration, coolant age, coolant flow, grinding wheel type, grinding wheel speed, grinding wheel wear, feed rate and prior processing of material, e.g. different heat-treat batches.

Wojtas, et al. (Ref. 9) explain that damage may start with the partial relaxation of desirable compressive stresses at temperatures less than 500°C. As temperatures increase to nearly 600°C, B-class thermal damage, also known as retempering burn, occurs. The effect will be an overtempering, causing a decrease in surface hardness and the onset or materialization of tensile stresses. Further temperature increase to greater than 720°C will cause D-class thermal damage, also known as rehardening burn. This defect will include regions of very hard and brittle material, as well as surrounding areas of B-class burn, "soft" material.

The residual stresses will also be complex due to ranging levels of damage across the surface. Some areas will be compressive, while others will be highly tensile (Refs. 2 and 9).

The existing techniques for detecting the damage described above include visual inspection via nital etching (Ref. 4), microhardness testing, residual stress profiling with x-ray diffraction and Barkhausen noise analysis. Each of the defects described above can be detected via Barkhausen noise analysis and can be done in a totally nondestructive manner. The x-ray diffraction technique can also be used in each case; however, it is extremely time-consuming, expensive, and destructive. The nital etching and microhardness techniques are quick and easy, but they can only detect B- and D-class damage. Furthermore, hardness testing is destructive and nital etching is subjective. Figure 4 shows some of the features of Barkhausen noise analysis compared to the most widely used grinding-burn detection technique, nital (temper) etching (Refs. 2 and 9).

It was seen in Figures 1 and 2 that the Barkhausen signal increased for decreasing hardness and for increasing tensile stresses. This is the exact scenario for retempering grinding burn as seen in Figure 5. Since grinding damage affects the hardness and stress in ways which increase the Barkhausen signal, detection of grinding damage by the Barkhausen noise analysis is quite simple. If the amplitude increases, then there is burn.

The exception to this rule is for rehardening zones. In the case of rehardening zones, the signal may decrease, but these zones are always surrounded by severely retempered zones, which exhibit large amplitudes of Barkhausen noise (MP).

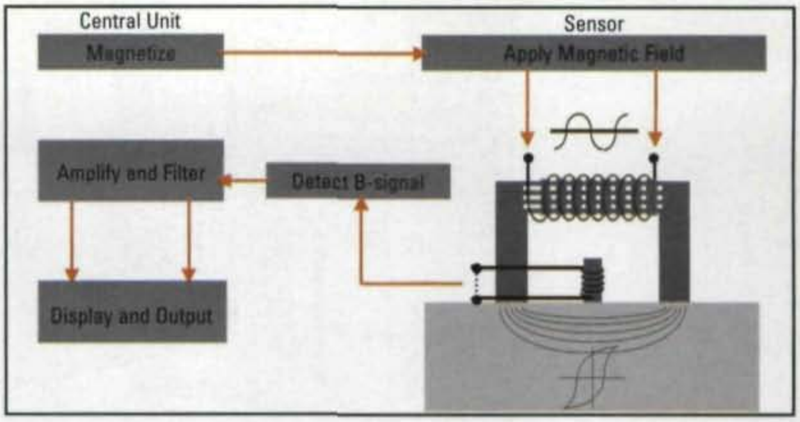


*Figure 3—Instrumentation required for Barkhausen noise analysis.*

| Comparison of Inspection Methods | | | |
|---|---|---|---|
| | Barkhausen Method | Nital Etch | Microhardness |
| • Nondestructive | Yes | No | Yes |
| • Use of Chemicals | No | Yes | No |
| • Automated | Yes | No | No |
| • Reliable | Yes | No | No |
| • Evaluation Through Coatings | Yes | No | No |
| • Danger of Hydrogen Embrittlement | No | Yes | No |
| • Influenced by Both Stress and Microstructure | Yes | No | No |

*Figure 4—Comparison of nital (temper) etch to Barkhausen noise analysis.*

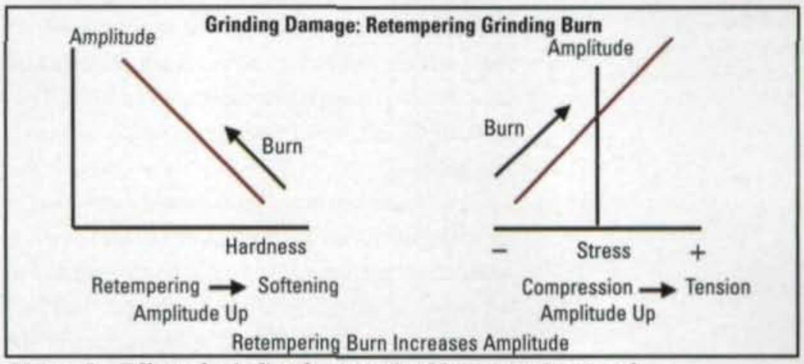


*Figure 5—Effect of grinding burn on Barkhausen noise signal.*

## Instrumentation for Gears

There are several different methods to make the Barkhausen measurements. They are manual measurement by general-purpose or custom sensors, manual measurements made with the aid of fixturing, and semiautomated or fully automated methods.

Here we introduce semiautomated Barkhausen noise evaluation of transmission gears.

## Outline of Instrumentation and System Operation

The inspection system, shown in Figures 6 and 7, consists of a linear x-y motion controlled sensor, a live center, a three-jaw chuck with software-controlled rotation, a Barkhausen noise analyzer, a computer, and data acquisition and analysis software. Parameters for rotation and x-y motion are programmed into the computer for each individual gear type. The operator then installs a gear manually,

*Figure 6—Gear inspection system, with gear inspection stand and computer/ROLLSCAN™ cabinet.*

selects the type of gear from the software and presses Start. The remaining operations are all automatic.

The sensor moves into place on the gear tooth—see Figures 8 and 9—then axially scans the preset locations on the tooth, up to four radial locations per tooth. The gear then rotates slightly, allowing the sensor to contact the opposite flank, which is then scanned in the same manner as the first flank. Next, the sensor moves away from the gear and the gear rotates, allowing the sensor to move in to test the next tooth. This continues for the preset number of teeth and the results for each scan are presented on the computer monitor with the status of ACCEPTED or REJECTED, based upon programmed rejection conditions.

The system can be set up to measure one tooth or all teeth, and it can be programmed to measure one tooth, then skip five and test the seventh tooth and so on. A typical setup is to use two scans per flank and to measure a total of four teeth at approximately 90° from one another. This type of setup drastically decreases the measurement time, compared with measuring each tooth, without sacrificing reliability. When the measurement is completed, the results can be saved to a file or output to a printer.

### Getting Started with Barkhausen Noise Analysis

In order to get started with Barkhausen noise analysis, one must first obtain a correlation between the Barkhausen noise signal and some other measure of the severity of burn, e.g. nital etching. Based upon the correlation data, a criterion for rejection can be established for the Barkhausen instrument. One simple inspection method is based upon the fact that the MP values can be directly related to the results of a visual nital etch inspection. By measuring a variety of production parts and comparing them with nital etch inspection, a correlation can be made and the level of burn can be quantified using the magnitude of the Barkhausen signal, or magnetoelastic parameter (MP).

By examination of the correlation, a criterion for rejection is established. The rejection criterion is then entered into the computer program for the type of gear being used. Once the rejection criterion has been entered, Barkhausen noise analysis of production samples may begin. An example of the setup used for one gear type on a motorcycle transmission gear system is shown in Figure 10.

The figure illustrates a correlation between the magnetoelastic parameter, MP, and the visual indication of burn from nital etching. The left graph is a correlation for the maximum MP values measured on all scans of a gear, while the right graph is a correlation for the difference between maximum and minimum MP values measured on all scans of a gear. On each graph, a cross has been added to indicate the rejection criterion. In each case, the lower left quadrant indicates acceptable samples while the upper right quadrant indicates unacceptable samples. Therefore, by setting the maximum rejection limit to 60 MP and the difference rejection limit to 20 MP, all parts rejected by nital etching will also be rejected by the Barkhausen noise analysis.

The example given indicates some scatter in the data, and it is only for a relatively small group of parts. Based upon this example, it would be wise to choose rejection criteria that are slightly lower than those indicated. This would be taking a conservative stance, but you would be 100% positive that no rejectable parts are passed. In order to increase confidence in results, all final correlations are being done with 60 sample groups tested by three different users. This technique will further increase confidence in the rejection criteria and limit the need for further analysis of the gears.

When a gear measures near or above the rejection criteria, it is common practice to check the gear further using nital etching. This type of "extra" analysis is excellent for confidence building, especially if the rejection criteria were established using a small group of parts. Over time, operators would become more confident that the analysis system and the established rejection criteria are reliable and true.

### Benefits of Automated Barkhausen Noise Inspection

***Early detection of damage***. Grinding damage usually occurs as a result of wheel wear, but may also occur due to incorrect feed rate, wheel speed, or various other changes, as mentioned before. In a production cycle that outputs large numbers of parts every hour, it is essential that errors are detected quickly. Nital etching techniques can take several minutes and are not always conveniently located with respect to the grinders. Because of this, etching is typically done once an hour or less; therefore, detecting errors is by no means fast. This can be a huge loss in time and money on damaged product. The Barkhausen technique can be established such that detection is always within a matter of minutes of the error, resulting in thousands of dollars in savings. Some users have reported a return on investment in as little as three months.

***Record of results.*** The Barkhausen noise amplitudes (MP values) are recorded for each individual gear, and the data can be saved and recalled for review, if necessary. Nital etching has no record of the results unless the operator keeps a logbook, and the etch results still are subject to human error.

***Quality-Performance Control Chart.*** The Barkhausen results can be used for statistical analysis, if necessary.

***Decrease warranty repairs.*** Barkhausen noise analysis can aid in monitoring and preventing the possibility of generating undesirable surface conditions in manufactured components. This is due to the increase in confidence when measuring burn. By eliminating etching and using a proper Barkhausen noise analysis, one can significantly enhance process capability, thus reducing risk of producing parts that challenge specification compliance.

***No consumables, low maintenance cost.*** Barkhausen noise uses no chemicals or consumables of any sort, whereas the acid etch technique requires close monitoring and is difficult to maintain with today's increasing environmental standards.

**Setting Up the Grinding Process Using Automated Barkhausen Noise Inspection**

For an application such as transmission gears, it is not unlikely for the same grinding machine to be used to grind several different types of gears. This is true of many applications, especially when one facility is required to produce hundreds of different types of similar parts. In these cases, quickly setting up the grinder and changing from part to part is essential.

As mentioned earlier, nital etching takes several minutes, and the etch facility may be located hundreds of feet from the grinder. A typical setup requires that the operator set up the grinder for a particular part number and then run a test sample. Then the part is etched and, based upon the results of the etching, changes are made to the grinder. This iterative process continues until the operator is satisfied with the results of the etching. This procedure can take from several minutes to an hour or even more, even for an experienced operator.

Setting up a grinder using Barkhausen noise analysis is based upon the same principle. But the

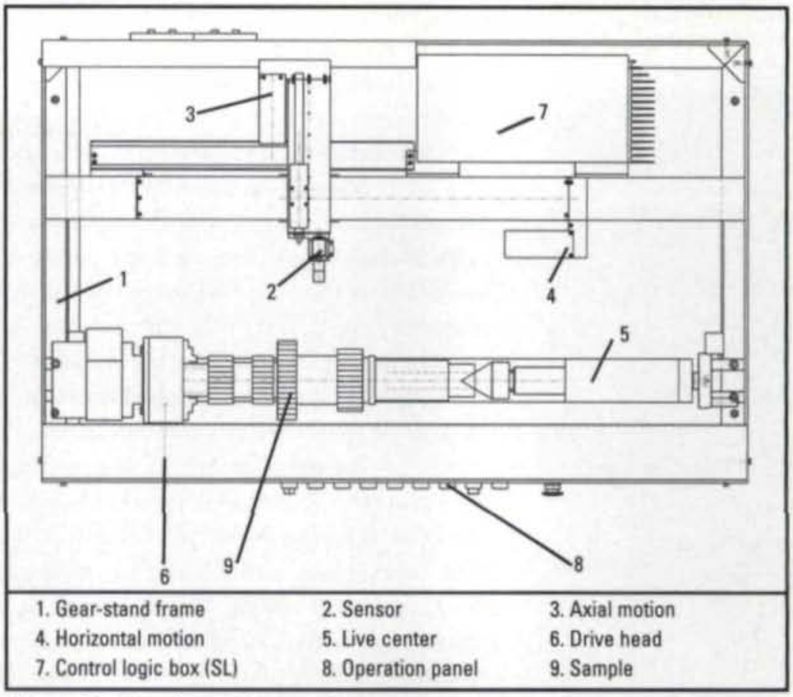


***Figure 7—Gear inspection stand.***

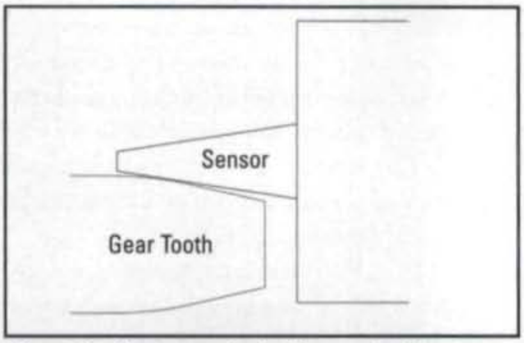


***Figure 8—Sensor contact with gear tooth.***

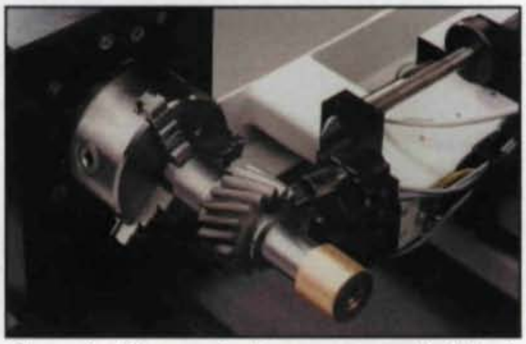

***Figure 9—Photograph of gear contact with helical-type gear. (Photo courtesy of Stresstech Oy, Finland.)***

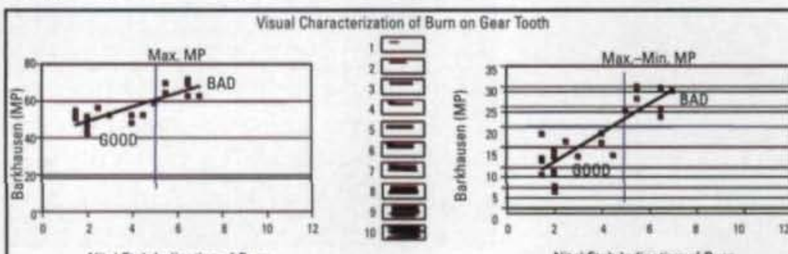


***Figure 10 —Maximum MP correlation with nital etch (left) and maximum–minimum correlation with nital etch.***

instrumentation is usually located very near the grinder and the feedback is immediate. Changes can be made to the grinder within a minute or two of the grinding operation on the test sample, and the time it takes to complete the iterative process is drastically reduced. In addition, the data is quantified, so that the operator has some idea of the changes necessary, rather than guesswork based upon etch results. It is not hard to see that using Barkhausen noise analysis simply for setup can save a lot of time and money.

### Monitoring the Grinding Process Using Automated Barkhausen Noise Inspection

After the initial setup of a grinding machine, it is wise to monitor the machine by testing production samples at periodic intervals or by as much as 100% inspection, if feasible. This type of analysis can be done quickly and easily using an automated Barkhausen noise analysis system. By testing as many parts as deemed necessary, based on the rate of production, this type of testing is used to insure that quality parts are being produced and to find any problems, such as a worn-out wheel, before they become costly. The typical Barkhausen noise analysis system can be an invaluable tool for monitoring finish-grinding operations during production, whether the throughput is two parts per hour or 200. It is a fast, easy and nondestructive technique of determining whether the grinder is correctly performing its function.

### Interpreting the Results

Interpreting the data from the analysis system is done by falling back on some of the basic theory of Barkhausen noise and the influential parameters that affect the signal. With a slight knowledge of gear design and processing, and a basic understanding of Barkhausen noise, a person can make some observations regarding the results of the analysis system. First, we know that Barkhausen noise increases when hardness decreases and when compressive stresses are relieved. In general, Barkhausen noise increases based upon the amount of damage done in grinding.

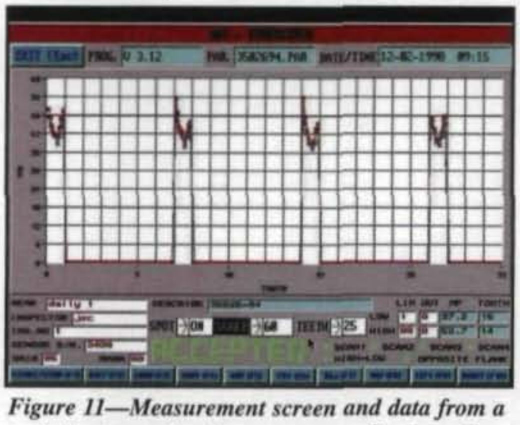

*Figure 11—Measurement screen and data from a typical setup using four scans per flank on four teeth from Stresstech's GEAR software.*

Intuitively, it makes sense that the worst defects will occur near the tip of the gear tooth, since there is less material there to dissipate the heat generated in grinding. Figure 11 shows the data output on the computer screen. The output represents a measurement on a gear using four scans per flank on a total of four teeth. The data is presented in a way that mirrors the image of a tooth.

The graph consists of two curves. One is for the maximum data points and the other is for the minimum data points. If we focus on one plot, the first data point on the far left is for the outermost point, radially, of the first flank. Then, moving to the right, the next three points are for the 2nd, 3rd and 4th scans of the first flank. Continuing rightward, we move to the innermost point on the opposite flank and then out to the tip of the opposite flank with the 8th point of the plot. That completes measurement of the first flank of tooth 1 and the opposite flank on tooth 2.

Moving on, the next tooth measured is the first flank of tooth 7 and then the opposite flank on tooth 8. This continues, until the final point on the opposite flank of tooth 22. This gear happens to have 27 teeth, and the setup is to test between teeth 1 and 2, 7 and 8, 14 and 15, and finally 21 and 22. This corresponds to testing at about every 90°. Now, returning to the type of damage we would expect on a gear tooth and reviewing the plots, it is evident that the larger MP values come from the tips of the gear teeth. This would validate the expectation that more burn will be evident near the tip, due to decreased heat dissipation.

There are two other observations that can be made with respect to the measurement in Figure 11. One is that the data for the maximum and minimum at any given point are very close. This indicates that at any given radial position, the change in the Barkhausen noise signal is negligible and therefore the change in microstructural properties and residual stresses, at that radial position, are also negligible. The second observation is that the data from flank to flank and from tooth to tooth are very similar. This indicates that the Barkhausen noise signal does not vary from tooth to tooth or on opposite flanks.

These observations can be very important in determining the cause of damage. For instance, if there is a variation from flank to flank that rejects one flank and not the other, it may be that the grinding wheel is not centered between the teeth and one tooth has more material removed than the other. These types of observations and thought processes can be a very valuable troubleshooting tool, resulting in time savings.

Another observation that can be made during measurement is an increase in the overall signal level of a part. The difference between the maximum and minimum values may remain small, but the level may increase from normal levels of 40–50 up to levels of 70–80. If this type of change occurs, it may not be the result of grinding damage. In fact, this type of change may be the result of prior processing. Several parameters could change, but the most common is a change in heat treatment. If the heat treatment changes, affecting the hardness or the amount of retained austenite, the Barkhausen signal observed after grinding will be changed (Ref. 8). If these kinds of changes are common, the difference between maximum and minimum rejection criteria becomes the best tool for detecting grinding damage.

But, if the maximum rejection criterion is used, these types of changes will be flagged. Using this type of rejection is preferred, because it scans for other changes in processing that could be potential problems. Once a potential problem is identified, it is then up to the process engineer to review the plots and troubleshoot the probable causes.

For example, a gear is tested that indicates high readings. The operator signals the process engineer, who requests that the gear be etched for further analysis. The gear does not have any visual indication of burn using the nital etching technique. The process engineer then evaluates the plots to find that the maximum values have exceeded the rejection criterion, but the maximum–minimum rejection condition is well within limits. The process engineer then decides to have a hardness test done.

The hardness test indicates a slightly lower hardness than usual. This may be the reason for the increase in signal. The process engineer then decides to check the retained austenite level and to cut a sample and investigate the case depth. The results indicate that the austenite level has decreased from normal levels and case depth is close to normal. The engineer concludes that the gears can be passed through quality control, but the furnace should be checked and retained austenite levels should be monitored.

As you can see from this example, such a system can be much more than a "grinder burn" detection system. That is precisely why it is referred to as a Barkhausen noise analysis system.

### Other Successful Applications of Barkhausen Noise Analysis

Barkhausen noise has been successfully applied in many areas, of which grinding is the most widespread application. Other applications include detecting defects in hard turning and heat treating, measuring the effectiveness of shot peening, measuring residual stresses, and predicting fatigue life. Some examples are detecting grinding damage on cam lobes, crankshaft journals, racks and pinions, bearings, and aircraft landing gear (even through chrome); measuring shot peen effectiveness on welds; and measuring the effects of straightening on camshafts and crankshafts.

### Conclusions

Barkhausen noise analysis is a very useful tool for measuring damage in ground steel components. The principles behind the measurement technique are sound, and application to measuring gears has proven to be not only useful for determining the amount of grinding damage, but also as a troubleshooting tool for process quality control. Barkhausen noise analysis is much faster than the existing method of nital etching, in addition to being a superior technique in terms of sensitivity to damage and objectivity of results.

The measurement technique and software are very user friendly. The system can save time and money in setup and monitoring, as well as in troubleshooting. When the Barkhausen system is fully implemented, etching facilities can be reduced to small quantities for use in a metallurgical laboratory. Overall, it has been shown that an automated Barkhausen noise analysis system can effectively monitor undesirable surface effects caused by grinding in a manner superior to any other in an easy-to-use, cost-effective device that has been shown to give a return on investment in as little as three months. ○

**References**

1. Fix, Robert M. "Applications of Barkhausen Noise Analysis (BNA), A Review of Three Cases Having Industrial Significance," First International Conference on Barkhausen Noise and Micromagnetic Testing, September 1–2, 1998, Hannover, Germany.
2. Griffiths, C.A. "Closing the Loop on Product Integrity on Bearings with 'Engineering Source Approval,'" Published by Split Ballbearing, Division of MPB Corp., July 1989.
3. Karpuschewski, B. "Introduction to Micromagnetic Techniques," First International Conference on Barkhausen Noise and Micromagnetic Testing, September 1–2, 1998, Hannover, Germany.
4. ANSI/AGMA 2007-B92, "Surface Temper Etch Inspection After Grinding," February 1992.
5. Pro, Richard J. "Grinding Burn Detection During Production Using Magnetic Barkhausen Noise Measurements," *Materials Evaluation*, Vol. 45, No. 6, pp. 610–612.
6. Seppi, Fred, "Findings of Barkhausen Noise Tests to Detect Grinding Burns and Residual Stress in High Strength Steel," Headquarters Ogden Air Logistics Center (AFLC), Hill Air Force Base, Oct. 1, 1986.
7. Shaw, B.A., T.R. Hyde and J.T. Evans, "Detection of Grinding Damage in Hardened Gear Steels Using Barkhausen Noise Analysis," First International Conference on Barkhausen Noise and Micromagnetic Testing, September 1–2, 1998, Hannover, Germany.
8. Suominen, L., K. Tiitto and R. Ehrman, "Effects of Retained Austenite on the Evaluation of Grinding Damage by Barkhausen Noise in Carburized Steels," Thirteenth Annual Conference on Properties and Applications of Magnetic Materials, May 17–19, 1994.
9. Wojtas, A.S., L. Suominen, B.A. Shaw and J.T. Evans, "Detection of Thermal Damage in Steel Components After Grinding Using the Magnetic Barkhausen Noise Method," First International Conference on Barkhausen Noise and Micromagnetic Testing, September 1–2, 1998, Hannover, Germany.

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# Engineered Gear Steels: A Review

Craig V. Darragh

**This paper was presented at the British Gear Association's Annual Congress 2001, a part of the Drives & Controls Conference 2001, held in London, England, in March 2001. The paper was published for that conference by Kamtech Publishing Ltd. of Surrey, England. It was later presented at the Basic Gear Manufacturing & Design 2002 Technical Program, in Nashville, TN, in January 2002. That program was organized by the Society of Manufacturing Engineers.**

The selection of the proper steel for a given gear application is dependent on many factors. This paper discusses the many aspects related to material, design, manufacture, and application variables. The results of several studies on the optimization of alloy design for gas- and plasma-carburization processing are reviewed.

## Introduction

Improved performance and reliability at the lowest cost per unit of life is a goal common to all industries. It is especially true for the automotive, truck, and power transmission industries, where systems comprised of gears, shafts, bearings, springs, discs, sheaves, rollers and/or other mechanical components are being asked to deliver higher strength and greater power throughput while using smaller, lighter weight designs. The aim is to achieve some combination of weight savings, higher fuel economy, lower vehicle emissions, decreased downtime and maintenance requirements, quiet operation and design flexibility. These, in turn, provide added value in the form of improved performance, manufacturability and life cycle costs.

## Comprehensive Approach

Many factors affect the ultimate performance of a component. These include raw material, design, processing/product and application variables as shown in Table 1.

Table 1—Important Variables.

| Raw Materials | Design | Processing/Product | Application |
|---|---|---|---|
| Cleanness<br>Alloy Selection<br>Alloy Design<br>Formability<br>Machinability<br>Chemistry Control<br>Hardenability Control<br>Strength/Toughness<br>Fatigue Strength<br>Inclusion Engineering<br>Surface Quality<br>Dimensional Quality<br>Price/Delivery | Innate Validity<br>Applied Stresses<br>Residual Stresses<br>Process Selection | Heat Treatment<br>• Case/Core Properties<br>• Type: carburize, nitride induction harden<br>• IGO Control<br>• NMTP Control<br><br>Distortion Control<br><br>Residual Stress Generation<br>• heat treat<br>• peening<br><br>Geometry/Contour Control<br><br>Surface Finish<br>• grinding<br>• polishing<br>• superfinishing<br>• peening<br><br>Surface Treatments/Coatings | Lubricant Type<br>• base<br>• viscosity<br>• temperature/oxidation stability<br>• additives<br><br>Lambda Ratio<br><br>Contamination<br>• chemical<br>• mechanical<br>• electrical<br><br>Loading<br>• nominal<br>• instantaneous<br><br>Modes of Damage<br>• surface<br>• subsurface |

Optimization of the process and product for any given component is complex and requires a comprehensive interdisciplinary engineering approach. An overall concept is illustrated in Figure 1.

The base of the performance pyramid should be considered for each component in a system. A successful design depends on quality engineering within and between disciplines for any given part. The metallurgical, mechanical and tribological aspects must all be considered. Process and product factors are extremely interdependent. One begets and/or depends on the other.

When designing a component, the engineer does not simply begin in the material column and select a grade with certain attributes. Rather, several important questions must first be asked:

1. What are the application rigors the component must endure?
2. How will the part be made? How will its basic form be generated? What heat treatment will be used?
3. How will a beneficial residual compressive stress state be generated in the contact surface region—via heat treatment and/or post-heat-treatment processes?
4. What types of surface finishes and geometry (contouring) aspects will be involved?
5. What lubricants, temperatures, contaminants and loading (nominal and instantaneous) must be considered?
6. Will surface engineering capabilities (finishes, textures, coatings, etc.) be used?

These are just a few of the application questions. Many others undoubtedly should be asked. The crux is that the engineer must draw on the various disciplines to design a given component. Once the questions are answered, the materials engineer can provide a knowledge-based recommendation for the material of choice to achieve the required manufacturability, performance and cost.

## System Upgrading

This approach can be sequentially applied to each component in a subassembly or full system. The engineering team can determine which component is the "weakest link." That part can then be upgraded. Obviously, some other component will then become the weakest link. By iteratively stepping through the components, the system can be continuously improved.

Most automotive transmission models will be expected to double in power throughput capacity from one useful lifetime to the next. Teamwork between the metallurgical, mechanical and

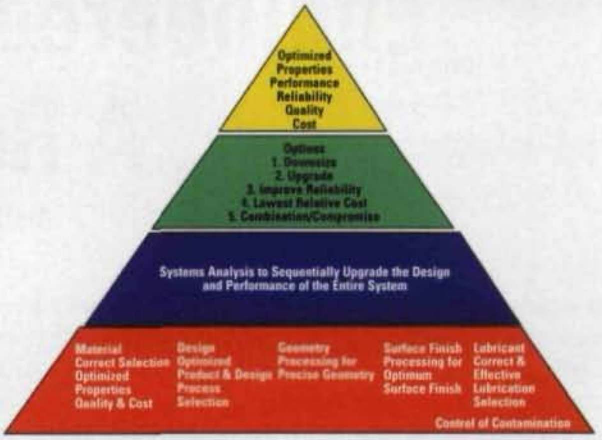



**Figure 1—The Performance Pyramid. Beginning with the base (Table 1), the individual components can be optimized. Subsequently, by moving up the pyramid, a system can be optimized.**

tribological team members can readily achieve such requirements—and, oftentimes, more.

### Engineering Advancements

Fortunately, technical advances in each of these areas have been occurring for many years. The subsequent portions of this paper will review some of the specific improvements related to gear steels and their thermal processing.

### Steel Cleanness

This factor heads the material listing because of its fundamental importance. It is the foundation upon which high performance can be built. It is generally well accepted that fewer and smaller inclusions translate to longer life relative to subsurface initiated fatigue.

Today's clean steels have resulted from many improvements in steelmaking practices. The melting furnace is basically used to provide liquid metal. Secondary metallurgical techniques in ladle refining and teeming practice have become the key elements. Important factors include degassing and deoxidation practices, temperature control, inert gas shrouding, improved refractories and the use of bottom-poured ingots or significantly improved tundish systems and large cross-section continuous casters (Ref. 1). It is especially important to prevent reoxidation during teeming/casting and any type of exogenous inclusions (Ref. 2).

Continuing advances in internal quality have resulted from the ability to accurately measure the internal cleanness over a significant volume of steel. Historical test methods, such as microscopic evaluation, magnetic particle testing and oxygen analysis, are valuable tools. But they are not capable of truly distinguishing relative differences in very clean steels. Ultrasonic testing has proven to be the critical tool. It has the ability to sample sufficient volume and the summed lengths of inclusions per unit volume can be correlated to fatigue life. This is illustrated in Figure 2, which depicts the improvements realized in rolling contact fatigue life of bearings as changes in melting practices created cleaner steels. The cleanness has been improved by four orders of magnitude while the life has improved more than two orders of magnitude.

The compositions and morphologies of any inclusions present are also important. The work by Stover and Leibensperger (Refs. 2 and 4) found alumina-type stringer oxides to have the greatest detrimental effect on contact fatigue life. Sulfides can become operative once the oxide cleanness is very good (Refs. 4 and 15). Other work (Refs. 5 and 6) is corroborative in showing lower sulfur levels and/or shape control of sulfides to be beneficial to fatigue life. These works show this is true for several types of fatigue.

While cleanness is critically important, it is crucial to recognize that cleanness alone cannot guarantee specific performance. Fatigue is a statistically-based phenomenon between competing modes of damage. If conditions such as poor/improper lubrication, contamination, misalignment, poor geometry, design or finish, etc. are present, the effects of clean steel may not be realized. However, assuming that sound engineering and manufacturing principles are followed to avoid or minimize surface-initiated fatigue modes, then clean steel is a necessity.

This is illustrated in Figure 3, which shows the interactive effects of surface finish and cleanness on gear bending fatigue. Steel A is a very clean bottom-poured material while Steel B is typical of an average bloom-cast material. This gear set was designed so the pinion would fail due to bending fatigue. The results strongly illustrate that the full advantage of clean steel can be realized when surface initiation factors are minimized (Ref. 1).

### Alloy Design for Carburized Gears

Intergranular oxidation (IGO) at the surface grain boundaries is an important issue for components that are conventionally gas-carburized. It is especially important for gears. Bearing manufacturers enjoy the benefit of grinding all contact surfaces and many non-contact surfaces. As a consequence, the IGO and the usual concomitant nonmartensitic transformation product (NMTP) microstructural layer are removed; but, in gearing, the flanks and especially the roots of the teeth are often not ground.

Fortunately, two methods exist to help combat this issue in gearing: alloy design and plasma carburizing.

Alloy design can be a very effective method to virtually eliminate IGO/NMTP during conventional gas-carburizing

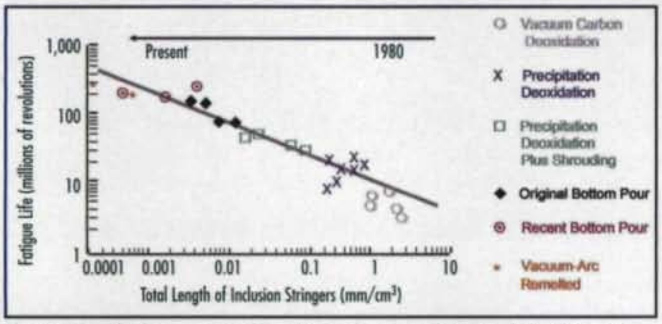



**Figure 2—Cleanness and rolling contact fatigue life improvements as steelmaking practices have changed.**

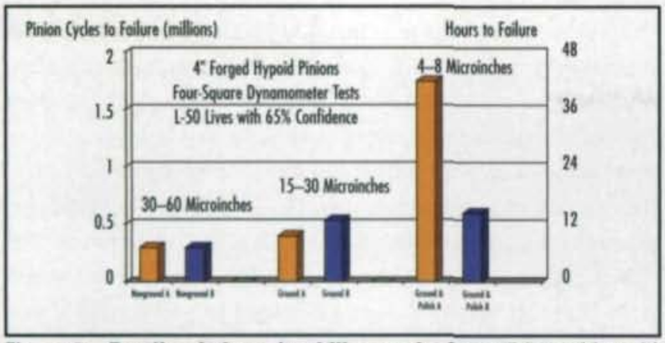



**Figure 3—Bending fatigue durability results from 4" forged hypoid pinions using four-square dynamometer tests.**

| Table 2—Relative Oxidation Potentials for Several Alloying Elements, in Descending Order (Ref. 7). | |
|---|---|
| Greater Than Fe | Ti, Si, Mn, Cr, (Fe) |
| Less Than Fe | (Fe), W, Mo, Ni, Cu |

| Table 3—Alloying Considerations. | |
|---|---|
| Decrease | Si, Mn, Cr, Ti, P, S |
| Increase | Mo, Ni |

(Refs. 7–14). The approach is based on the oxidation potentials of the alloying elements (Ref. 7), which are shown in Table 2.

Alloying elements with affinities for oxygen greater than that of iron (Fe) can form oxides in the surface region, particularly in the grain boundaries. As a consequence, they are removed from the matrix and their hardenability effect correspondingly minimized. The oxidized layer is often confined to 10–20 microns; but, the associated NMTP layer can be significantly deeper (Refs. 7 and 13). Importantly, elements with affinities for oxygen less than that of iron are not oxidized and their hardenability effect is not lost; hence, the alloying approach shown in Table 3.

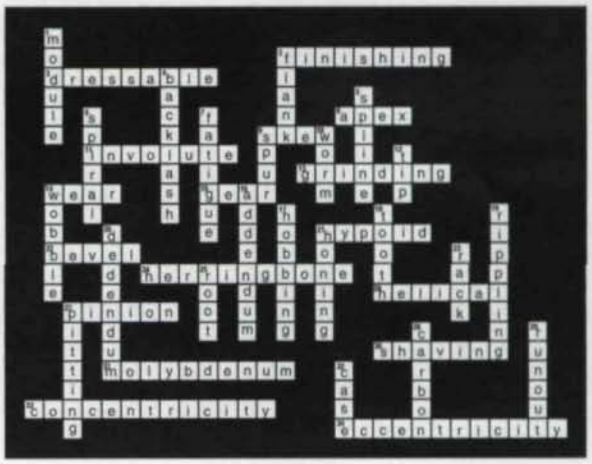
In this approach, silicon (Si) is quite important since it forms the greatest amount of oxide to the deepest depth (Refs. 7 and 13). The oxides of manganese (Mn) and chromium (Cr) form closer to the surface, with the chromium oxides being the shallowest. Many are compound oxides. Excellent descriptive work may be found in References 7, 8, 9, 11 and 12. Phosphorus (P) and sulfur (S) are controlled due to their inherent effects on toughness. Hyde demonstrated the effect of phosphorus on bending fatigue, as shown in Figure 4 (Ref. 12). Basically, it is sufficient to maintain $P < 0.015\%$, which can be readily achieved.

Sulfur is a prime example of an element where consideration must be given to all processing and product factors. For example, low sulfur is very desirable for toughness, formability, and fatigue resistance. But, higher sulfur is often quite necessary for machinability. Thus, the engineer must weigh all competing requirements when establishing an alloy approach. This is true for all the elements. All the production and application factors must be considered. If an element is lowered for one reason, but it has a decided effect on other factors, the engineer must find an approach to replace its effect.

Molybdenum (Mo) plays a crucial role. It does not oxidize



# GEAR CROSSWORD ANSWERS



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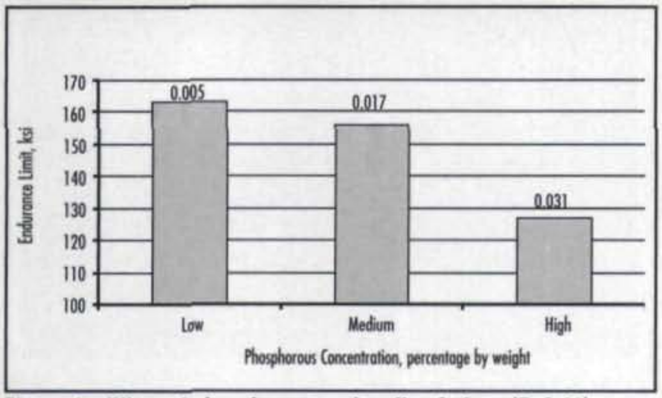


**Figure 4—Effect of phosphorous on bending fatigue (Ref. 12).**

**Table 4—Chemical Composition of Steels in IGO/NMTP Studies.**

| Steel Type | C | Mn | P | S | Si | Cr | Ni | Mo |
|---|---|---|---|---|---|---|---|---|
| 4615 Modified | 0.16 | 0.52 | 0.010 | 0.015 | 0.24 | 0.12 | 1.75 | 0.54 |
| 8620 Modified | 0.21 | 0.92 | 0.014 | 0.023 | 0.11 | 0.50 | 0.38 | 0.16 |

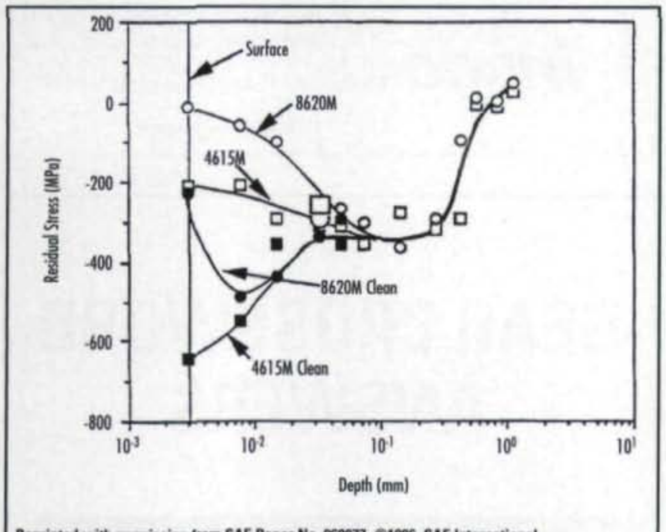




**Figure 5—Residual stress distributions in the gas-carburized bending fatigue specimens, both before and after glass-bead cleaning (Ref. 9).**

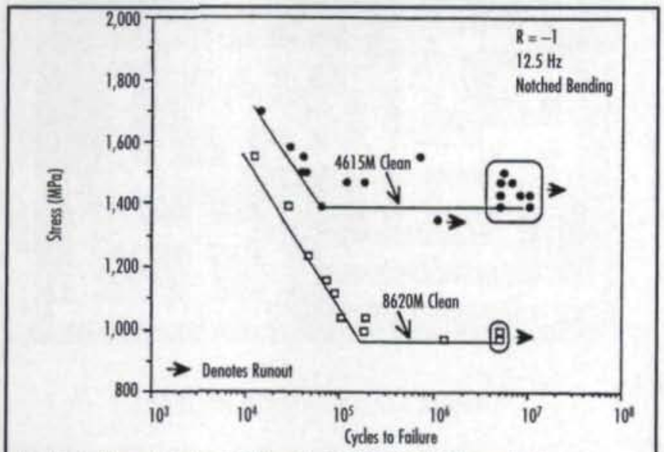




**Figure 6—Bending fatigue behavior as carburized (Ref. 9).**

and therefore remains in solution to maintain the surface hardenability. Importantly, it maintains the martensitic surface microstructure and beneficial residual compressive stresses. Increased molybdenum contents are required if silicon and/or manganese and/or chromium are lowered. Molybdenum plays the crucial role along with nickel (Ni)—if utilized—of replacing the corresponding hardenability loss. (It is important to note that nickel is a desirable element for both hardenability and toughness. However, its use is often minimized by request due to cost considerations.) The effect of silicon loss on hardenability is often greater than commonly expected so that molybdenum needs to be added to compensate for the hardenability loss.

The effect of IGO/NMTP has primarily been noted on the bending fatigue resistance of gear teeth (Refs. 8–15). The fatigue resistance is lowered by three main effects: a) formation and effect of the grain boundary oxides, b) a lower-strength NMTP surface microstructure, and c) a corresponding loss of surface residual compressive stresses (Refs. 8, 9, 11, 12, 13 and 14).

Bending fatigue work undertaken in References 9–11 was directed at determining the relative importance of these effects. Several of the findings are reviewed below. Each of these studies involved the same two steels: an 8620 modified (lower silicon) and a 4615 modified (higher molybdenum). Their compositions are shown in Table 4. While viable gear steels, neither is optimum to prevent all of the above effects. While newer alloy designs have proven better, the results described below remain valid and form the basis for additional work.

Both steels heat-treated very similarly. The case hardness profiles were similar, and the case microstructures were martensite with approximately 25% retained austenite. However, there were differences at the as-carburized surfaces. The 8620 modified exhibited IGO (manganese, chromium oxides near the surface; iron, silicon oxides at deeper depths) with significant corresponding NMTP formation (primarily pearlite with smaller amounts of bainite) (Ref. 9). The 4615 modified, owing to its higher silicon level, also exhibited IGO (manganese, silicon oxides) but—due to its higher levels of molybdenum and nickel—maintained the hardenability of the surface matrix and did not exhibit any NMTP microconstituents. As a result, the steels exhibited the residual stress profiles shown in Figure 5 (Ref. 9). The specimens that were glass-bead cleaned after heat treatment, were tested in four-point bending rigs devised by Ford Motor Co. personnel, described in SAE960977 (Ref. 9). The results are shown in Figure 6.

Analysis of the results by Dowling suggested the difference in endurance limits was due ≈50% to the better residual compressive stress state in the 4615 modified and ≈50% due to the lower-strength NMTP surface layer in the 8620 modified (Ref. 9). It is important to note that both steels exhibited IGO of similar depths, and thus the initiation of fatigue via this "metallurgical notch effect" is assumed to be similar. Apparently, the better residual stress state, plus higher strengths of the 4615 modified's surface, delayed initiation to higher stress levels.

These same two steels were also tested in full planetary gear sets in SAE960978 (Ref. 10). The results were similar. The 4615 modified's performance was approximately 20% higher than that of the 8620 modified's.

**Plasma-Carburizing Effects**

As mentioned earlier, another method of preventing the effects of IGO on gear bending fatigue is to utilize plasma-carburizing rather than conventional gas-carburizing. A third study was conducted in which the same two materials were both gas-carburized and plasma-carburized. Details are in Reference 11. The residual stress profiles of the four sets are shown in Figure 7, and the four-point bending fatigue data are shown in Figure 8. In this study, none of the specimens was glass-bead cleaned.

It is important to note: When plasma-carburized, neither steel exhibited any NMTP and only a few small oxide particles (iron, chromium oxides) were found at the very surface of the 8620 modified. As a consequence, the residual stress states and endurance limits of these two specimen sets were similar. Also, the two plasma-carburized sets were both significantly better than the gas-carburized 8620 modified (which showed significant IGO and NMTP, with a correspondingly poorer residual stress state).

The gas-carburized 4615 modified specimens still had the best residual stress condition and corresponding endurance limit. This may be the result of a thinner case depth profile in the gas-carburized 4615 modified. Researchers at Climax Molybdenum Co. (Ref. 8) have shown there is an optimum case depth to maximize the residual compressive stress state and thus maximize performance.

However, recent work at the University of Newcastle (England) found similar results between gas- and plasma-carburized specimens (Ref. 16). In addition, work by Krauss also showed differences in the bending endurance limits. Krauss' conclusions suggested a relationship to grain size and the amount of retained austenite in the gas and plasma specimens (Ref. 17). This phenomenon deserves further study.

**Corroborative Studies**

The IGO/NMTP studies reviewed above have been corroborated by Hyde and Irani (Refs. 12 and 13) and recently by Shaw,

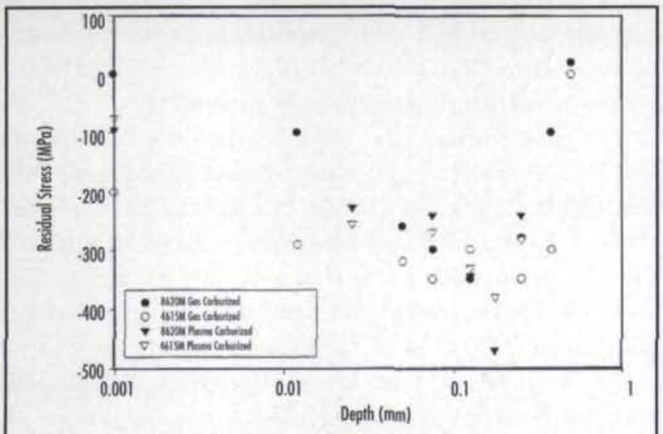


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**Figure 7—Residual stress data for both gas- and plasma-carburized bending fatigue specimens of both steels, 4615M and 8620M (Ref. 11).**

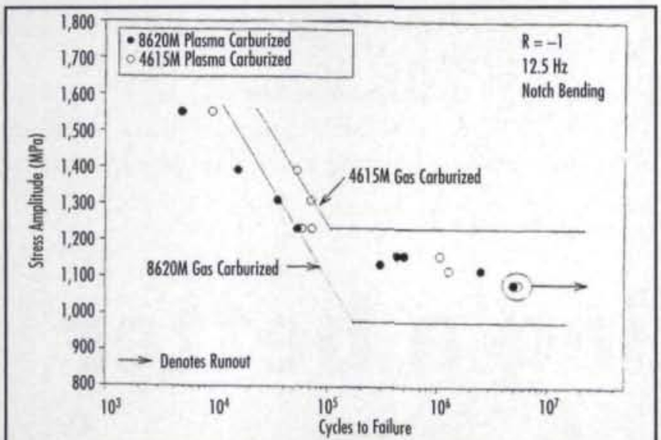


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**Figure 8—Bending fatigue behavior for gas- and plasma-carburized specimens (Ref. 11).**

Hofmann, and Evans (Refs. 14 and 15). Both have documented the fractography of the initiation and propagation stages of bending fatigue and have studied the effects of additional residual stress enhancement (e.g., peening, grinding, superfinishing, etc.).

As Shaw and Hofmann note, "bending fatigue can be controlled through improved surface quality, steel quality, and control of the residual stress state" (Ref. 16). As this paper indicates, such aspects can be engineered via different methods. These methods allow the initial product and process designers to choose how to best produce a gear for a given application. Integrating the important variables from Table 1 with the various disciplines, the engineer can determine how the gear material and processing should be designed.

## Summary

The process, product, and performance characteristics of mechanical systems' components are dependent on many variables related to material, design, process control, and application requirements. Application engineering is a complex exercise that must weigh and counterbalance many competing issues. Fortunately, today's steels and many of the processes can be engineered to achieve maximum performance. Clean steel forms the foundation upon which to build. Knowledge of the requirements for forming, machining, and heat-treat response can then be combined with manufacturing and application requirements to design the steel composition.

Details of one aspect, control of IGO/NMTP relative to bending fatigue, were reviewed. If gears are ground in the roots and on the flanks, this issue is moot. If the roots are not ground, then alloy design or plasma-carburizing is a viable solution. If the flanks are not ground, it is advisable to minimize IGO/NMTP effects as they will likely decrease contact fatigue resistance.

The use of an interdisciplinary concurrent engineering methodology and the performance pyramid, shown in Figure 1, permits individual components and/or their overall systems to be optimized relative to properties' performance, reliability, quality, and cost. ⭘

### References

1. Darragh, C.V., J.D. Stover, and R.L. Widner. "High Quality Steels for the 21st Century," ASME, *Rail Transportation RTD-Vol. 8*, Book No. G 00947-1994, 1990.
2. Leibensperger, R. L., and J.D. Stover. "Inclusions, Rolling Contact Fatigue and Power Dense Transmission Design," International Conference on Low Residual Steel, The Indian Institute of Metals & Tata Steel, Jamshedpur, India, Feb. 8–9, 1999.
3. Wolfe, J.O., B.J. Zorc, P.C. Glaws and J.A. Eckel. "Clean Engineering Steels—Progress at the End of the 20th Century," ASTM Centennial Symposium—Advance in the Production and Use of Steel With Improved Cleanness, Atlanta, GA, U.S.A., May 4, 1998.
4. Stover, J.D. "Inclusions and Rolling Contact Fatigue," 2nd International Bearing Steels Symposium, Arles, France, June 6–8, 1995.
5. Collins, S.R. "The Effects of Forging on MnS Inclusions as Fatigue Initiation Sites," Ph.D. Thesis, Case Western Reserve University, 1994.
6. Sanyo Tokushu Seiko. "Mechanical Structure Steel With Good Rolling Fatigue Life and Good Isotropy," Japanese Patent Application JP58052457, 1983.
7. Chatterjee-Fischer, Ruth. "Internal Oxidation During Carburizing and Heat Treating," *Metallurgical Transactions A*, Vol. 9A, November 1978, pp. 1553–1560.
8. Doane, Douglas V. "Molybdenum in Carburizing Steels," Climax Molybdenum Co., Ann Arbor, MI, 1984.
9. Dowling, W.E. Jr., W.J. Donlon, W.B. Copple, R.A. Chernenkoff, and C.V. Darragh. "Bending Fatigue Behavior of Carburized Gear Steels: Four-Point Band Test Development and Evaluation," *SAE Paper 960977*, SAE International Congress & Exposition, Feb. 26–29, 1996.
10. Phelan, P.E., D.J. Sell and W.E. Dowling. "Bending Fatigue Behavior of Carburized Gear Steels: Planetary Gear Test Development and Evaluation," *SAE Paper 960978*, SAE International Congress & Exposition, Feb. 26–29, 1996.
11. Dowling, W.E. Jr., W.T. Donlon, W.B. Copple, C.V. Darragh. "The Influence of Heat Treat Process and Alloy on the Surface Microstructure and Fatigue Strength of Carburized Alloy Steel," *SAE Paper 1999-01-0600*, SAE International Congress and Exposition, March 1–4, 1999.
12. Hyde, R.S. Ph.D. Thesis, Colorado, School of Mines, 1994.
13. Hyde, R.S. and Z.J. Irani, Timken Research Report 5635, July 1, 1977.
14. Hofmann, D. and B.A. Shaw. "Improved Fatigue Resistance of Gears Through Material Enhancements," University of Newcastle, U.K.–Design Unit, 2nd Balzers Surface Technology Forum, 2000.
15. Shaw, B.A., D. Hofmann, and J.T. Evans. "Identification of Failure Modes in Hardened Gears," Drives and Controls Conference '98, Kamtech Publishing Ltd., U.K., Session 5, 23–30, 1998.
16. Hofmann, D. Facsimile Exchange With C.V. Darragh, Dec. 27, 2000 and Jan. 5, 2001.
17. Krauss, G. "Microstructure of Carburized Steels," *Heat Treating*, April 1993, pp. 12–16.

**Craig V. Darragh** *is a senior product technologist with The Timken Co., located in Canton, OH. He has 39 years' experience in product and process analysis and development/application of alloy steels for major industrial sectors, with an emphasis on gears, bearings and other mechanical systems components.*

# New Appointments, New Publications

## Ash Gear's General Manager Dies

Thomas A. Burkhart, general manager of Ash Gear & Supply, died Aug. 3 of cancer. He was 64 years old.

Mr. Burkhart started work at Ash Gear of Novi, MI, in 1975. In 1977, he created Ash Gear's first product catalog.

Mr. Burkhart was born May 19, 1938, in Grosse Pointe Farms, MI. He graduated with a bachelor's degree in business administration from West Jefferson College in Pennsylvania. In 1962, he started in the gear industry in Detroit, at Michigan Tool, a division of Excell-o, and rose to the position of office manager.

Mr. Burkhart worked the past 18 years with his daughter, Patricia Burkhart, Ash Gear's purchasing coordinator.

## Gleason Corp. Names CEO

David J. Burns was named CEO of Gleason Corp. of Rochester, NY. He replaced James S. Gleason, who stepped down from that position after 21 years.

Burns has worked in numerous departments at Gleason since he started with the company in 1978. For the past three years, he has served as president and COO. Among his accomplishments are the opening of a new machine tool factory in Rochester and the negotiation of two major acquisitions in Germany, according to the company's press release.

Burns is the third CEO outside the Gleason family in the company's seven-CEO history.

James Gleason will continue as chairman.

## Samputensili and Seiwa Merge Sales and Service Activities

Samputensili S.p.A. of Bologna, Italy, and Seiwa Corp. of Shimane, Japan, agreed to consolidate the sales and service activities of their companies.

In Japan, Seiwa will exclusively distribute and service all Samputensili machine tools under the brand name SU SEIWA. Furthermore, Seiwa will represent Samputensili Cutting Tools in southwest Japan.

*Existing SU Japan locations will* continue to distribute and service Samputensili cutting tools throughout the rest of the country, in collaboration with Seiwa.

Samputensili will distribute the Seiwa hob resharpening and honing machine tools under the SU SEIWA brand name through its sales and service network in Europe and the Americas.

## Publication of BGA Handbook

The British Gear Association of Burton-on-Trent, U.K., has published its 2002 buyers guide and member handbook.

The book can be purchased for 10£ (approximately $6.42) from the BGA.

For more information, contact the BGA by telephone at (44) (1283) 515-521 or on the Internet at *www.bga.org.uk.*

## United Grinding Acquires Ewag USA

All operations of Ewag USA of North Kingstown, RI, will be merged into those of United Grinding Technologies Inc.

Ewag, currently in the business of producing tool-grinding machines and centers, will be classified as a UGT product division that specializes in tool- and cutter-grinding machines. This division will be based in Miamisburg, OH. The rest of Ewag's business activities will be integrated into the UGT structure as well.

With headquarters in Miamisburg, OH, UGT offers grinding solutions for various types of parts-manufacturing applications, including surface, profile, creep-feed and cylindrical grinding, including I.D., O.D., centerless and superfinishing.

Terms of the merger will be completed by January 1.

## Bodycote Opens North American Service Center

Bodycote Thermal Processing opened a facility in Boaz, AL, for case hardening of austenitic stainless steels.

The treatment process, called Kolsterising, can be used in applications such as manufacturing of commercial equipment and automotive components. Under this treatment, carbon is diffused into the workpiece surface without the formation of chromium carbides.

Previously, the treatment was only available from Bodycote's facility in Apeldoorn, Netherlands.

Paul Dymond will serve as North American business development manager for the new operation.

## Birchmere Capital L.P. and Wilder Deem Appoint New President

Ian Sadler was hired as president of Birchmere Capital L.P. of Pittsburgh, PA, and Wilder Deem of New York, NY.

Previously, Sadler served as president of the Pennsylvania Foundry Group, a division of Atchison Casting Corp. of Atchison, KS.

In April 2002, Birchmere Capital and Wilder Deem bought Miller Centrifugal Casting Co., which patented the bimetallic casting process used in the worm gear business. A foundry, Miller Centrifugal is located in Cecil, PA.

Sadler has worked in management positions in quality control, production management and financial turnarounds for 30 years.

With a graduate degree in metallurgy, he has served as manager of metallurgy and quality control for U.S. Steel, vice president of metallurgial services for National Roll Co. and vice president of quality assurance for Blaw Knox Rolls. Currently, Sadler serves as president of the Iron and Steel Society of Warrenville, PA.

## NEMA Revises Condensed Motors and Generators Standard

The National Electrical Manufacturers Association has condensed MG 1-2002, *Information Guide for General Purpose Industrial AC Small and Medium Squirrel-Cage Induction Motors.*

New in this revision is information about the NEMA Premium motor efficiency standard, according to the association's press release.

These types of motors can be used in industrial, commercial or military applications.

## New Business Development Director Named at HI TecMetal Group

Charles Higgins was appointed as director of new business development at HI TecMetal Group of Cleveland, OH.

With more than 35 years' experience in OEM marketing and management disciplines, Higgins most recently worked with a remanufacturer of material handling and construction equipment driveline components.

## Gleason Cutting Tools Expands Gear Shaper Cutter Line

Gleason Cutting Tools Corp. has expanded its gear shaper cutter line with the installation of new CNC form grinding equipment at its facility in Loves Park, IL.

According to the company's press release, this technology will ensure higher levels of accuracy in manufacturing small shanks and special forms as compared to typical manual machine processes.

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## New Engineered Iron from Dura-Bar

Dura-Bar Plus is a material that optimizes machining speeds and feeds, maximizes tool life, decreases downtime for tooling changes and reduces scrap, according to Dura-Bar.

According to the company's press release, customers report turning the product at roughing speeds up to 2,200 surface feet per minute using 65-45-12 iron.

Additionally, the product can cause less tool wear at higher machining speeds. Irons are available in round bars in diameters of 5/8–20". Squares/rectangles can be obtained in sizes up to 18.5" x 22".

For more information, contact Dura-Bar of Woodstock, IL, by telephone at (815) 338-7800 or on the Internet at *www.dura-bar.com.*




## New Family of Analytical Gear Testers from Gleason Mahr

The GMX275 is the first in a new series of analytical gear testers called the GMX series from Gleason Corp. and Mahr GmbH.

According to Gleason's press release, the testers are designed to deliver elementary measurement of internal and external cylindrical gears, bevel gears and gear tools.

The testers can perform gear tooth and flank form audit or select testing for bevel and cylindrical gears using a single fixturing setup. Additionally, they use a four-axis inspection system with direct-driven worktable for high acceleration and accurate positioning. Features include variable speed control, interchangeable live centers and constant clamping force.

For more information, contact Gleason Corp. of Rochester, NY, by telephone at (585) 473-1000 or on the Internet at *www.gleason.com.*

## New Coating from IonBond

The Maximizer is a new coating from IonBond for use by the round shank, gear tooling and hobbing markets.

A *multi-layered AlTiN coating*, the product lets users accelerate feeds and speeds, enhance protection from heat and wear and improve edge protection and performance over TiCN and TiN, according to IonBond's press release.

In hobbing applications, the coating's oxidation threshold can reach 1,600°F.

For more information, contact IonBond's Detroit Coating Center by telephone at (248) 398-9100 or on the Internet at *www.ionbond.com.*

### New Gage Products from M&M Precision

The DOP-150 and the mini-man roll tester are included in the new line of functional gage products from M&M Precision Systems Corp.

The DOP-150 provides a universal comparator package that can inspect internal and external gears and splines. The package is 150 mm in size and can accommodate external parallel axis gears to 6" in diameter and internal gears and splines to 1" in diameter.

The mini-man roll tester is a composite action, double-flank gage designed for direct shop floor use. This tester can accommodate up to a 6" center distance. Users can choose between traditional hand rotation or a crank mechanism.

For more information, contact M&M Precision Systems Corp. of Dayton, OH, by telephone at (937) 859-8273 or on the Internet at *www.mmprecision.com.*

### New Quick Change System from Positrol Inc.

The new Chuck-Change System from Positrol Inc. can be installed on lathes, grinders, gear hobbing machines and machining centers.

*Designed for multiple workholding* changeovers on an individual machine, the system can reduce setup for small lot runs and can allow for maximum scheduling flexibility.

With the ability to mount on most machine spindles, the product includes a special system receiver with a draw-tube connection that becomes an integral part of the machine spindle, according to the company's press release. System adapters are then fitted to the range of workholding devices needed for the product mix.

With this receiver/adapter system, changeovers are performed by releasing cams, pushing the release button, rotating the device counter-clockwise and removing the workholding device from the receiver.

For more information, contact Positrol Inc. of Cleveland, OH, by telephone at (513) 272-0500 or on the Internet at *www.eworkholding.com.*

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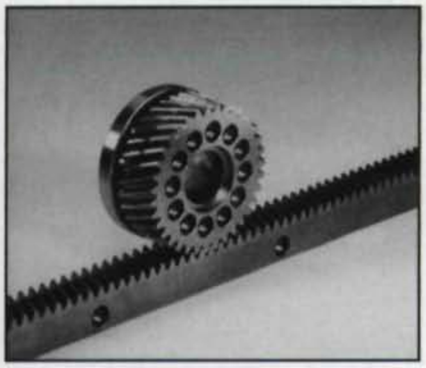

## New Rack and Pinion System from Alpha Gear Drives

According to alpha gear drives Inc., its new precision rack and pinion system offers maximum possible feed dynamics with short acceleration times because of its compact design and low mass moments of inertia.

The company added that all rack and pinion mounting surfaces are ground to tight tolerances, providing users with flexible mounting options. Standard rack lengths of 167–500 mm are available. Load capacities up to 13,000 N are available.

For more information, contact alpha gear drives Inc. of Elk Grove Village, IL, on the Internet at *www.alphagear.com.*

## Two-Speed Gearboxes from Andantex

Andantex introduced a series of two-speed gearboxes that provides speed and torque ratios required for a range of production assignments.

By augmenting the latest spindle drive motor technology, the RAM-MSD enables machines to keep pace with any spindle requirement, according to the company's press release. The units mount in-line between the water-cooled motor and the spindle inside the machine tool's RAM.

Additional features include a hollow-through bore, low backlash and planetary gearing to facilitate low vibration.

For more information, contact Andantex USA of Wanamassa, NJ, by telephone at (800) 713-6170 or via e-mail at *info@andantex.com.*

## New Planetary Gearboxes from Bosch Rexroth

The new GTM planetary gearboxes mount to servomotors for high precision applications and can be used in factory automation.

According to the company's press release, the small internal cavity of the gearbox reduces noise so the product is rated up to 10 dB lower than its nearest competitor.

Another product feature is the cold fusion process between the coupling and the sun gear that allows high emergency-stop torque for safety and reliability.

For more information, contact Bosch Rexroth Corp., located in Hoffman Estates, IL, by telephone at (847) 645-3747 or on the Internet at *www.boschrexroth-us.com.*

## New Gearmotor from Sumitomo Machinery

The Astero gearmotor line from Sumitomo Machinery Corp. of America is designed for small conveyor, commercial and packaging machinery applications.

Available from 6–90 watts, the gearmotors consist of a die-cast aluminum housing and steel gears. According to the company's press release, a two-piece assembly (reducer-motor) is included for enhanced flexibility. The gearmotors have reduction ratios from 3:1 to 200:1.

Additional options include a brake pack and speed controller.

For more information, contact Sumitomo Machinery Corp. of America, located in Chesapeake, VA, by telephone at (757) 485-3355 or on the Internet at *www.smcyclo.com.*

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## TECHNICAL CALENDAR

**November 6—Mechanical Drive Systems—Problems, Solutions and Instrumentation for Rotating Machinery.** The Riverside Hotel, Burton on Trent, U.K. Sponsored by the British Gear Association, the seminar will cover the dynamics of shaft-mounted gearboxes, the effect of coupling characteristics on dynamic gearbox torques, and torsional resonances in geared drives and instrumentation systems for rotating machinery. 117£ (approximately $75) for BGA members, 176£ (approximately $113) for nonmembers. For more information, contact the BGA by fax at (44) 12-835-158-41 or on the Internet at *www.bga.org.uk.*

**November 12—Manufacturing of Powder Metal Gears.** Hilton Northbrook, Northbrook, IL. This event focuses on investigations of gear-processing problems, advances in heat treating and induction hardening and near-net shaping of gears. $495 for SME members, $595 for nonmembers. For more information, contact the Society of Manufacturing Engineers by telephone at (800) 733-4763 or on the Internet at *www.sme.org.*

**November 13–14—Advanced Gear Processing and Manufacturing with Tabletop Exhibits.** Hilton Northbrook, Northbrook, IL. Sponsored by the Society of Manufacturing Engineers, this program analyzes the issues in processing and manufacturing high-quality gears. $795 for SME members, $895 for nonmembers. For more information, contact the SME by telephone at (800) 733-4763 or on the Internet at *www.sme.org.*

**November 17–22—International Mechanical Engineering Congress & Exposition.** New Orleans Hilton/Ernest N. Morial Convention Center, New Orleans, LA. Sponsored by the American Society of Mechanical Engineers, attendees can participate in 30 sessions in areas such as aerospace, design engineering, heat transfer, applied mechanics, fluid engineering and noise control. $550 for ASME members, $750 for nonmembers. For more information, contact the ASME by telephone at (212) 591-7037 or on the Internet at *www.asme.org.*

**January 6—Advanced Gear Design.** Ohio State University, Columbus, OH. Open to engineers in the industry via video correspondence, this 10-week course is a survey of advanced techniques for designing spur and helical gears. Topics include strength of materials, lubrication, vibrations, dynamics, manufacturing and inspection. The course ends March 14. $1,900. For more information, contact the Gear Lab at Ohio State University by telephone at (614) 292-5860 or on the Internet at *www.gearlab.org.*

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All candidates must be currently authorized to indefinitely work full time with The Timken Company in the United States, under United States immigration laws. The Timken Company is an Equal Opportunity Employer.

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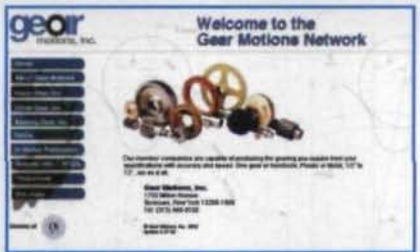


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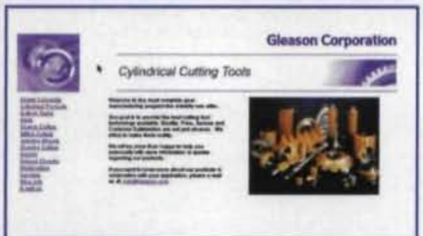


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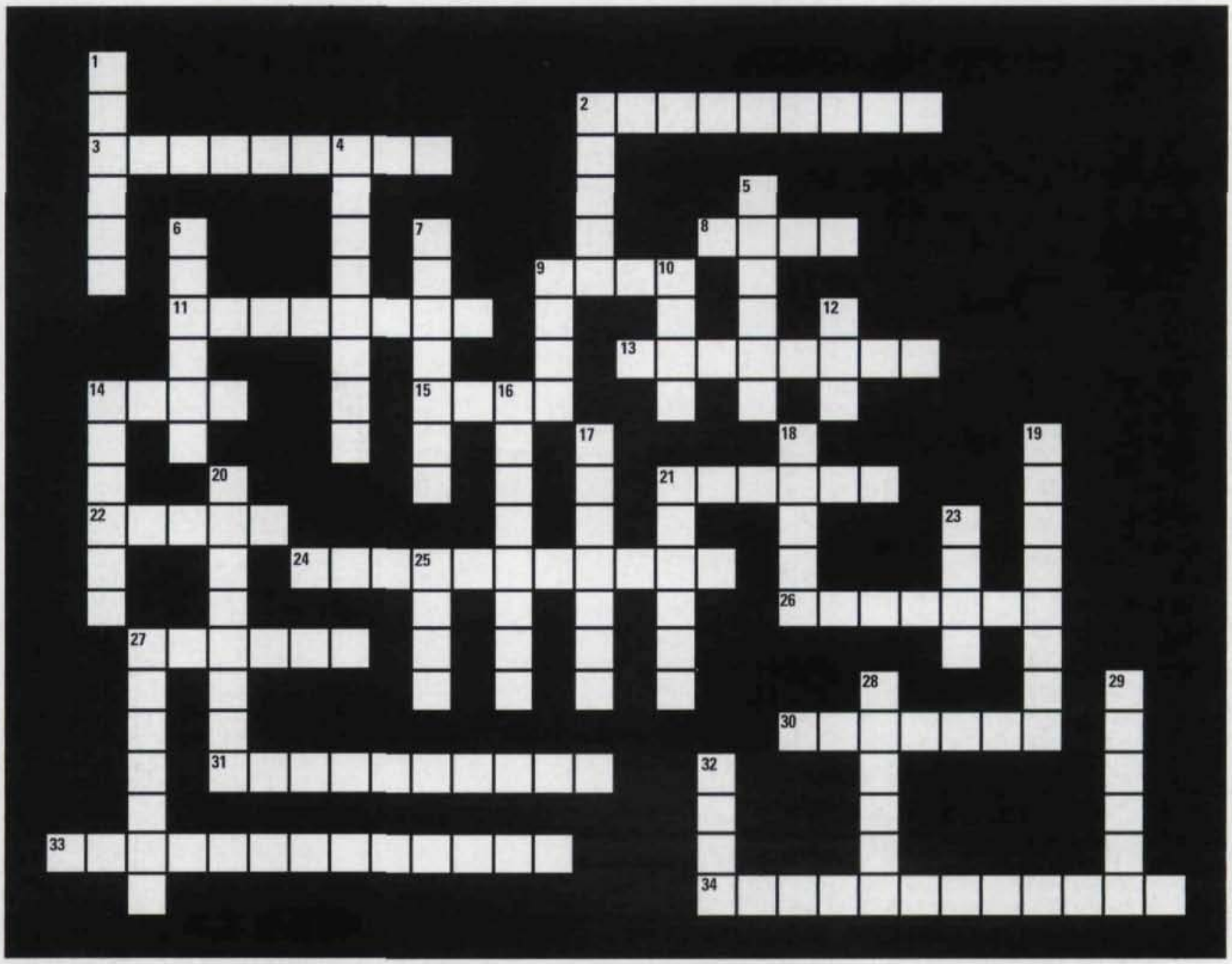
# GEAR CROSSWORD

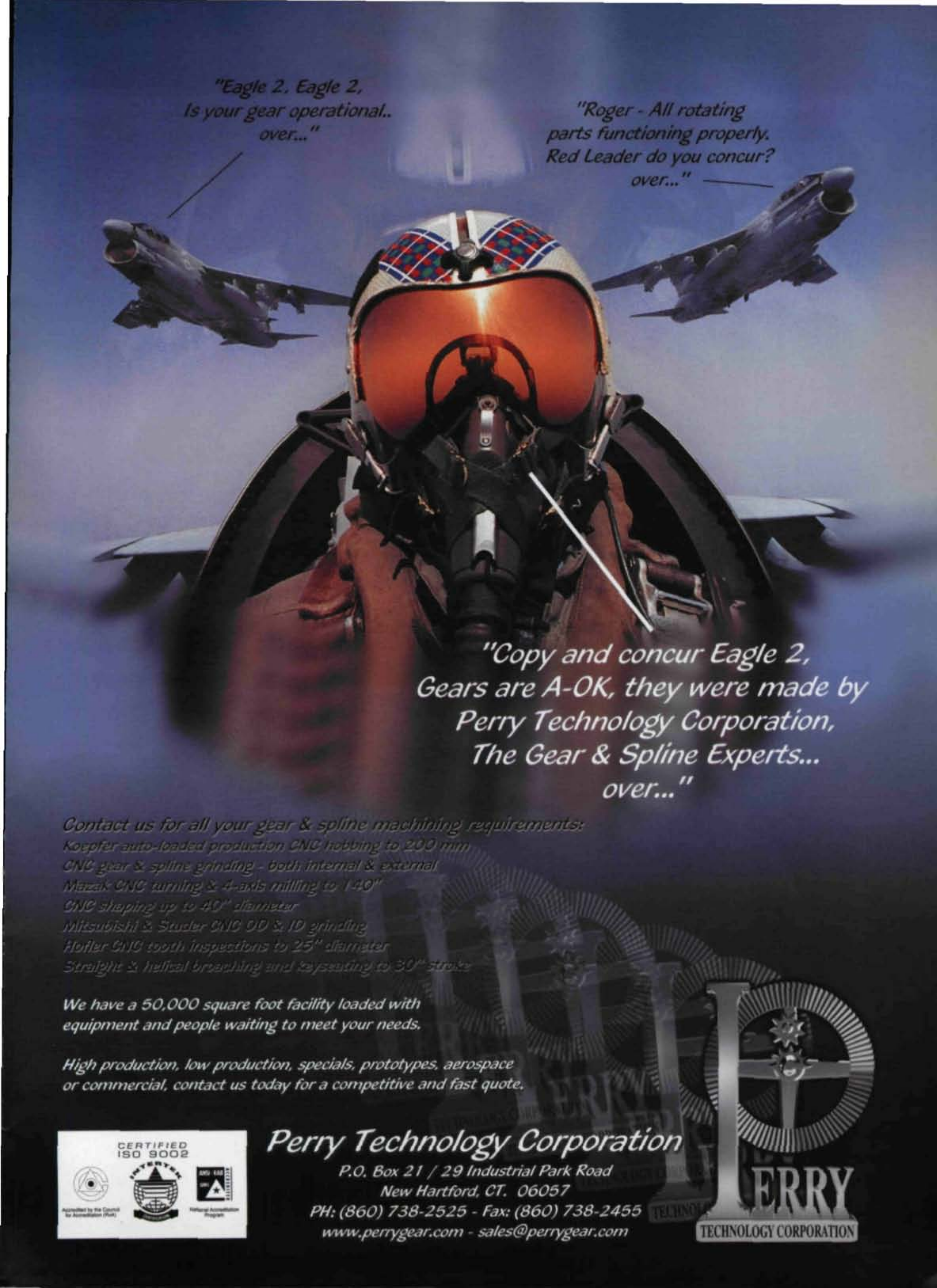


**Across**
2. Completing
3. Can be attired
8. Peak
9. Distort
11. Complex
13. Gnashing
14. Put clothes on
15. Equipment
21. Slang for hypodermic identification?
22. Slant
24. Part of food fish's skeleton?
26. Spiral-like
27. Bird's wing
30. De-bearding?
31. Atomic number 42
33. Common center
34. Rich man's odd habit?

**Down**
1. Lunar _____, for Aldrin and Armstrong
2. Side of a military formation
4. Whipping motion, in reverse
5. Slat
6. Well-thrown football has a tight one
7. Tire out
9. Cowboy-boot accessory
10. Type of invertebrate
12. Iceberg part
14. Side-to-side stagger
16. Book supplement
17. Type of gear cutting
18. Incisor, for example
19. Forming small waves
20. Difference between pitch and root
21. Improving a skill
23. Device for torture by stretching
25. Cheer
27. Extracting a fruit's seed
28. A copy, old-style word
29. Exitquickly?
32. Perry Mason investigation

***Not as dense as *The New York Times* crossword puzzle, but hey, there's a reason we don't do this for a living.**

**Answers on page 37.**



"Eagle 2, Eagle 2, Is your gear operational.. over..."
"Roger - All rotating parts functioning properly. Red Leader do you concur? over..."
"Copy and concur Eagle 2, Gears are A-OK, they were made by Perry Technology Corporation, The Gear & Spline Experts... over..."
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