September/October 2009

GEAR TECHNOLOGY

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The Journal of Gear Manufacturing

25 YEARS 1984-2009

Gear Expo 2009

- Product Preview
- Guide to Gear Expo
- Special Events

Feature Article

- Grinding Gears for Racing Transmissions

Technical Articles

- Carbide vs. PM-HSS Hobs
- Gear Corrosion During Manufacturing
- Tooth Fillet Profile Optimization
- Carburizing Large Transmission Parts

Plus

- Addendum: Kid Tested, Museum-Approved


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GEAR TECHNOLOGY

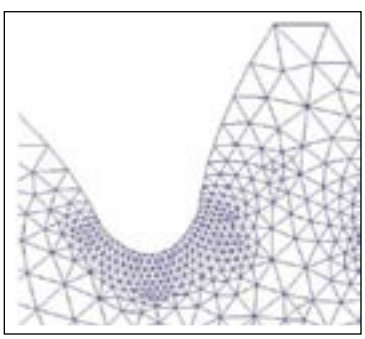
September/October 2009

CONTENTS

Gear Expo 2009

FEATURE

TECHNICAL ARTICLES



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GEARTECHNOLOGY

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gear up

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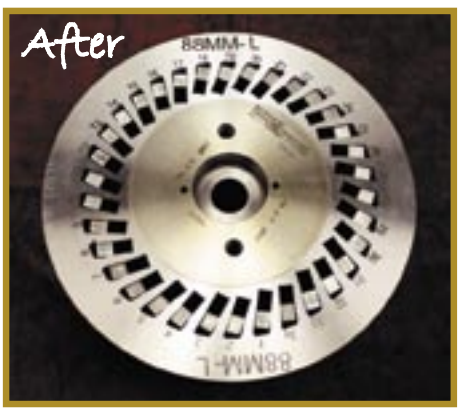

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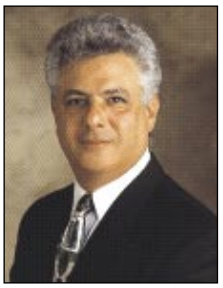

Why do *YOU* Read *Gear Technology*?

A year ago, we sent out a small e-mail survey with one simple question: "Why do you read *Gear Technology*?" At that time, we were extremely gratified, even somewhat overwhelmed, by the enthusiastic and appreciative response of our readers, and I wrote about the survey and the results in my editorial in the September/October 2008 issue.

When we sent out the survey this year with the same question, you'd think we would have been prepared for the results. We weren't. If anything, our readers are even more appreciative than they were a year ago.

We expected that *Gear Technology*'s articles would be well received. We spend a lot of time and effort ensuring that our technical articles are the most relevant, accurate and useful articles possible. We take great pride in the importance of the articles and the breadth of subjects we've covered over the years. That effort is reflected in the readers' comments:

"I have spent 35 years in the gear industry and have found *Gear Technology* essential in keeping up with the latest gear design and processing innovations," said a project manager for a Tier One automotive supplier.

"I am particularly interested in the technical articles, and I appreciate the fact that the quality of the articles seems to have increased in the last few years," said a senior engineer at an East Coast gear manufacturer.

"The technical articles make up a large part of my ongoing education," said the VP of engineering at a major Midwest gear manufacturer.

In addition to these, there were many more comments praising our articles and their importance to the industry and its education. We received responses from a wide variety of companies including people working in gear design, manufacturing, testing, inspection and heat treating. We also heard from gear buyers and users, as well as the people who manufacture, sell, service and install gear manufacturing equipment, tooling and fixturing. Even with such a wide spectrum of readers, there seems to be something for everybody in *Gear Technology*.

What surprised us most was the number of respondents who specifically cited the importance of the information in the advertisements. They consider the ads to be an important part of their gear industry education. They look to the ads for a current understanding of the state of the art and updates about what new products and processes are available in the marketplace, as well as who can supply them. Of course, we here at *Gear Technology* are very appreciative of our advertisers. But it's also extremely important for the advertisers to understand that the readers consider their advertisements to be a part of their educational experience when reading *Gear Technology*.

"The advertisements do their part in bringing the latest technologies to the fore," said a gear engineer for a major worldwide speed reducer manufacturer.

"We are investigating equipment updates and purchasing some new equipment for cutting and inspecting gears, so we find the advertising as well as the articles helpful," said the director of manufacturing at a major U.S. gear manufacturer.

"The ads help me find vendors we need to fill the gaps in our productions capabilities," said an engineering manager at a major gear manufacturer.

So I'd like to compliment our advertisers for helping us educate the gear industry. The information provided in the ads is often just as valuable to our readers as the information in our articles.

Although the survey is extremely gratifying to us here at *Gear Technology*, we would like even more feedback. What could we or should we be doing that we're not? What types of information do you need that we're not already providing? We'll be at Gear Expo, booth #1241, serving espresso to any who are interested. We'd love to sit and chat with you about how we can make *Gear Technology* even better for you. But even if you can't make it to the show, we hope you'll drop us a line at *publisher@geartechnology.com*.

In any business, you can't be successful unless your customers are successful. At *Gear Technology*, we try to provide you with the information that helps you be more productive and profitable, no matter what part of gear manufacturing you're involved with. So we need you to tell us how we can help you.

Ultimately, you are our customer, and we want you to be as successful as possible.

Michael Goldstein,
Publisher & Editor-in-Chief

Introducing the

Gear [illegible] Machine

This is going to be big.

Sorry, Mitsubishi Heavy Industries isn't quite ready to debut the newest and most exciting gear machine to arrive in the U.S. market. You'll have to wait until we reveal it at GEAR EXPO 2009, on September 15-17 in Indianapolis, Indiana.

For now, suffice it to say the new machine from MHI will make an immediate impact on the worldwide automotive machining industry.

To see what the fuss is about and learn all about this game changer, be sure to attend GEAR EXPO and make your way to the Mitsubishi Heavy Industries America exhibit booth #841. After the event, the machine will be on display and MHI representatives will discuss its specifications and capabilities.

Contact Mitsubishi Heavy Industries America today to ask about our exclusive VIP events at GEAR EXPO.

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Gear Expo: Changing with the Times

Joe T. Franklin, Jr., President, AGMA

One of the reasons AGMA has been successful over our 93-year history is that the association's agenda, programs and activities reflect the voices of our members.

The Board of Directors, advisory committees and councils and staff vigilantly review programs and vet them with members for needed changes, updates or cancellations. The organization today is much changed from what it was a quarter-century ago, a decade ago—even a year ago.

Gear Expo is a biennial event. Such a schedule demands careful review and updates to keep it fresh and representing the needs of the exhibitors and attendees.

The Solutions Center was an important part of Gear Expo in 2005 and 2007, so AGMA is bringing it back for the third consecutive show.

In 2005, we introduced the very popular Solutions Center, which allows exhibitors to give focused presentations on new technology and products and then invite interested listeners back to their booths for more discussion. The Solutions Center is on the exhibit floor for the convenience of participants.

We have added more education and training courses and keynote presentations in the Solutions Center. We have encouraged other engineering and technology-oriented associations and groups to build more valuable education programs for attendees.

To offer more value for attendees and more attendees for the exhibitors, Gear Expo 2009 is co-located with the ASM Heat Treating Society Conference & Exposition, owned by ASM International—The Materials Information Society. Customers of one are almost always customers of the other.

Also new this year, the U.S. Department of Commerce selected Gear Expo for certification as one of its International Buyer Trade Shows. Embassies around the world have encouraged their commercial officers to bring interested delegations to Gear Expo. We will have an international center on-site with representatives of the U.S. Commercial Service to help exhibitors and attendees benefit from increased exports of products represented at the show.

Gear Expo is a smaller trade show, but it is also the only event of its kind for the gearing industry. The show brings together the equipment builders, gear manufacturers and an interested, the show. Gear Expo is a major networking event for the gearing industry.

A number of exhibitors may see many of their customers during the show. Keeping in-touch with their base is fundamental to successful business. Others see longtime friends and competitors in the relaxed environment of Gear Expo.

Gear Expo is a win-win-win for the attendees, exhibitors and the gearing industry.

Let us work our magic and create your perfect gears

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Custom Gear Cycle Times

Plummet with Help from Reishauer, Siemens

Custom Gear and Machine, Inc., of Roscoe, IL, recently purchased a Reishauer RZ400 gear grinder and, on one job, has seen the cycle time drop from 40 minutes to six minutes, according to Tim Rose, vice president of manufacturing, who runs the business with co-owners Dave Patterson and Mike Rasmann.

Rose explains, "We were looking to expand our gear grinding capability and the Reishauer RZ400 offered us many benefits, including 400 mm O.D., 10 mm root diameter, up to 999 teeth capability, helix angles to ±45 degrees and a z-axis of 300 mm, all features we could use on a daily basis. We also liked the easy access four-door configuration and serial interface, plus the machine's auto wheel dresser and add-ons of materials and part handling devices."

Custom Gear and Machine's new Reishauer RZ-400 helps them cut cycles times to a fraction of what they were using an older machine.

Siemens controls allow a customized user interface.

Custom Gear and Machine, Inc. was already running an older Reishauer grinder, but the company was seeking to improve its throughput and overall grinding department performance. The RZ400 has three features that helped achieve these goals. The machine has more than double the surface speed, going from 1,900 rpm to 4,000 rpm. It also has a seven-start grinding wheel versus a single-start variety. Also, the flushing and grinding integrity were significantly improved from the older machine with coolant pressure increasing from 30 psi to 300 psi.

Custom Gear and Machine, Inc., founded in 1994, is a full-service gear manufacturer, producing spur and helical gears to AGMA 8 thru 14 standards and up to 30" diameters typically, plus splined shafts to 54" in length. Its customers include builders of agricultural equipment, construction and off-road vehicles, machine tools, printing presses, food processing equipment, overhead cranes, materials handling devices, lift equipment, process equipment such as large water pumps and more.

Dennis Richmond, vice president for Reishauer, handles North American sales and service for the Swiss-based machine builder. Richmond says, "Our previous gear grinders at Custom only allowed them a 13" diameter, and they were looking to step up to a larger, 16" max

continued

diameter. Plus, they were seeking other features we were able to offer. We use the Siemens numerical controls on our machines for a variety of reasons, especially the architecture's ability to allow our engineers to customize the front ends. This simplifies the addition of new part programs and helps operators more easily navigate the programming and set-up. When the data input is completed for the current screen, for example, the operator is prompted to enter data for the next screen and so on, until the program is completed."

Rose confirmed this point, adding that Custom Gear's machinists are each responsible for the set-up, running and maintenance of their machine. "They take a real pride in making sure the jobs are done right and that the machine is always in great shape."

One of the current machinists running the Reishauer RZ400, Daniel Warren, noted that he had not previously run a machine with a Sinumerik CNC from Siemens onboard, but explained, "I got great training from Reishauer and was up to speed very quickly. We were making parts within a few days after the installation, and I was completely comfortable with the easy operation of the CNC in less than a month."

In describing the automatic wheel dressing sequence, Warren also noted how the CNC automatically adjusts the settings to compensate for the reduced wheel diameter after dressing, bringing the wheel to the correct point of contact with the subsequent workpieces every time.

Data such as gear configuration, fixture design and all tool settings are entered into the screens, including pitch, pressure angle, teeth and dressing steps. Once a new part pro-

gram is completed, the operator at Custom Gear can begin working through the Reishauer-designed man-machine-interface (MMI) set-up screens, which also function in the same manner. Reishauer further allows its customers to add their own HMI screens for features onto the Siemens CNC for data acquisition, training aids and even SPC protocol operations. This service enables the customers to have a common look across the screens on many machines in their shop. This is especially helpful in work cell set-ups where a single machinist is running multiple machines.

Reishauer also uses other aspects of the Siemens product and service package for added functionality, including Siemens motor and drive packages for building the control structure on its machines. According to Richmond, this allows a seamless integration between all drives and the numerical control unit (NCU). It also makes a much easier task out of the integration of ancillary machine devices such as chip conveyors, filtration systems, wheel dressing stations and especially the critical materials handling and part loading devices frequently built with its machines for customer work cell set-ups. Siemens uses the Profibus networking protocol, enabling Reishauer to link various control devices and other machine tools together, thus greatly reducing the field

continued

work integration and wiring time during installs. Reishauer uses Profibus to link the onboard Siemens Sinumerik 840D CNC to VFDs, other drives, electronic gearboxes and balancing systems for the grinding wheel on its machines.

Mike Rasmann, vice-president of operations at Custom Gear, concludes, "Our investment in the new Reishauer gear grinder has expanded our capability, allowed us to produce more parts for more existing customers and even opened some new business doors for us. With the added benefit of increased safety on the machine, it was a win-win situation for us, all around."

Rose echoed this sentiment, adding, "It's a great machine. When we have any need for assistance on the machine, including parts and especially application engineering, we know the answer is just a phone call away. Reishauer has been there for us on many occasions. This is a big reason we've done business with them for 15 years and will continue to do business with them in the future."

For more information:

Custom Gear and Machine, Inc.
5466 East Rockton Road
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Fax: (815) 389-4548
sales@cgearinc.com
www.cgearinc.com

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Fax: (847) 888-0343
Reishauer-us@reishauer.com
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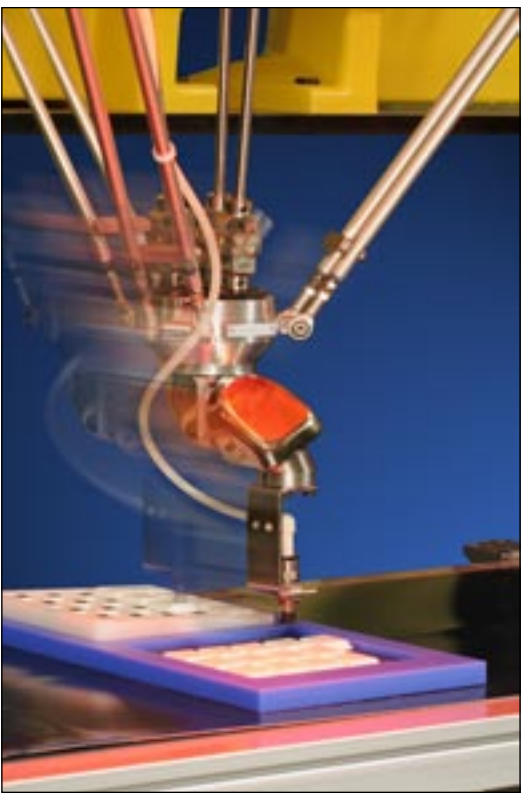

The M-1iA compact assembly robot.

At the International Robots, Vision and Motion Control Show in Chicago, FANUC Robotics presented heavy-duty and compact assembly robotics that emphasized the company's latest six-axis technology. Demonstrations included intelligent assembly and Certified Education Robot Training (CERT) units.

The M-200iA/1200 super heavy-duty robot is able to lift parts weighing up to 3,000 lbs. This is the second in FANUC's line of heavy-duty robots designed to handle truck, tractor, automotive frames and other large castings. The M-2000iA/1200 has a rigid arm design with a vertical lifting stroke of 6.2 m for transferring extremely heavy items.

The machine was equipped with iRVision 2-D error proofing and Dual Check Safety Speed and Position Check software, demonstrating its high capacity

continued

payload and wrist, by loading and unloading a machine tool bed in front of a 2-D camera. The M-2000iA/1200 operates with the company's latest R-30iA controller with integrated intelligent functions such as vision and force sensing.

"This machine has the highest payload and the strongest wrist compared to all other electric six-axis robots available today," says Ian Orr, product manager at FANUC. "It can support a 1,350 kg payload with a 0.6 m offset from the faceplate and full articulated motion at the wrist. One M-2000iA/1200 robot can handle a super heavy part, which previously required dual robots, conveyors, lifts and other fixed automation."

FANUC also presented a six-axis, parallel-link robot designed for small part handling, high-speed picking and assembly applications. The M-1iA is a lightweight and compact robot that provides higher speeds and accuracy compared to traditional assembly robots, according to the company's press release. The robot can be installed in a variety of orientations and has a three-axis wrist for flexibility.

"Assembly customers require higher speeds and accuracy to meet their production goals," says Nishant Jhaveri, product manager at FANUC. "The M-1iA's flexibility and speed far exceed the capabilities of other vertically-articulated or SCARA-type robots."

During the exhibition, FANUC demonstrated a CERT mobile training unit with a LR Mate 200iC robot equipped with iRVision 2-D. The robot located blocks with holes, inserted pegs into the holes at 30, 60 and 90 degree angles and then removed the pegs from the block.

The CERT program, launched in 2008, certifies instructors at educational institutions to train their students to program FANUC robots, and is available to qualified high schools, community colleges and universities. It is now being used in schools across the country. "CERT has proven to be a very effective program for training students to be qualified for successful

careers in high-tech manufacturing," says Kevin Ostby, vice president, customer resource center. "In just over a year there are literally hundreds of students across the country learning to use a FANUC industrial robot while getting practical knowledge of how math and science are applied in manufacturing."

For more information:
FANUC Robotics America, Inc.
3900 W. Hamlin Rd.
Rochester Hills, MI 48309
Phone: (248) 377-7570
www.fanucrobotics.com

CNC Shapers

MACHINE MULTIPLE SURFACES QUICKLY

Ohio Broach and Machine Company introduces a line of CNC Shaper machines that machine multiple surfaces in seconds, and various parts can be fixtured for machining with repetitive cuts in one shaper cycle. The machine head uses CNC controls to oscillate a tool up and down at 600 cycles a minute while the machine axes feed work into the tool. This combination of tool and axes feed can produce a multitude of form on parts.

The CNC Shaper machines are customized individually for customer requirements. They are suited for machining small and medium sized parts with special intricate forms, shaping blind hole forms in addition to out-

continued

side shapes and forms against shoulders or other obstructing features. They can be used for gear manufacturing and in the medical, electrical and aerospace industries.

All axes of the CNC Shaper machines are servo-controlled, ball screw driven and controlled through the CNC interface. The main slide ways use a preloaded linear roller system for quick, accurate axis movement. Two models are available: the OB-VM16-2 and the OB-VM20-2. Both have a two-inch standard stroke as an available option.

"The new CNC Shaper machines offer manufacturers capabilities that are more efficient than traditional EDM machines, which are slower and more expensive," says Jeffrey Frantz, sales manager for Ohio Broach and Machine Company. "One new shaper machine can now do the work of two or three standard cutting machines. This translates into less capital outlay, lower inventories, reduced lead and production time and less labor."

For more information:

Ohio Broach and Machine Company
35264 Topps Industrial Parkway
Willoughby, OH 44094
Phone: (440) 946-1040
Fax: (440) 946-0725
jfrantz@ohiobroach.com
www.ohiobroach.com

D.C. Morrison

REDESIGNS KEYSEATER FOR RIGIDITY

The 3" Keyseater from D.C. Morrison has been redesigned with a back support bracket twice the length of the older models, so it demonstrates improved rigidity and allows for more accurate keyways in a variety of materials, even those that are typically difficult to cut.

A hydraulically-actuated overhead support is a new addi-

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The ZP40 is designed to profile grind spur and helical external and internal gears using dressable corundum or sintered grinding wheels. An integrated measuring device further increases machine's flexibility. The ZP machine can be set up to accommodate application-specific requirements for maximum flexibility, high precision and optimum productivity.

It is specifically designed to accommodate shaft pinions, mating bull gears and internal ring gears.

Extended capacity for gears and profiles is:

- Internal and external gear grinding up to 4m(160") OD x 1.5m(60") face.
- The ability to inspect lead, profile and spacing up to 4m (160")

Havlik GEAR

Div. of Havlik International Machinery Inc.

455 Sheldon Dr., Cambridge, Ontario N1T 2B7 tel 519-624-6240 fax 519-624-4119

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tion to the keyseater, so operators can move the support with the push of a button. A programmable logic controller and human machine interface were added for more user friendly programming. The Morrison Keyseater doesn't require positioning in a pit or bushings to center the keyways. The machine cuts from 1/8" to 3" wide and up to 14" deep.

For more information:
D.C. Morrison
201 Johnson Street
Covington, KY 41011
Phone: (888) 246-6365
Fax: (859) 581-9642
dcmorrison@fuse.net
www.dcmorrison.com

Slater

DOUBLES BROACH HOLDER LINE

The Rotary Braoching Tool Holders line for CNC, screw and swiss lathe machines and milling machines from Slater Tools Inc. has been expanded to offer 38 broach holders. The tools are used to put hex and square shaped holes into metal parts such as for aerospace applications and orthopedic bone screws.

According to Peter Bagwell, engineer and marketing manager for Slater Tools, Slater broaches are often used to make gears with spline shapes. "The expand-

ed use of rotary broaching tool holders in new and used CNC machines has created the need for a larger variety of function and adaptability in these tool holders," Bagwell says.

"Rotary Broaching tools can be used to make various gear forms with smaller diameters and shallow depths. Broaching can be done on a CNC machine, lathe or mill, and most often costs less than performing secondary operations," Bagwell says. "The most popular gear forms are serrations, splines and involute forms."

The Swiss type holders include new diameter sizes and some include longer shank lengths. They are suitable for applications where the form being broached is less than 0.050 inches in diameter.

For more information:

Slater Tools Inc.
44725 Trinity Drive
Clinton Township, MI 48038
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Fax: (586) 465-3030
direct@slatertools.com
www.slatertools.com

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Höfler

- **Hofler Rapid 1250** The revolutionary gear grinder offers PowerStroke high speed grinding for 50% cycle time reductions and our newest Topological gear grinding software featuring 5 Axis of synchronized live grinding motions
- **Hofler Helix 400SK** The Helix series, with its multiple configurations, is the most successful line of small form grinders with almost 400 installed worldwide in the aerospace and small gear production industries.

Wenzel

- **Inova Gear** Used for small gear (both helical and bevel) and gear tooling inspection with an integral Barkhausen probe for gear burning checks
- **LHT 2600 (2.6 meter)** This advanced gear checker is targeted for wind turbine gears with integral CMM capabilities

Fässler and more!

- **Fassler** Gear Honing and Diamond Broaching machines and tools (Exhibit 911)
- **Escofier** FCR force controlled gear and spline rolling machines and tools
- **Bharat Forge Ltd** Large gear forgings for wind, mining and oil patch
- **DTR** Gear cutting tools

Great Lakes Gear Technologies, Inc. serves as a sales representative and consultant for the world's most advanced gear manufacturing companies. In addition to manufacturers of wind turbines and gear jobbers our equipment is targeted to the aerospace, automobile, truck, motorcycle, mining, steel, oil, and power transmission industry.

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Gear Expo 2009
Product Preview

Lindsey Snyder, Assistant Editor

GEAR EXPO 2009 & FALL TECHNICAL CONFERENCE
INDIANA CONVENTION CENTER
INDIANAPOLIS, IN
EXPO: TUESDAY–THURSDAY, SEPT. 15-17, 10 A.M.–6 P.M.
FTM: SUNDAY–TUESDAY, SEPT. 13-15, 10 A.M.–6 P.M.

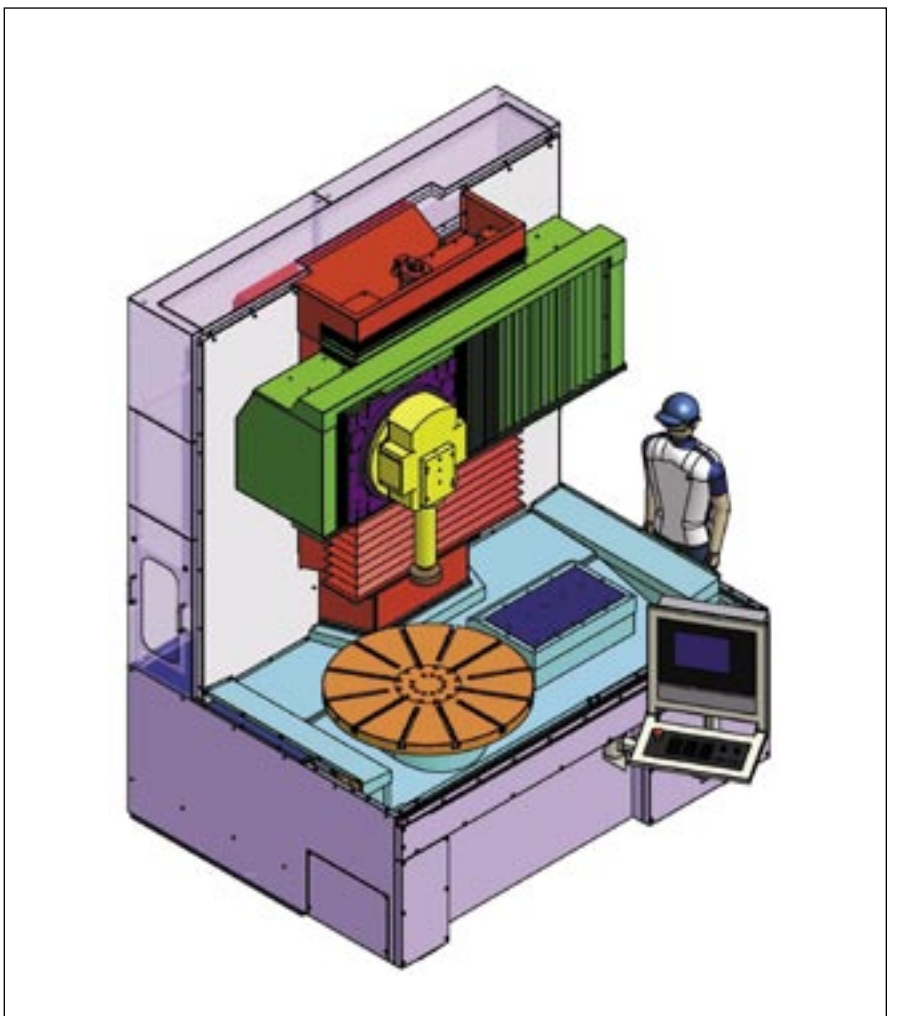
Sure, Gear Expo undoubtedly has a ton to offer attendees in education, research and networking alone, but what really draws the crowd in are the physical products and technology on display from exhibitors. Otherwise it would just be another technical meeting or social reception—and AGMA could save a few bucks on space to say the least.

There may be familiar faces in the crowd, but it's what everyone's looking at that is new and different. An expanse of shiny new tools and machinery with different features, gadgets, and designs compete to resonate with visitors long after the hall closes. Exhibitors have two years to make the most from product and technology advances, so visitors are more than simply reminded of the last Gear Expo. Here's a peek at what some exhibitors are hoping to wow with on the show floor:

Bourn & Koch
Booth 741

In an effort to replace the legacy lines of Motch turning centers, Springfield vertical grinders, Blanchard vertical rotary surface grinders, Bullard

continued



Bourn & Koch will introduce its VBG platform of machine with the 1000VBG, a vertical OD/ID grinding machines that comes equipped with gear inspection software to ensure ODs and IDs are ground concentric to the pitchline of a gear.

turning products and Fellows mid-range mechanical stroking gear shapers, Bourn & Koch is introducing the "composite platform" machine, which is identified as a basic, low-cost common building block with innovative, no or low maintenance technologies and integral and linear motors with high precision feedback. The B&K 1000VBG CNC Vertical OD/ID grinding machine is the first of these machines to be released, debuting at Gear Expo.

One key feature of the 1000VBG is gear inspection software that includes a circular geometry inspection system for inspecting roundness and runout. This allows manufacturers to grind hardened gear IDs and ODs concentric to the pitchline of a finished gear. The machine is being manufactured to U.S. standards and European CE standards, and it is available in one meter, 1.5 meter and 2.5 meter versions.

In most cases, the composite platform design has 40 percent fewer parts than the old legacy designs, so purchase cost is significantly lower for customers. Bourn & Koch can stock the platform base units, columns and cross slides, which were previously the most expensive components with the longest leads on the older designs. Stocking the base units reduces the build cycle time by at least six weeks.

The composite platform machine can be constructed in four configurations: the vertical grinding machine with hard finish turning capabilities, a vertical turning center, vertical gear shaper, a rotary surface grinder or any combination of these.

For more information:
Star SU LLC
5200 Prairie Stone Parkway
Suite 100
Hoffman Estates, IL 60192
Phone: (847) 649-1470
Fax: (847) 649-0112
sales@star-su.com
www.star-su.com

Gleason
Booth 715

In Gleason's approach to be the "total gear solutions provider," it is introducing various machines, tooling and the Gleason Global Services support system at Gear Expo, all for aiding various processes for bevel and cylindrical gear production and inspection from start to finish.

As part of Gleason's new genera-

Gleason's GP 300 ES gear shaper will be on display at Gear Expo.

tion of GP series machines, the GP 300 ES CNC Gear Shaping Machine exhibits high flexibility and is designed to improve cycle times for shaping spur and helical gears, internal and external, up to 300 mm in diameter. Instead of a mechanical helical guide, the GP 300 ES uses an electronic helical guide that features Siemens 840D CNC and proprietary software to apply the extra rotational motion on the cutter spindle required to produce any helix angle.

The 350GMM Analytical Gear Tester is representing the GMM Series inspection systems from Gleason at the show. Models are available for gears up to three meters in diameter, and standard features include a Renishaw 3-D probe head for total inspection of all gears and gear cutting tools. Analytical gear testers from Gleason all run on Gleason's *GAMA* software, which is based on Windows VB.NET. The software uses an intuitive user interface with input screens designed to be simple for programming workpiece and cutting tool data.

Many gear cutting tools are part of Gleason's booth, including the latest introduction, the Opti-Cut index inserts for gashing, hobbing and shaping large cylindrical gears. In comparison to traditional high speed steel cutters, Gleason says that Opti-Cut lowers cost-per-part by up to 50 percent. The tooling family is diverse with an array of cutter body sizes, inserts and geometries for meeting a variety of roughing and finishing, internal and external gear production needs.

For more information:
Gleason Corporation
1000 University Avenue
P.O. Box 22970
Rochester, NY 14692
www.gleason.com

Sigma Pool
Booth 727

Liebherr and Klingelnberg are both exhibiting machines at the Sigma Pool booth. Liebherr's LC 180 CNC Gear Hobbing Machine features direct-drive cutter and table axes, a Siemens 840D control and non-contact meshing system. Numerous combinations of drive speed and torque provide the capabilities to accommodate new cutting tool technologies, such as chamfer cutting. Chip augers and stainless steel liners are designed into the machine base and work area for efficient chip removal.

Klingelnberg's P26 Gear Measuring Center inspects parallel axis gears, bevel gears, cylindrical gears with external and internal teeth, worms and worm gears, rotors, camshafts and crankshafts. Features include temperature compensation and roughness measurement of the tooth flank. The P series gear measuring centers are available from 260 to 3,500 mm and are appropriate for use on workpieces up to 260 mm OD. The P26 uses the Gear Inspection Assistant (GINA) operator interface, and measuring programs are available for hobs, shapers and shaving cutters.

The P26 is compact with a small footprint. Linear motor drives are a new feature for the measuring axes. A workpiece temperature sensor minimizes the time taken for parts to cool down. A surface roughness probe for parallel axis and bevel gears is an optional feature that attaches to the standard probe head.

For more information:

Liebherr Gear Technology, Inc.
1465 Woodland Drive
Saline, MI 48176
Phone: (734) 429-7225
Fax: (734) 429-2294
info.lgt@liebherr.com
www.liebherr-us.com

Sigma Pool's booth will feature the Klingelnberg P26 measuring center.

KISSsoft
Booth 615

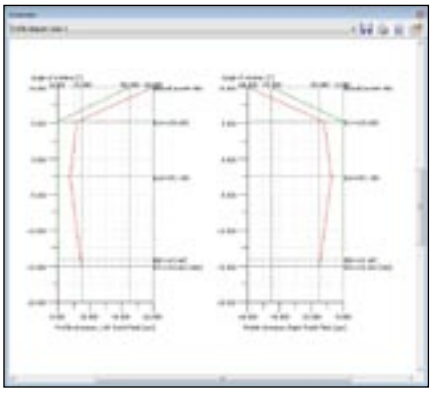
KISSsoft 08/2009 features improvements in the shaft and gear modules, as well as other areas.

A toolbar was added to speed up the shaft editor function. Copy and paste capabilities are useful for repeated parts. A list gives an overview of geometry, bearings and force elements. Outer and inner contour of the shaft can be exported or imported to the DXF format. Users can automatically determine documentation points in the shaft editor at a random position for displaying the most important results for deflection line, reaction forces, stress and more in the respective cross section.

Profile and flank line diagrams, called K-charts, are available in the cylindrical and crossed axis helical gear modules. The diagrams are created according to ANSI/AGMA 2000-A88, and they are the basis for quality assurance in gear manufacturing.

Local wear in *KISSsoft 08/2009* is calculated from real contact situation and graphically presented combined with worn out flank. The material database was expanded to include 17 new material definitions of the company SABIC, and they include measured

continued



The latest software release from KISSsoft includes the ability to produce K-charts.

wear parameters for dry-running conditions.

The measuring device position used to calculate measurement over balls or rolls is now determined by applying the ball or roll to the actual tooth form. This is an advantage because it can be applied to an arbitrary tooth form.

For more information:
KISSsoft, U.S.A., LLC
3719 North Spring Grove Road
Johnsburg, IL 60051
Phone: (815) 363-8823
Fax: (815) 363-8832
dan.kondritz@kisssoft.com
www.kisssoft.ag

Hydra-Lock
Booth 617

The full line of hydraulic workholding solutions from Hydra-Lock is on display, featuring part holding solutions for cutting/machining, measurement/inspection/metrology, balance and assembly.

Special emphasis is being paid to the Conform-A Chuck and Conform-A Arbor products. They use a plastic material known as Hydra-Fibre, which allows the chuck or arbor to expand, up to 0.125 inches depending on size, and adjusts to hold thin-walled and out-of-round components without rounding. The Conform-A products can locate on a rough machined surface and establish an average center line. The chuck can support the weak component area and endure tool pressure by locating on the entire surface. Accuracies are typically within ±0.001 inches.

For more information:
Hydra-Lock Corporation
25000 Joy Boulevard
Mount Clemens, MI 48043
Phone: (800) 634-6973
Fax: (586) 783-5007
weholdit@hydralock.com
www.hydralock.com

Hydra-Lock's Conform-A arbor.

Mahr Federal
Booth 515

The GMX 400 class I universal gear tester is for universal and specialized gear manufacturing processes featuring a four-axis power PC controller with automatic tailstock and 3-D scanning probe head. It analyzes a range of gear and gear tool applications with ODs up to 400 mm (15.75 inches).

The GMX 400 can be used as a stand-alone on the shop floor or in gear lab applications. The system is capable of correcting alignment errors using Wobble angle compensation software, single cycle measurement and multiple gear shaft analysis.

Mahr introduced a similar measurement system a few years ago, but this version has new features. "It has a new controller and is therefore faster than it was," says Pat Nugent, Mahr Federal vice president of metrology systems. "The biggest change is in the development of software since that time. That was why we were waiting to bring it back to the U.S. market. We felt that we needed substantially more software option packages and features within those packages. We believe that we now have those."

The GMX 400 analyzes gears and gear tools and will be on display in the Mahr Federal Booth at Gear Expo.

For more information:
Mahr Federal Inc.
1144 Eddy Street
Providence, RI 02905
Phone: (401) 784-3275
Fax: (401) 784-3246
information@mahr.com
www.mahr.com

Kapp Group
Booth 923

The Kapp KX 500 Flex Gear Center is being demonstrated by the Kapp Group. It grinds and measures external spur and helical gears of modules up to 10 mm (0.4 in) with a maximum OD of 500 mm (19.7 in) and gear width up to 520 mm (20.5 in).

The KX 500 Flex features a multi-station indexing table and optional twin-spindle dresser for dressing speed and flexibility. Automation options are determined by customer requirements. The machine is designed for application-specific solutions such as continuous generating grinding with dressable or CBN plated worms, discontinuous profile grinding with dressable or CBN wheels or some combination of both these methods.

The Kapp booth is emphasizing education at Gear Expo with direct video and audio links to the facility in Boulder, CO where wet grinding of various workpiece types will be demonstrated. Hourly learning sessions are taking place on profile grinding, generating grinding and workholding setup. Kapp and Niles applications engineers are at the booth for answering specific questions pertaining to the learning sessions.

For more information:

Kapp Technologies
2870 Wilderness Place
Boulder, CO 80301
Phone: (303) 447-1130
Fax: (303) 447-1131
info@kapp-niles.com
www.kapp-niles.com

The Kapp KX 500 gear grinder.

Emuge Corp.
Booth 700

The Emuge System SG expanding-bush design workholding solution is used for hobbing, shaping and shaving for gear production as well as milling and inspection.

The solution is designed based on a series of short tapers that expand or contract in contact with axial force. The System SG can be designed for ID or OD clamping. It features a large surface area contact with the workpiece, which is capable of holding almost the whole diameter of the clamping area.

The System SG gives the workpiece a slight axial movement towards an end stop for stiff operation, and it handles higher transferable torque values typical of modern machining operations.

For more information:

Emuge Corp.
1800 Century Drive
West Boylston, MA 01583

Phone: (800) 323-3013
Fax: (800) 393-1302
info@emuge.com
www.emuge.com

System SG workholding from Emuge.

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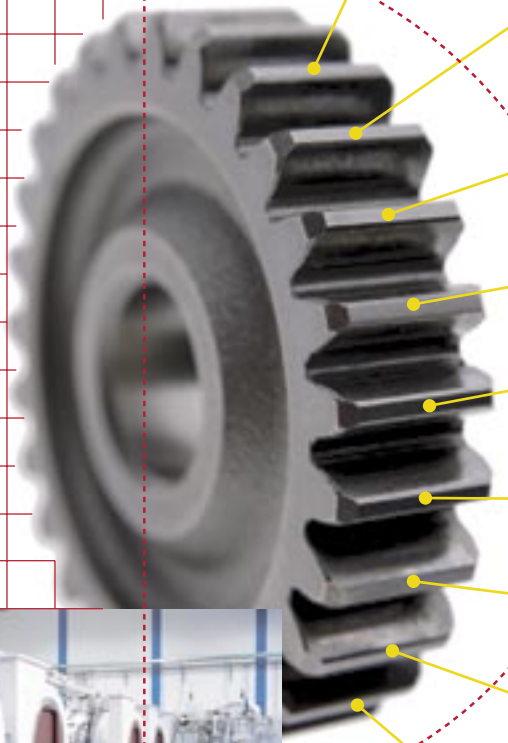

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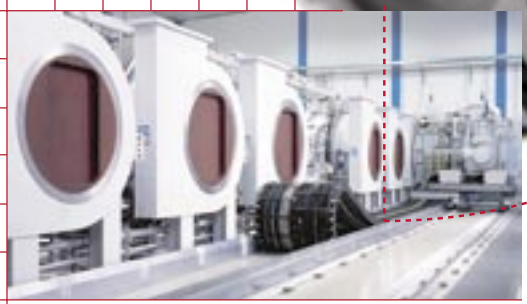

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Gear Expo 2009

Solutions Center Presentations

The forum of short exhibitor presentations known as the Solutions Center is back for the third consecutive Gear Expo. As *Gear Technology* went to press, there were more than 20 presentations scheduled, including three keynote presentations, one of which is Dr. Mike Bradley's annual Gear Market Report.

Presentations are open to all show visitors free of cost. The Solutions Center can be found at the rear of the exhibition hall and is fully equipped for large crowds with a sound system and LCD projector for speakers to use. The schedule, as of August 14, is as follows:

Tuesday, September 15

10:30 a.m.
Erasteel SAS
How to Increase Productivity in Gear Cutting

11:00 a.m.
KEYNOTE PRESENTATION:
Energy Efficient Motor and Drive Systems
Matt Murray, SEW-Eurodrive, Inc.

12:00 p.m.
Lunch

1:00 p.m.
Kleiss Gears, Inc.
Metal to Plastic Gear Conversion

1:30 p.m.
AK Gears, Thermotech
Design Essentials for Plastic Gear Performance

2:00 p.m.
Gleason Corporation
New Developments in Straight Bevel Gear Manufacturing

2:30 p.m.
ALD-Holcroft
Low Distortion Heat Treatment Solutions

3:00 p.m.
Promess Incorporated
Foundations of Function Testing Gear Assemblies

3:30 p.m.
J. Schneeberger Corp.
In-Process Compensation & Innovative Solutions for Challenges Relating to Hob & Shaper Cutter Sharpening & Manufacturing

4:00 p.m.
American Stress Technologies
Next Burning Question—Freedom from AGMA 2007-B92?

Wednesday, September 16

10:30 a.m.
Romax Technology
Advanced CAE Tool for the Analysis of Gear Whine, Rattle, Durability and Efficiency

11:00 a.m.
KEYNOTE PRESENTATION:
Gear Market Forecast
Dr. Mike Bradley, AGMA Economic Consultant

12:00 p.m.
Lunch

1:00 p.m.
Kapp Technologies
Embedded Intelligence for Optimized Grinding of Large Gears

1:30 p.m.
S.L. Munson
Subject to be announced

2:00 p.m.
Emuge Corporation
Workholding Solutions

3:00 p.m.
ALD Vacuum Technologies
LPC Heat Treatment Services for Gear Manufacturers

3:30 p.m.
Eldec Induction USA
In-Line Hardening for Time and Money

Thursday, September 17

10:30 a.m.
Gleason Corporation
Combining New Technology and Inspection Machine Performance

11:00 a.m.
Koepfer America
Advanced Gear Tool Sharpening

11:30 a.m.
S.L. Munson
Subject to be announced

12:00 p.m.
Lunch

1:00 p.m.
KEYNOTE PRESENTATION:
Entering the Wind Industry Supply Chain
Gene Cuenot, Vestas Nacelles

2:00 p.m.
Eldec Induction USA
In-Line Hardening for Time and Money

Seminars and

Gear Expo 2009 is also featuring a series of meetings, training sessions and seminars of special interest to visitors. As a supplement to AGMA's education programs, the American Bearing Manufacturers Association (ABMA) and the Society of Manufacturing Engineers (SME) are holding seminars on current gear-industry topics. The following is a schedule of special events. For more detailed descriptions and information on registering for these events, visit *www.gearexpo.com*.

Training School for Gear Manufacturing

Presented by: AGMA
Tuesday, September 15–Thursday, September 17
Price: $395 member/$525 nonmember

Why Bearings Fail

Presented by: ABMA
Thursday, September 17
Price: $295

SME Gear Manufacturing Conference

Presented by: Society of Manufacturing Engineers (SME)
Tuesday, September 15–Wednesday, September 16, 9 a.m.–4 p.m.
Full conference registration: $495 member/$595 nonmember
One-day registration $265 member/$365 nonmember
For full conference schedule and presenters, visit *www.sme.org/gears*.

Entering the Wind Turbine Gearbox Supply Chain

Presented by: AGMA
Wednesday, September 16
Price: $295

Special Events

ASM Heat Treating Society Education Courses

(*Ed. note. The Heat Treating Society has a complete technical program with many gear-themed sessions. For more information on those, visit* www.asminternational.org/heattreat.)

Heat Treating for the Non-Heat Treater

Sunday, September 13, 8 a.m.–4 p.m.
Instructor: Scott MacKenzie
Price: $300 nonmember, $275 ASM Member, $250 HT member

Heat Treatment of Gears 1/2 Day Workshop

Tuesday, September 15, 1 p.m.–5 p.m.
Presenters: Dale J. Weires, Daniel H. Herring, Scott MacKenzie, Fred Specht and B. Lynn Ferguson
Price: $200

A Review of Surface Treatments for Gears and Tooling

Wednesday, September 16, 1–6 p.m.
Instructor: David Pye
Price: $200

Practical Heat Treating

Thursday, September 17, 8 a.m.–4 p.m.
Instructor: David Pye
Price: $300 nonmember, $275 ASM Member, $250 HT member

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Ticona Engineering Polymers
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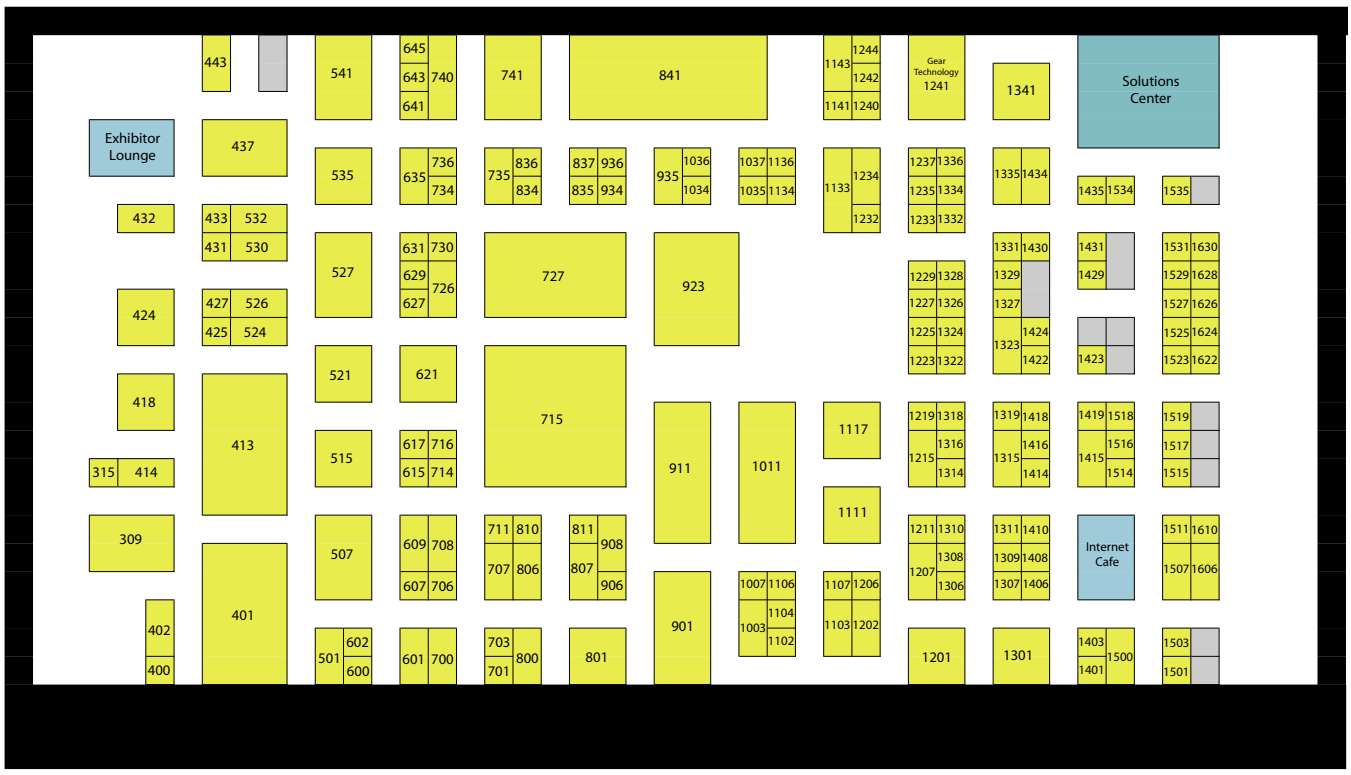
Florence, KY, USA 41042

Gear Expo 2009

September 15–17, 2009 ■ Indiana Convention Center ■ Indianapolis



Alphabetical List of Exhibitors

***See page 43 for these listings arranged by booth number. All listings are current as of August 15, 2009. For updated information, visit* www.gearexpo.com.**

AA Gear, LLC	524
ABA-PGT Inc.	1328
ADF Systems Ltd.	1335
Advanced Nitriding Solutions, LLC	1035
Aerocom Industries	1234
AGMA	901
ALD Thermal Treatment, Inc.	806
ALD-Holcroft Vacuum Technologies Co.	806
American Stress Technologies, Inc.	714
Ancon Gear & Instrument Corp.	1136
Arrow Gear Co.	1143
Artec Machine Systems	1106
Ash Gear & Supply	730
Barit International Corp.	1233

Bearings 2000 Sales Co.	1406
Beijing United Chinese Business International Consulting Co. Ltd.	1525, 1527, 1622, 1624, 1626
Bevel Gears India	501
Bluewater Thermal Services	1235
Bodycote Thermal Processing	936
Boneng Transmission Co., Ltd.	1523
Bourn & Koch Machine Tool Co.	741
Brelie Gear Co.	1037
Broach Masters/Universal Gear Co.	735
Broaching Machine Specialties	1501
Canton Drop Forge	1323
Capstan Atlantic	1314
Carl Zeiss IMT Corp.	1507

GEAR EXPO GUIDE

Centric International, Inc.	629
Chamfermatic Inc.	400
Cincinnati Gearing Systems	1202
Circle Gear and Machine Co.	1311
Cleveland Deburring Machine Co.	1308
Clifford-Jacobs Forging Co., Inc.	810
CNC Design Pty. Ltd.	1319
Colonial Tool Group	1341
Compass Automation	432
Comtorgage Corp.	1403
Cornell Forge Co.	1104
Creative Automation Inc.	835
CRI Machining	1511
Davall Gears Ltd.	1318
DixiTech CNC	836
DMG Chicago	541
Doncasters Gear Products	1500
Drake Manufacturing Services Co.	309
DTR Corp.	1315
Eaton Performance Products	433
Eaton Steel Bar Company	1215
Eldec Induction, USA	740
EMAG LLC	413
Emuge Corp.	700
Engineered Abrasives	1310
Engineered Lubricants Co.	1431
Engineered Tools Corp.	908
Erasteel, Inc.	1232
European Technology Center NA	1514
Euro-Tech Corp.	532
Excel Gear, Inc.	641
Fässler Corp.	1111
Fairfield Manufacturing Co., Inc.	1003
First Gear	402
Forest City Gear Co.	507
Forst USA	1244
Fubri SRL	1517
The Gear Machinery Exchange/ gearmachineryexchange.com	1241
Gear Solutions and *Wind Systems* magazines	1103
Gear Technology	414
Gear Technology and *Power Transmission Engineering* magazines	1241
Gearspect	707
GearTec, Inc.	1219
Geiger, Hans-Juergen	800
Gibbs Machinery Co.	601
Gleason Corp.	715

Golden Port International Inc.	1240
Goldstein Gear Machinery LLC	1241
Great Lakes Gear Technologies, Inc.	1011
Great Taiwan Gear Ltd.	726
Halifax Rack & Screw	1206
Hangzhou Chinabase Machinery Co., Ltd.	1007
Hangzhou Ever-Power Transmission Co., Ltd.	1630
Hangzhou Sanp Machinery Co., Ltd.	1529
Hanik Corp.	600
Harbin Tool Works	1519
Havlik Gear	437
Hexagon Metrology	1419
HobSource Inc.	906
Hoffmann Filter Corp.	807
Höfler Maschinenbau GmbH	911
Hydra-Lock Corp.	617
IBC Coating Materials & Technology	1423
IFPE 2011	1211
Induction Heat Treating	811
Induction Tooling, Inc.	801

Industrial Machinery Digest	1434
Ingersoll Cutting Tools	1336
Innovative Rack & Gear Co.	309
Interstate Tool Corp.	1331
IonBond LLC	1322
Ishmeet Forgings Pvt. Ltd.	1326
I-Tech International Corp.	535
J. Schneeberger Corp.	431
Jason Finishing Group – Osborn/Jacksonlea	1422
JRM International Inc.	1133
Kapp Technologies	923
Kisssoft USA LLC	615
Kleiss Gears, Inc.	1223
Klingelnberg GmbH	727
Koepfer America, LLC	413
Li Gear Inc.	1309
Liebherr Gear Technology, Inc.	727
LMS North America	1332
Ludeca Inc.	1334
Luoyang Hongtuo Heavy Gear-box Co., Ltd.	1628

GEAR EXPO GUIDE

Machine Tool Builders Inc.	418
Mahr Federal Inc.	515
McNeil Industries (OLS Deburring Systems)	1515
Metal Improvement Co.	602
Micro Gear	627
Midwest Gear/Penn Machine	1408
Midwest Thermal-Vac Inc.	1107
Mitsubishi Heavy Industries America, Inc. Machine Tool Division	841
Mohawk Machinery Inc.	631
New England Gear	1117
O & D Manufacturing	1316
Parker Industries, Inc.	443
Perry Technology Corp.	1102
PFG Design Services, Inc.	1141
PlaTeg GmbH	1435
Power Transmission Engineering and *Gear Technology* magazines	1241
Precision Gage Company, Inc.	635
Preco Inc.	1606
Presrite Corp.	621
Process Equipment Co.	521
Promess, Inc.	1201
Proto Manufacturing Ltd.	1518
QC American/American Broach & Machine Co.	716
QMS Inc.	1329
R.P. Machine Enterprises, Inc.	401
Raycar Gear & Machine Co.	734
Reishauer Corp.	527
Reliance Gear Corp.	711
REM Chemicals, Inc.	1207
Riley Gear Corp.	1034
Riten Industries Inc.	1401
Rockford Heat Treaters Inc.	1534
Romax Technology Inc.	1036
Roto-Flo & U.S. Gear Tools	1301
RotoMetrics	706
Russell, Holbrook & Henderson	708
S.L. Munson & Co.	526
Saikuni Manufacturing Co. c/o Dreamtec Consulting, LLC	309
Samputensili	741
Scot Forge	1237
Seitz Corp.	1227
SIC Marking USA	1410
Smart Manufacturing Technology	837
Society of Manufacturing Engineers	1306
Solar Atmospheres	1418

St. Louis Gear Co., Inc.	1242
Star SU, LLC	741
Supreme Industrial Works	425
Taylor-Winfield Corp.	1430
The Metal Treating Institute	424
Thermotech, Inc.	1229
Ticona Engineering Polymers	607
Tifco Gage & Gear	530
TMFM, LLC	315
Tokyo Technical Instruments Inc.	1415
Toolink Engineering Inc.	1234
TSA America LLC	609
TW Metals	703
UFE, Inc.	1324
United Gear & Assembly, Inc.	1219
Vancouver Gear Works Ltd.	1134
Vela Gear Systems	1414
Viking Forge Corp.	1225
Virgo Communications & Exhibitions	1503
Walker Forge, Inc.	934
Wiscon Products	427
Woodworth Inc.	834
X-R-I Testing	1307
Y-12 National Security Complex	736
Zhejiang Hengfengtai Reducer Mfg.	701
Zhuzhou Gear Co. Ltd.	1531
ZVL/ZKL Bearings Corp.	935

Exhibitors by Booth Number

See page 39 for these listings arranged by alphabetically by exhibitor. All listings are current as of August 15, 2009. For updated information, visit www.gearexpo.com.

Drake Manufacturing Services Co.	309
Innovative Rack & Gear Co.	309
Saikuni Manufacturing Co. c/o Dreamtec Consulting, LLC	309
TMFM, LLC	315
Chamfermatic Inc.	400
R.P. Machine Enterprises, Inc.	401
First Gear	402
EMAG LLC	413
Koepfer America, LLC	413
Gear Technology	414
Machine Tool Builders Inc.	418

GEAR EXPO GUIDE

The Metal Treating Institute	424
Supreme Industrial Works	425
Wiscon Products	427
J. Schneeberger Corp.	431
Compass Automation	432
Eaton Performance Products	433
Havlik Gear	437
Parker Industries, Inc.	443
Bevel Gears India	501
Forest City Gear Co.	507
Mahr Federal Inc.	515
Process Equipment Co.	521
AA Gear, LLC	524
S.L. Munson & Co.	526
Reishauer Corp.	527
Tifco Gage & Gear	530
Euro-Tech Corp.	532
I-Tech International Corp.	535
DMG Chicago	541
Hanik Corp.	600
Gibbs Machinery Co.	601
Metal Improvement Co.	602
Ticona Engineering Polymers	607
TSA America LLC	609
Kisssoft USA LLC	615
Hydra-Lock Corp.	617
Presrite Corp.	621
Micro Gear	627
Centric International, Inc.	629
Mohawk Machinery Inc.	631
Precision Gage Company, Inc.	635
Excel Gear, Inc.	641
Emuge Corp.	700
Zhejiang Hengfengtai Reducer Mfg.	701
TW Metals	703
RotoMetrics	706
Gearspect	707
Russell, Holbrook & Henderson	708
Reliance Gear Corp.	711
American Stress Technologies, Inc.	714
Gleason Corp.	715
QC American/American Broach & Machine Co.	716
Great Taiwan Gear Ltd.	726
Klingelnberg GmbH	727
Liebherr Gear Technology, Inc.	727
Ash Gear & Supply	730
Raycar Gear & Machine Co.	734

Broach Masters/Universal Gear Co.	735
Y-12 National Security Complex	736
Eldec Induction, USA	740
Bourn & Koch Machine Tool Co.	741
Samputensili	741
Star SU, LLC	741
Geiger, Hans-Juergen	800
Induction Tooling, Inc.	801
ALD Thermal Treatment, Inc.	806
ALD-Holcroft Vacuum Technologies Co.	806
Hoffmann Filter Corp.	807
Clifford-Jacobs Forging Co., Inc.	810
Induction Heat Treating	811
Woodworth Inc.	834
Creative Automation Inc.	835
DixiTech CNC	836
Smart Manufacturing Technology	837
Mitsubishi Heavy Industries America, Inc. Machine Tool Division	841
AGMA	901
HobSource Inc.	906
Engineered Tools Corp.	908
Höfler Maschinenbau GmbH	911
Kapp Technologies	923
Walker Forge, Inc.	934
ZVL/ZKL Bearings Corp.	935
Bodycote Thermal Processing	936
Fairfield Manufacturing Co., Inc.	1003
Hangzhou Chinabase Machinery Co., Ltd.	1007
Great Lakes Gear Technologies, Inc.	1011
Riley Gear Corp.	1034
Advanced Nitriding Solutions, LLC	1035
Romax Technology Inc.	1036
Brelie Gear Co.	1037
Perry Technology Corp.	1102
Gear Solutions and *Wind Systems* magazines	1103
Cornell Forge Co.	1104
Artec Machine Systems	1106
Midwest Thermal-Vac Inc.	1107
Fässler Corp.	1111
New England Gear	1117
JRM International Inc.	1133
Vancouver Gear Works Ltd.	1134
Ancon Gear & Instrument Corp.	1136
PFG Design Services, Inc.	1141
Arrow Gear Co.	1143
Promess, Inc.	1201

GEAR EXPO PREVIEW

Cincinnati Gearing Systems	1202
Halifax Rack & Screw	1206
REM Chemicals, Inc.	1207
IFPE 2011	1211
Eaton Steel Bar Company	1215
GearTec, Inc.	1219
United Gear & Assembly, Inc.	1219
Kleiss Gears, Inc.	1223
Viking Forge Corp.	1225
Seitz Corp.	1227
Thermotech, Inc.	1229
Erasteel, Inc.	1232
Barit International Corp.	1233
Aerocom Industries	1234
Toolink Engineering Inc.	1234
Bluewater Thermal Services	1235
Scot Forge	1237
Golden Port International Inc.	1240
Gear Technology and *Power Transmission Engineering* magazines	1241
Goldstein Gear Machinery LLC	1241
Power Transmission Engineering and *Gear Technology* magazines	1241
The Gear Machinery Exchange/gearmachineryexchange.com	1241
St. Louis Gear Co., Inc.	1242
Forst USA	1244
Roto-Flo & U.S. Gear Tools	1301
Society of Manufacturing Engineers	1306
X-R-I Testing	1307
Cleveland Deburring Machine Co.	1308
Li Gear Inc.	1309
Engineered Abrasives	1310
Circle Gear and Machine Co.	1311
Capstan Atlantic	1314
DTR Corp.	1315
O & D Manufacturing	1316
Davall Gears Ltd.	1318
CNC Design Pty. Ltd.	1319
IonBond LLC	1322
Canton Drop Forge	1323
UFE, Inc.	1324
Ishmeet Forgings Pvt. Ltd.	1326
ABA-PGT Inc.	1328
QMS Inc.	1329
Interstate Tool Corp.	1331
LMS North America	1332
Ludeca Inc.	1334

ADF Systems Ltd.	1335
Ingersoll Cutting Tools	1336
Colonial Tool Group	1341
Riten Industries Inc.	1401
Comtorgage Corp.	1403
Bearings 2000 Sales Co.	1406
Midwest Gear/Penn Machine	1408
SIC Marking USA	1410
Vela Gear Systems	1414
Tokyo Technical Instruments Inc.	1415
Solar Atmospheres	1418
Hexagon Metrology	1419
Jason Finishing Group – Osborn/Jacksonlea	1422
IBC Coating Materials & Technology	1423
Taylor-Winfield Corp.	1430
Engineered Lubricants Co.	1431
Industrial Machinery Digest	1434
PlaTeg GmbH	1435
Doncasters Gear Products	1500
Broaching Machine Specialties	1501
Virgo Communications & Exhibitions	1503
Carl Zeiss IMT Corp.	1507
CRI Machining	1511
European Technology Center NA	1514
McNeil Industries (OLS Deburring Systems)	1515
Fubri SRL	1517
Proto Manufacturing Ltd.	1518
Harbin Tool Works	1519
Boneng Transmission Co., Ltd.	1523
Hangzhou Sanp Machinery Co., Ltd.	1529
Zhuzhou Gear Co. Ltd.	1531
Rockford Heat Treaters Inc.	1534
Preco Inc.	1606
Luoyang Hongtuo Heavy Gear-box Co., Ltd.	1628
Hangzhou Ever-Power Transmission Co., Ltd.	1630
Beijing United Chinese Business International Consulting Co. Ltd.	1525
Beijing United Chinese Business International Consulting Co. Ltd.	1527
Beijing United Chinese Business International Consulting Co. Ltd.	1622
Beijing United Chinese Business International Consulting Co. Ltd.	1624
Beijing United Chinese Business International Consulting Co. Ltd.	1626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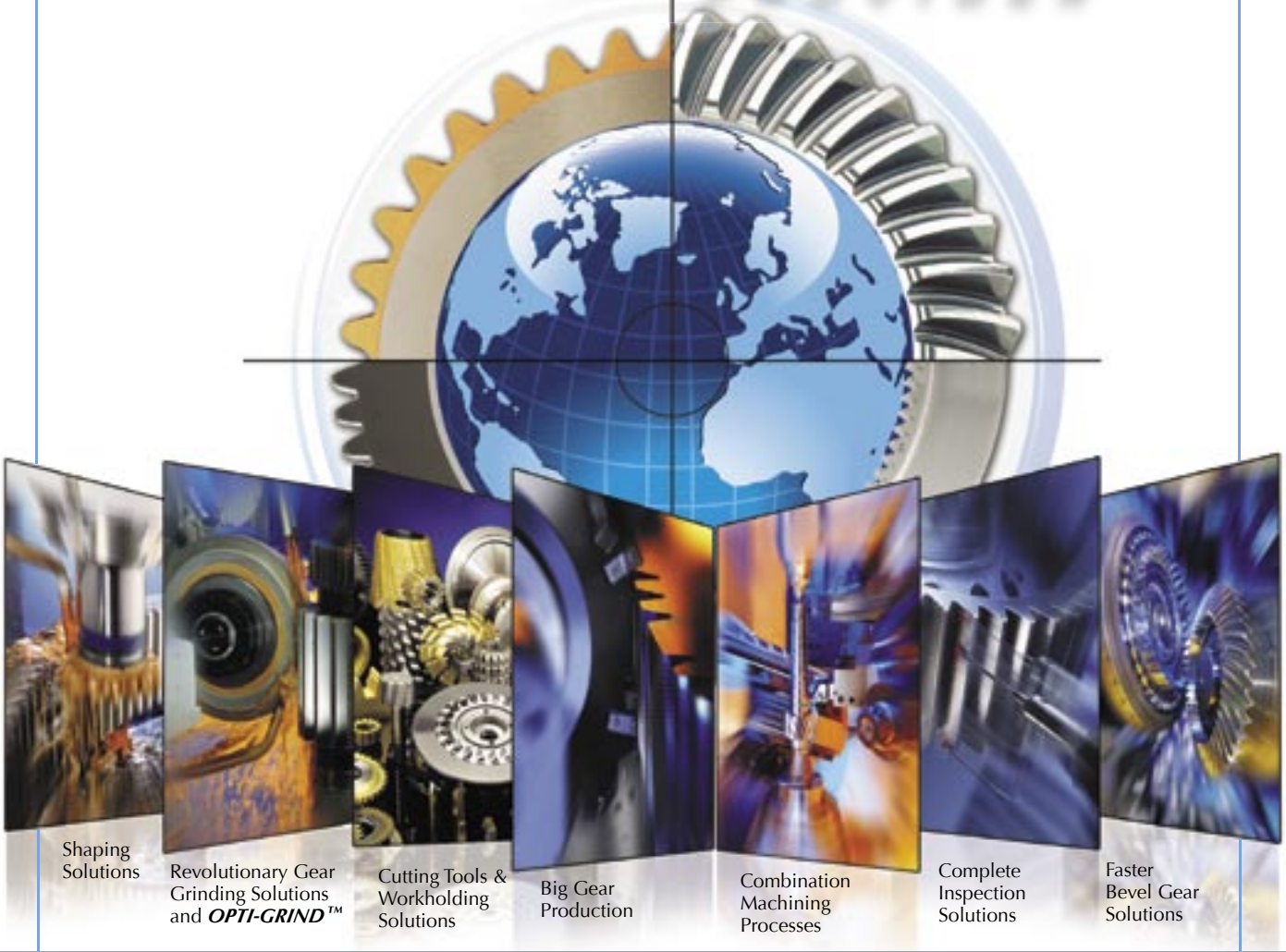

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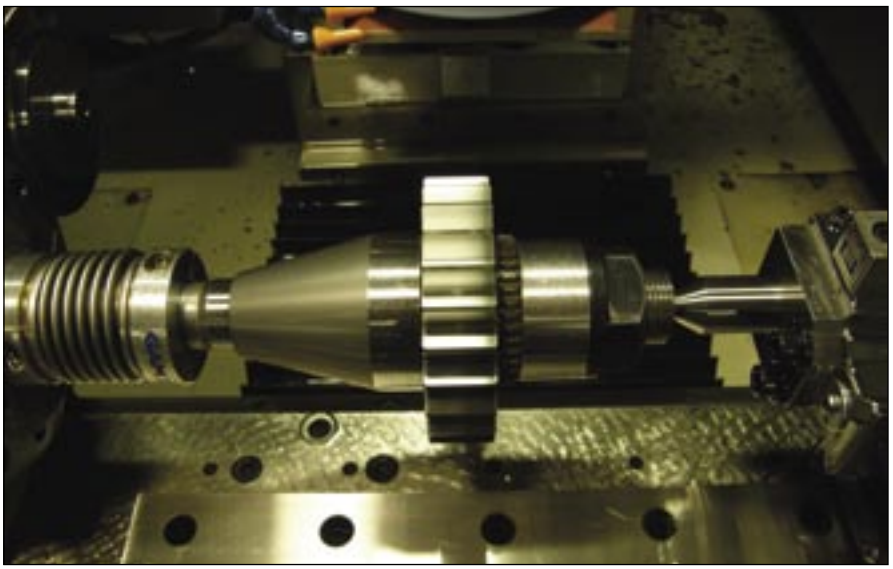
So when Sprint Cup teams build cars, there's one transmission firm on the short list: G-Force Transmissions. Long's Machine and Tool, headquartered in Cleona, PA is the parent company of G-Force Transmissions and Long's Shifters. Since 1979, they've developed an excellent reputation with oval track and drag racers, becoming the largest custom stick shift transmission builder in the country. Up to half of all Sprint Cup teams on any given Sun day are running with G-Force transmissions. Many NHRA professionals and Sportsmen's Class

continued

Kasey Kahnes, #9, Richard Petty Motorsport. Sprint Cup car running with a G-Force transmission.

Kevin Harvick's first victory with his Nationwide car running with a G-Force transmission.

Drake GS:G2 Linear Motor Profile Gear Grinder.



Transmission gear in machine for G-Force Transmission.

Typical Menu Entries - Drake GearSmart™ Program

NUMBER OF TEETH	000	DIAMETRAL PITCH	00
		MODULE	00
FACE WIDTH	0.0000	HELICAL ANGLE	00.000
BLANK O.D.	0.0000	TIP MOD	0.00000
TOTAL DEPTH	0.0000	CROWN	0.00000
WHEEL DIA	00.00	FIN STOCK	0.0000
RUF PASSES	00	FIN PASSES	00
RUF WHEEL SFM	00000	FIN WHEEL SFM	00000
RUF WORK SFM	000	FIN WORK SFM	00
DRESS COUNT	00	DRESS WHL SFM	0000
DRESS AMOUNT	0.0000	DRESS FEED IPM	00

Drake *GearSmart* software menu entries. Operators enter values and software converts it into a part program.

drag racers also rely on G-Force transmissions.

The reason is simple. G-Force focuses on quality and performance. Prototypes are tested in the company's own race cars before they enter production. Each production transmission is continually checked and rechecked throughout the machining and assembly process.

All G-Force transmission gears are made from 9310 VAR (vacuum arc remelt) steel, which produces a stronger internal structure and improves gear strength. Processing steps on gears are hob, heat treat and grind.

When it came time to improve production on these gears, Long's Machine and Tool looked for a machine tool builder who shared their commitment to quality.

Lew Reinbold, manufacturing manager, said, "We were looking for an American builder who really understood gear making and was easy to deal with. We manufacture in small quantities and change jobs frequently, so we needed a profile grinder that was easy to set up, easy to operate and that was capable of holding our tight tolerances all day long."

After considering several builders, they settled on Drake Manufacturing of Warren, OH. The machine they picked was the Drake GS:G2 4-Axis Linear Motor Profile Gear Grinder.

No Programming Required

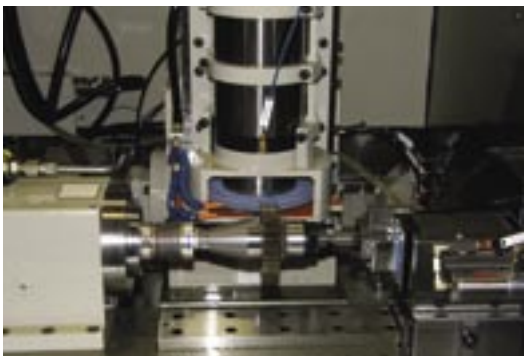
The runoff at the plant proved the machine could do the job, but it was Drake's programming service that really impressed Reinbold. "Drake was able to program our gear processing information into the control—even rewriting the menu prompts, so they read just like our gear data sheets. They even rewrote the software modules to change involute profiles and tip modifications to our specifications. By entering our data into the on-screen menus, we can set up and program a new job in 15 minutes or less."

GearSmart is the name Drake gives to its gear processing software. All Drake gear grinders (as well as rack mills, external, universal and thread grinders) are programmed before delivery to run customers' specific parts. Dressing forms, grind paths, spindle and work rpm are generated based on the operator's menu inputs. Menu prompts are based on specific customers' existing terminology. Operators just fill in the values. No customer programming knowledge is required.

Two AGMA Classes Better than Expected

As for repeatability, Reinbold

continued



A gear ready to be ground in Drake GS: G2 Gear Grinder.

explains, "The Drake grinder is very thermally stable, varying no more than 50 millionths from one gear to the next. We grind our gears to DIN standard 3962, looking for Q4. But in almost all cases, we achieve Q1 to Q2, which is 2–3 classes better."

Linear motor axis positioning with 0.05 µm-resolution linear scale feedback helps the G2 achieve its accuracy. Its mineral-filled, cast polymer base contributes significantly by damping vibration and controlling thermal growth. Also enhancing accuracy is the machine's direct-drive synchronous torque motor that controls C-axis positioning. It has an 8-million-count encoder providing feedback resolution of 0.2 arc seconds and guaranteed index accuracy better than 10 arc seconds.

Acoustic Emissions Monitoring

The Drake G2 grinder is equipped with an acoustic emissions (AE) stock dividing system that automatically locates the rough-cut gear teeth and positions the wheel spindle to grind equal amounts of stock from adjacent gear teeth.

Close up of a G-Force transmission gear.

Dyno Tests

Independent testing of G-Force transmissions, subsequent to the addition of ground gears, showed improvements in durability and a reduction in gear noise and vibration. Parasitic drag tests indicated less horsepower is taken from the engine by the transmission, meaning more power is available at the wheel.

While credit must be given to G-Force's team of designers, the pay-off is reserved for the gears they produce on the Drake GS:G2 Gear Grinder.

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Comparison of PM-HSS and Cemented Carbide Tools in High-Speed Gear Hobbing

Fritz Klocke, Philipp Kauffmann,
Rolf Schalaster and Arne Stuckenberg

Management Summary

This article examines the dry hobbing capabilities of two cutting tool materials—powder metallurgical high-speed steel (PM-HSS) and cemented carbide. Cutting trials were carried out to analyze applicable cutting parameters and possible tool lives as well as the process reliability. To consider the influences of the machinability of different workpiece materials, a case hardening steel and a tempered steel were examined. The results of the cutting trials show that carbide tools are superior to PM-HSS tools. When machining case hardening steel, the advantage is the high productivity. When machining tempered steel, a longer tool life can be reached. This shows that carbide offers higher potentials for gear hobbing.

Introduction

For green machining of external gears, dry hobbing with PM-HSS and cemented carbide are established processes in the industry. Although some have investigated the use of cermets for gear hobbing, these materials are not an alternative to PM-HSS or cemented carbide. Cermets do not provide any advantage compared to carbides regarding productivity, tool life or process reliability. Because of the high expected tool cost, they can not be used economically for gear hobbing.

Focusing again on the common cutting materials PM-HSS and cemented carbide, the question came up: Which are the most effective cutting conditions for which cutting material? Today's hobs combined with modern, hard material coatings are able to reach high productivity and tool life. Typically, carbide tools can be used at high cutting speeds, while the advantages of PM-HSS are relatively low tool costs and high chip thicknesses.

The goal of this study is to evaluate the potentials of the cutting materials PM-HSS and cemented carbide for gear hobbing. For this, applicable cutting parameters, resulting tool lives and estimated manufacturing costs will be considered.

For the trials, the case hardening steel 16MnCr5 and the tempered steel 42CrMo4V are compared. The case hardening steel has a strength of R_m = 570 N/mm², and the tempered steel has a strength of R_m = 1,090 N/mm². The real trials were made in an analogy process for gear hobbing. In these trials, a single fly-cutter was used, and through the kinematics of the machine tool, the full hob was simulated. The tool simulated a hob with a module of 2.5 mm, 15 gashes and 2 starts. The examined gear is typical of the automotive sector. All tools were coated with an aluminum chrome nitride coating (Al,Cr)N.

Wear Development and Performance of the Applied Cutting Materials

Generally, for the case hardening steel, higher cutting parameters can be chosen due to the lower strength of the workpiece material. With carbide tools, higher cutting speeds

continued

Tool:
PM-HSS: HS 10-2-5-8
carbide: HF K30F
coating: (Al,Cr)N
m_n = 2.5 mm
α_{n0} = 20°
d_{a0} = 80 mm
z_0 = 2; right
n_i = 15

Workpiece:
material: 16MnCr5N
R_m = 565 N/mm²
z_2 = 48
b = 25 mm
β_2 = 24.62°; right

Reduction Factors
$L_{real}/L_{analogy}$ (empirical):
PM-HSS: 50 %
HM: 33 %

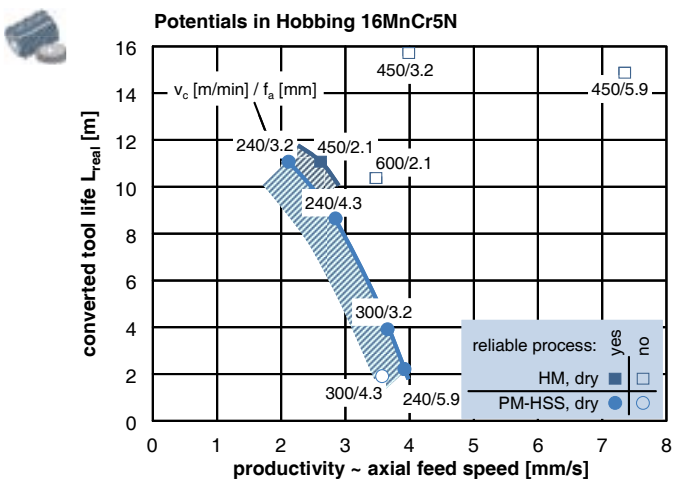

Figure 1—Potentials in machining case hardening steel 16MnCr5N.

can be reached because of their high warm strength. In contrast PM-HSS has a higher toughness, and so higher axial feed usually can be chosen.

For the rating of a cutting tool, two different properties are required. One is the tool life, and the other is the reliability. The process must be reliable against sudden chipping at the cutting edge. Carbide tools are especially at risk of getting damaged—not only during the cutting operation, but also by mishandling—due to their high brittleness.

The investigations in wear development showed that for machining the case hardening steel with the carbide tools, a cutting speed of v_c = 450 m/min and an axial feed of 2.1 mm can be reached reliably, as seen in Figure 1.

The converted tool life shown on the vertical axis is reduced by an empiric factor for the conversion of results from the analogy trials to real hobbing operations. This factor was already determined in former trials. The main wear characteristic is flank wear. With higher cutting parameters, even higher tool life can be realized, but the process is not reliable.

For a reliable machining operation with PM-HSS as cutting material, lower cutting speeds have to be chosen, but higher axial feeds are possible. A view on the wear behavior of PM-HSS shows that the defined wear criterion of VB_{max} = 0.15 mm is reached by the flank and the root almost at the same time. In general, PM-HSS allows for a wider range of parameters to be used, whereas for carbide, only a very small range of cutting parameters leads to reliable processes. However, when considering the productivity in combination with the tool life, PM-HSS offers only a small range as well. Overall, the carbide has a slight advantage against the PM-HSS because of carbide's high productivity and tool life.

For machining tempered steel, similar effects can be seen. But the reachable cutting parameters for both the carbide and PM-HSS tools are lower due to the higher strength of the 42CrMo4V (Figure 2). With the PM-HSS tools, gears can only be machined reliably with cutting speeds of v_c < 120 m/min. With carbide tools, higher axial feeds result in huge cracks that make the process unreliable. The reliable and therefore usable area of cutting parameters is marked shaded. Concerning the productivity, tempered steel should be machined with carbide because of the much higher reachable tool life and an equal productivity, as measured by the axial feed speed.

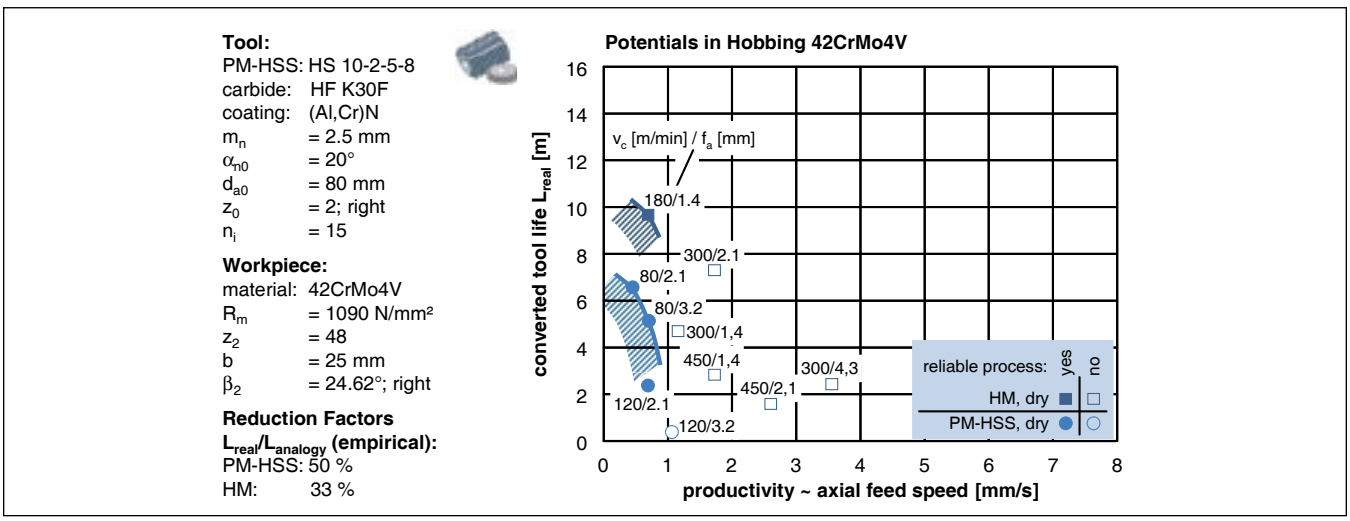

Figure 2—Potentials in machining tempered steel 42CrMo4V.

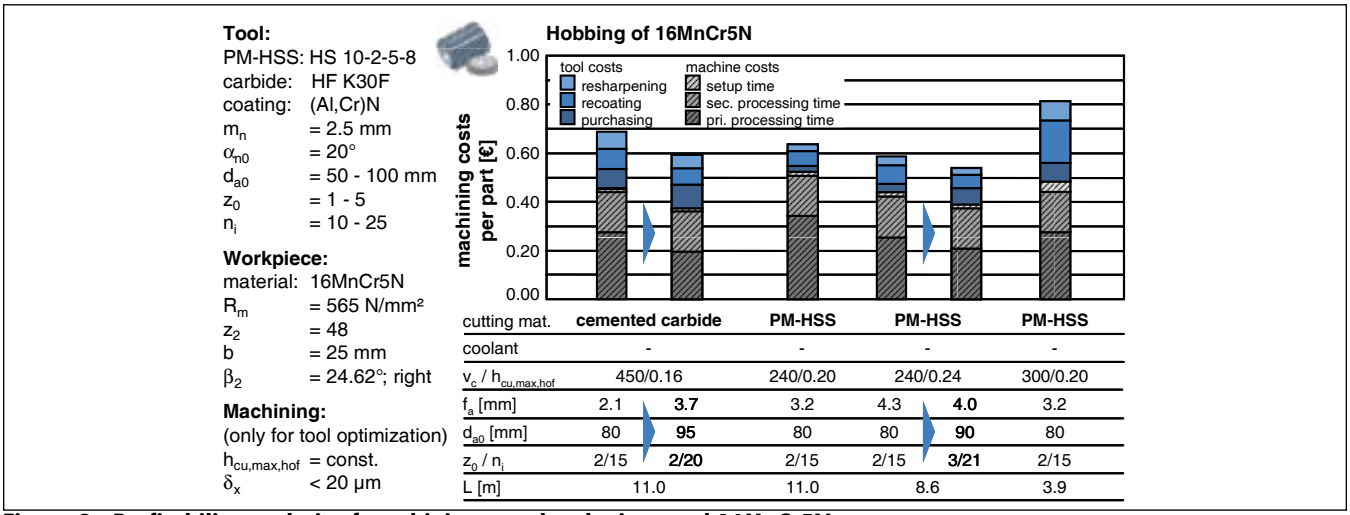

Figure 3—Profitability analysis of machining case hardening steel 16MnCr5N.

Economic Analysis

For deciding which cutting material is preferable, not only the productivity and the tool life are important, but also the tool costs. Generally the tool costs for a PM-HSS hob are lower. The tool costs consist of three parts: the purchase cost, the recoating cost and the resharpening cost. The recoating and resharpening costs are especially important in the economic analysis of hobbing tools.

The costs for recoating are similar for both cutting materials. But the purchase costs and the resharpening costs, due to the strength, are higher for carbide tools. For a closing analysis regarding which is the best tool, the total costs of ownership are interesting.

For the material 16MnCr5, an analysis on the profitability is shown in Figure 3. Starting with the investigated parameters in the analogy process trials, the process is successively optimized with gear hobbing calculation software. The first, third, fourth and sixth column each show the machining cost per part for cutting parameters used in the trials. The cost per part for PM-HSS at medium cutting speed (third and fourth columns) is already without any optimization lower than for machining with carbide.

Only the PM-HSS trial with very high cutting speeds (sixth column) is not competitive. With the results of the trials, an optimization is made with the target of an axial feed rate with feed marks of $d_X < 20$ µm and a constant maximum chip thickness for each cutting parameter. The tool outside diameter and number of starts and gashes is varied. With these default values, the software calculates every tool design which achieves these requirements. The result is again lower costs per part and still the lowest overall cost for a PM-HSS variant.

For tempered steel (not displayed here), the situation is just the other way around. For tempered steel, machining with carbide leads to lower costs per part.

Conclusion

Based on the current state of the art regarding tool development, the capabilities of PM-HSS and cemented carbide have been examined as materials for gear hobbing. Cutting trials were carried out in fly-cutter gear hobbing to analyze applicable cutting parameters and possible tool lives as well as the process reliability. To consider the influences of the machining properties of cutting different workpiece materials, a case hardening steel with a tensile strength of R_m = 570 N/mm² and a tempered steel with R_m = 1,090 N/mm² have been examined.

Machining case hardening steel has shown that a cutting speed of v_c = 450 m/min can be reached employing carbide tools at relatively low axial feeds. A high tool life can be reached reliably using these parameters. Enhanced machining parameters may lead to an increased tool life, but the fly-cutters fail because of breakouts of the cutting edge.

By the application of PM-HSS at a cutting speed of v_C = 240 m/min and medium axial feeds, an appropriate tool life can be reached. By raising the cutting speed or the axial feed beyond these values, heavy crater wear causes reductions in tool life.

To reach acceptable tool lives reliably in machining tempered steel, the cutting parameters must be reduced significantly for both cutting materials because of the high mechanical and thermal load.

With the carbide cutting material, tool lives that are similar to those achieved when machining case hardening steel can be achieved.

The results of the cutting trials show that carbide tools are superior to PM-HSS tools. When machining case hardening steel, the advantage is the high productivity. When hobbing tempered steel, a longer tool life can be reached. This shows that carbide basically offers higher potentials for gear hobbing.

However, the economic analysis shows that both cutting materials can be employed at similar machining costs. A trend can be identified that the application of high speed steel is slightly cheaper for machining case hardening steel while carbide tools offer advantages in cutting tempered steel.

The study shows that PM-HSS and carbide tools are capable of hobbing in a similar way. Carbide tools offer high productivity and good tool life while PM-HSS shows very low tool costs. Basically, PM-HSS hobs can be used beneficially to cut materials with lower hardness and tensile strengths, while tougher materials should be machined with carbide tools. However, the machinability of actual gears in an industrial environment is also affected by the specific tooth profile and the workpiece material.

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Gear Corrosion During the Manufacturing Process

Omer El-Saeed, Gary Sroka and Gregory Blake

Management Summary

No matter how well gears are designed and manufactured, gear corrosion can occur that may easily result in catastrophic failure. Since corrosion is a sporadic and rare event and often difficult to observe in the root fillet region or in finely pitched gears with normal visual inspection, it may easily go undetected. This paper presents the results of an incident that occurred in a gear manufacturing facility several years ago that resulted in pitting corrosion and intergranular attack (IGA). It showed that superfinishing can mitigate the damaging effects of IGA and pitting corrosion, and suggests that the superfinishing process is a superior repair method for corrosion pitting versus the current practice of glass beading.

Introduction

Pitting corrosion. Pitting is one of the most insidious forms of corrosion; it can cause failure by perforation while producing only a small weight loss on the metal. Also, pits are generally small and often remain undetected. A small number of isolated pits on a generally uncorroded surface are easily overlooked. A large number of very small pits on a generally uncorroded surface may not be detected by visual examination, or their potential for damage may be underestimated. When pits are accompanied by slight or moderate general corrosion, the corrosion products often mask them (Ref. 1).

Surface pitting is often barely visible even at 10–30X magnification. The corroded region below the surface can be much larger than indicated by the surface area of the pit. ASTM G46, Standard Guide for Examination and Evaluation of Pitting Corrosion (Ref. 1), states:

"Pits may have various sizes and shapes. A visual examination of the metal surface may show a round, elongated or irregular opening, but it seldom provides an accurate indication of corrosion beneath the surface. Thus, it is often necessary to cross section the pit to see its actual shape and to determine its true depth."

For example, the G46 standard presents a chart of possible variations in the cross-sectional shapes of corrosion pits (Fig. 1). Consequently, just one insignificantly appearing narrow pit could ultimately lead to bending fatigue failure.

Crevice corrosion. Crevice corrosion is a localized form of corrosion that occurs in narrow openings or spaces where the localized chemical environment is different than that of its surroundings. The change in the crevice chemical environment can be caused by a depletion of the inhibitor or the oxygen, a shift to acid conditions or a buildup of aggressive ion species in the crevice. Crevice corrosion commonly occurs under washers, seals, threads and surface deposits. When the chemical environment within the crevice is different than that of its surroundings, an electrochemical cell is created, resulting in corrosion that can be as damaging as pitting corrosion.

Intergranular corrosion. Another type of corrosion attack is intergranular or intercrystalline corrosion, during which a small volume of metal is preferentially removed from paths that follow the structural dissimilarities along grain boundaries to produce fissures or cracks. The same kind of subsurface fissures can be produced by transgranular or transcrystalline corrosion. In this a small volume of metal is removed in preferential paths that proceed across

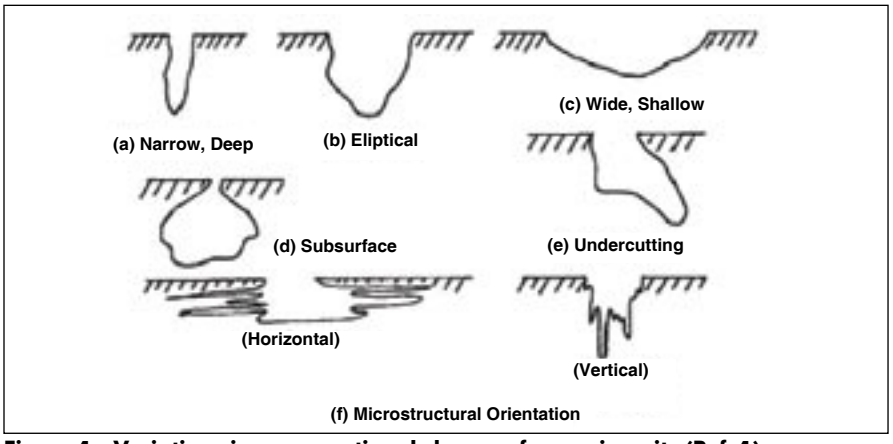

Figure 1—Variations in cross-sectional shapes of corrosion pits (Ref. 1).

or through the grains. Intergranular and transgranular corrosion sometimes are accelerated by tensile stress. In extreme cases the cracks proceed entirely through the metal, causing rupture or perforation. This condition is known as stress corrosion cracking (SCC) (Ref. 1).

Nguyen, et al. (Ref. 2) in an earlier paper discussed why gears are very susceptible to corrosion during the manufacturing process. In order to protect workers and the environment, the use of oil-based rust preventives and rust-inhibiting machining coolants have been minimized. The gear manufacturing process is complex, and requires machining, plating, carburization, grinding, plating removal and nital etch inspection, often followed by glass beading or shot peening. During this entire process, gears are often left exposed to the environment for several weeks without the use of rust preventives. They are handled by a number of personnel and experience many back-and-forth trips between the shop floor and the metrology laboratory.

Aerospace gears require state-of-the-art design and precision manufacturing to meet the needs of today's performance demands. Having said that, all of the efforts can be for naught if pitting and intergranular corrosion occur. Such corrosion can lead to disastrous, premature failure. The severity of the problem will be illustrated with two actual experiences described in detail in Part I and Part II of this paper. Part I is a short experiment to answer the question whether or not one drop of sweat inadvertently falling on an aerospace gear could result in serious damage. Part II discusses a study of IGA and pitting corrosion that was detected on aerospace gears, and the ability of superfinishing to remove this damage.

Part I: Unexpected Low-Cycle Bending Fatigue Failure

Recently, the Aerospace Research Bloc at the Gear Research Institute of The Pennsylvania State University conducted a study of bending fatigue performance of AMS 6308 test gears (Ref. 3). (AMS 6308 is commercially available as Carpenter's Pyrowear 53 and Latrobe's Lesco 53.) Several gears experienced unexpected low-cycle bending fatigue failure, and the root cause was determined to be corrosion pits in the root fillet region. The disturbing part of this finding is that the pitting was not visible to the naked eye, and could only be seen at 30X magnification. Consequently, these pits escaped the manufacturer's as well as the testing laboratory's inspections.

Since aerospace gears lack rust preventives during portions of the manufacturing cycle, one might question whether or not one drop of sweat inadvertently falling on a gear could cause major corrosion problems—leading to premature bending fatigue failure.

Test procedure

Test specimens: Because of their ready availability, Falex AMS 6260 (E-9310) Steel V-Blocks (Part # 000-502-024) having a 58–60 HRC were chosen as test specimens. These were cleaned of their rust preventive using a non-chlorinated solvent (carburetor cleaner) followed by acetone, as recommended by Falex. A drawing of the V-Block is shown in Figure 2. One of the V-Blocks was left in the ground (as-received) condition. See Table 1 for the surface roughness values of the ground V-Block and Figure 3 for the surface profile.

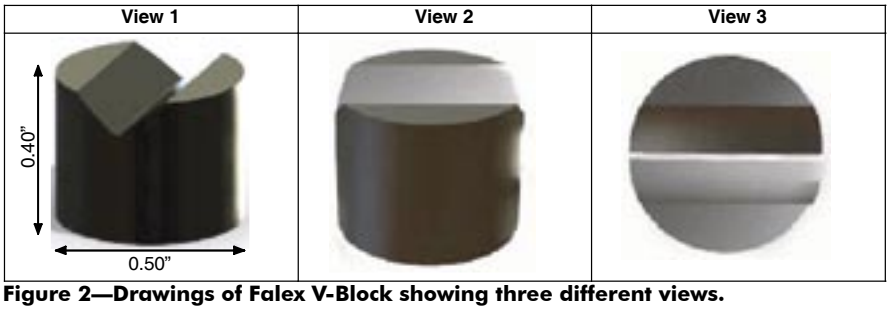

Figure 2—Drawings of Falex V-Block showing three different views.

Table 1—Surface parameters of the ground V–Block

Surface parameter	µin
R_a	7.6
R_z	54.1
R_{max}	58.4

Table 2—Surface parameters of the superfinished Falex V–Block

Surface parameter	µin
R_a	3.1
R_z	23.0
R_{max}	28.5

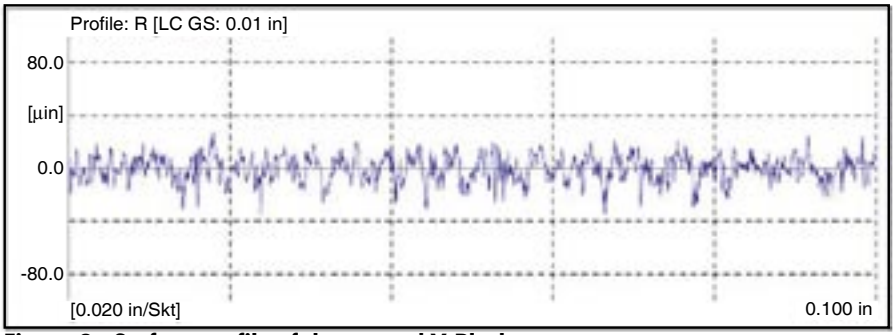

Figure 3—Surface profile of the ground V-Block.

Another V-Block was superfinished. See Table 2 for the surface roughness values of the superfinished V-Block, and Figure 4 for the surface profile.

The process used to superfinish the V-Block was chemically accelerated vibratory finishing, and has been described in detail elsewhere (Refs 4–5). A brief description of the process follows.

The superfinishing process. The unique and significant feature of the process is the surface leveling/smoothing mechanism utilized to achieve the surface finish. A reactive chemistry is used in the vibratory machine in conjunction with the media. When introduced into the machine, this chemistry

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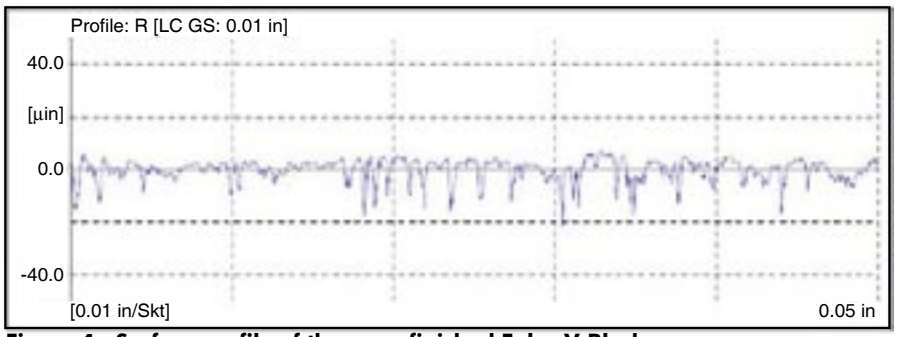

Figure 4—Surface profile of the superfinished Falex V-Block.

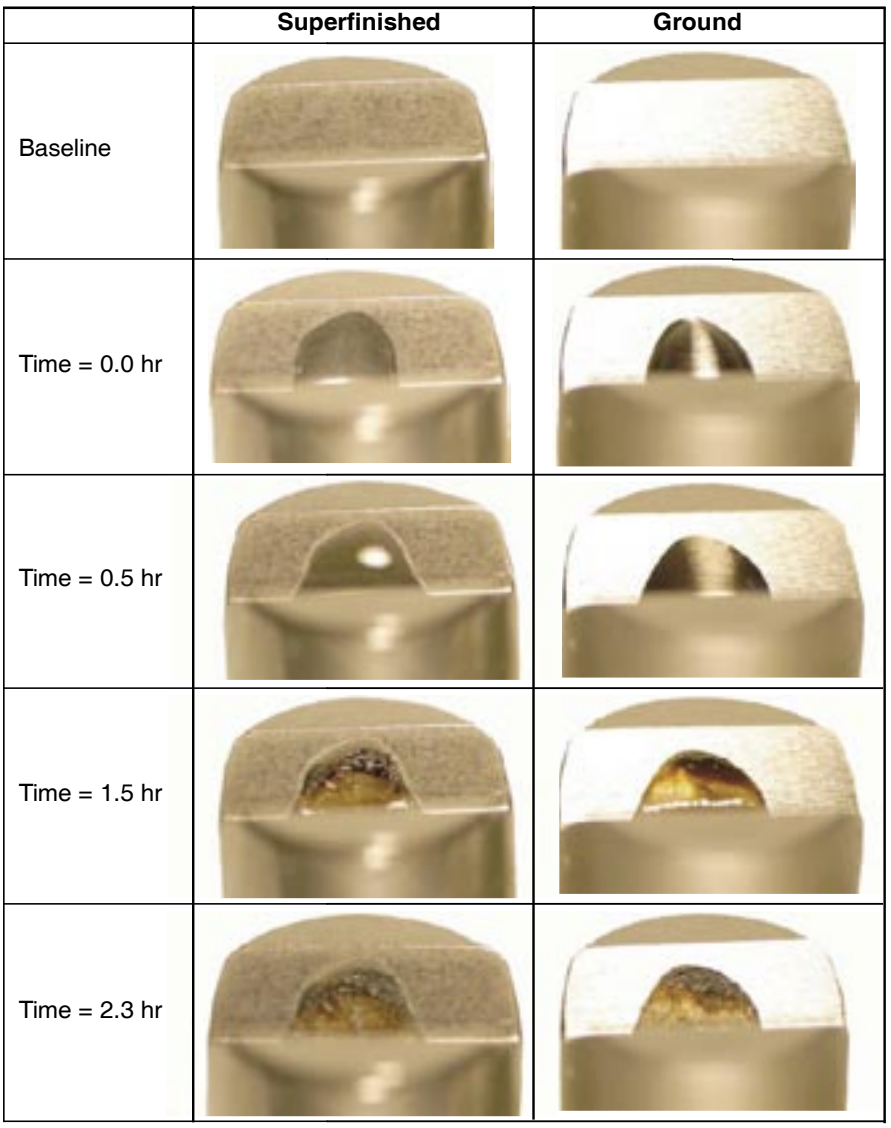

Figure 5—View 2: Photographs of a superfinished (l) and ground V-Block (r) with one drop of artificial sweat deposited on the surface.

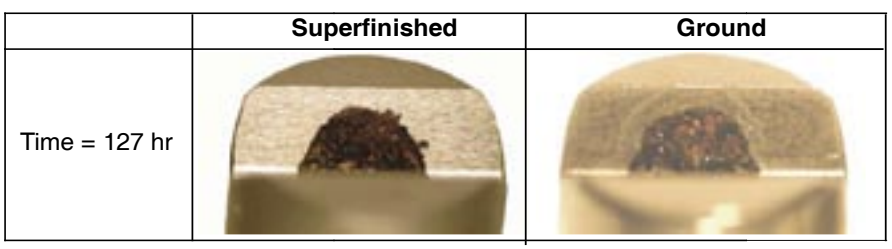

Figure 6—View 2: Photograph of the superfinished (L) and ground V-Block (R) surface after 127 hours.

produces a stable, soft conversion coating across the asperities (peaks and valleys) of the gears. The rubbing motion across the gears developed by the machine and media effectively wipes the soft conversion coating off the "peaks" of the gear's surfaces, thereby removing a microlayer of metal. The "valleys" are left untouched since the media bridges over them and cannot wipe the conversion coating. The conversion coating is continually reformed and wiped off during this stage, producing a surface leveling/smoothing mechanism. This mechanism is continued in the vibratory machine until the surfaces of the gears are free of asperities. At this point, the reactive chemistry is rinsed from the machine with a neutral soap. The conversion coating is wiped off the gears one final time to produce the mirror-like surface.

Artificial sweat. ISO 3160-2 gives a formula for artificial sweat. It consists of 20 g/L sodium chloride (NaCl), 17.5 g/L ammonium chloride (NH_4Cl), 5 g/L urea (NH_2CONH_2), 5 g/L acetic acid (CH_3COOH) and 15 g/L racemic lactic acid ($CH_3CH(OH)COOH$) with the pH adjusted to 4.7 by NaOH.

Procedure. One drop of artificial sweat was placed on the test region of a superfinished V-Block and a ground V-Block. The specimens were then allowed to set in an air-conditioned office exposed to the atmosphere, and were examined as time progressed.

Results. Surprisingly, serious corrosion was observed in only 1.5 hours. After 2.3 hours the artificial sweat appeared dried, and a heterogeneous deposit was observed on each specimen, giving the impression that conditions were ripe for crevice corrosion attack (Fig. 5).

After 127 hours, heavy corrosion products were observed on the surface of the V-Block specimens. The layer appeared thicker on the ground versus the superfinished surface (Fig. 6).

This layer was mechanically removed; the V-Block was polished with 1,500-grit paper to remove the greater part of the corrosion deposits. The surface was then cleaned with

#0000 steel wool, followed by ultrasonic cleaning in a mildly caustic solution. Pitting corrosion, crevice corrosion and IGA were observed on both the superfinished surface and ground surface (Figs. 7–8).

Conclusions.

1. A single drop of sweat has the potential to cause serious corrosion damage on aerospace gears.

2. Corrosion pits that are only visible under 30X magnification can cause low-cycle bending fatigue, as reported by the Aerospace Bloc. Therefore, one drop of sweat inadvertently falling on a gear can result in premature failure.

3. In this study, the superfinished and the finely ground surfaces were equivalent with regards to corrosion resistance.

4. Currently, production aerospace gears are not scrupulously examined in their root fillet area using 30X magnification. It is suggested that aerospace gear corrosion warrants further investigation.

Part II: IGA and Pitting Corrosion During Manufacturing

In 2000, Rolls-Royce Corp. sent used/scrap carburized AISI 9310 gasifier train gearshafts to REM Chemicals, Inc. for edge radiusing (Fig. 9).

The gearshafts were superfinished using chemically accelerated vibratory finishing (Fig. 10) as described elsewhere (Refs. 4-5).

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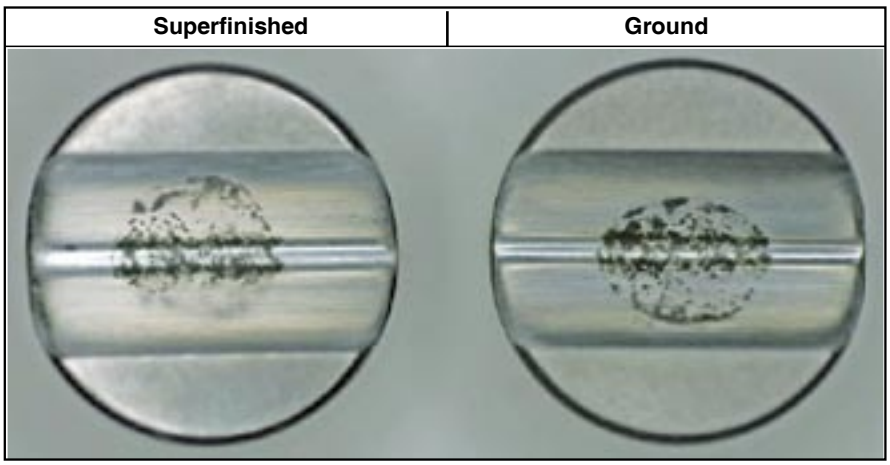

Figure 7—View 3: Superfinished (l) and ground (r) after mechanical cleaning, showing residual corrosion.

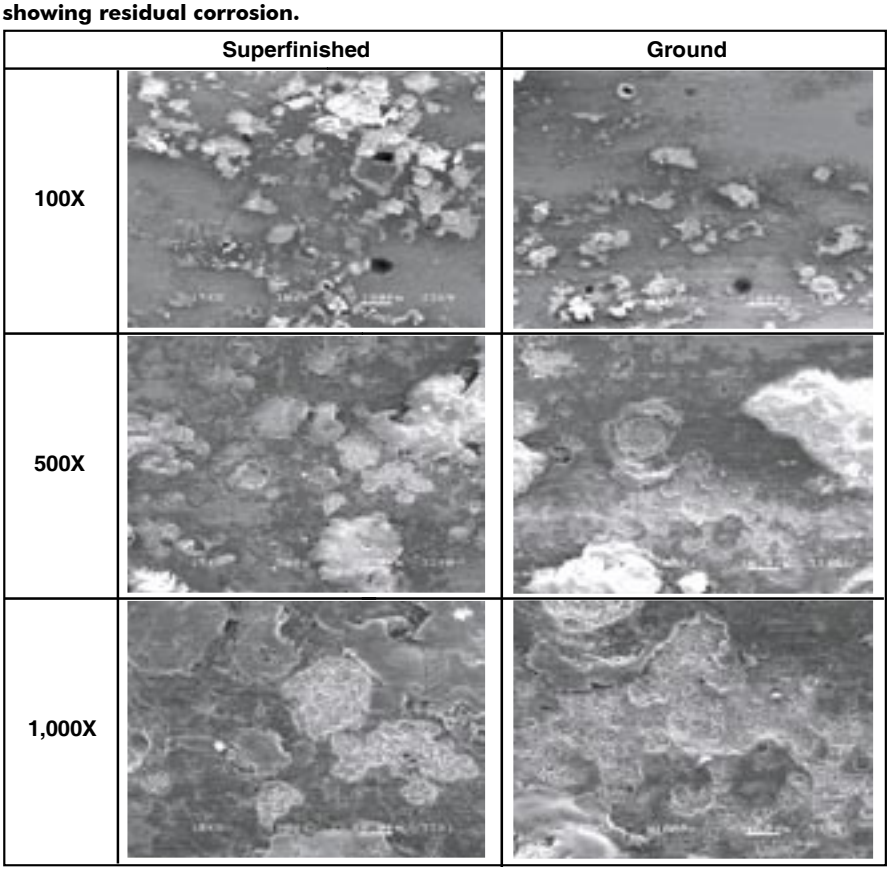

Figure 8—SEM images of test specimens after mechanical cleaning. Superfinished (l) and ground (r). Deep pits are visible in the 100X images. The white deposits cover shallower pits. IGA cracks are visible in the 1000X images.

Figure 9—As-received used/scrap carburized AISI 9310 gasifier train gearshaft.

Figure 10—Superfinished used/scrap carburized AISI 9310 gasifier train gearshaft.

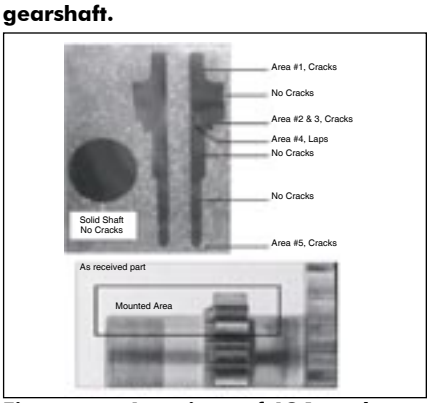

Figure 11—Locations of IGA and contact damage on gearshaft sections (top) taken from the gearshaft (bottom).

Superfinishing occurs in a mildly acidic medium. Consequently, the superfinished gearshafts were rigorously inspected for metallurgical damage upon return to Rolls-Royce. Surprisingly, intergranular attack (IGA) and surface microcracks were detected, and these were initially attributed to the superfinishing process. REM conducted their own inspection of a non-superfinished, scrap/used gearshaft at a metallurgical laboratory (Anderson & Associates, Houston, TX). The gearshaft was sectioned, polished, and examined. IGA as well as other surface damage were found proving that the damage was produced during the manufacturing process prior to superfinishing. Figure 11 shows the sections and the target inspection areas. Photomicrographs of the various areas are shown in Figures 12–16.

In order to demonstrate that the superfinishing process did not cause IGA, a Falex 9310 V-Block was superfinished under the same conditions as the AISI 9310 gearshaft. The V-Block was sectioned, polished and the V-area was examined. The photomicrographs showed no IGA or pitting (Fig. 17). This definitively confirmed that superfinishing does not induce IGA.

Once it was proven the superfinishing process does not induce IGA or pitting on AISI 9310, Rolls-Royce then questioned whether it would remove the IGA or exacerbate the problem by deepening the cracks. The reason for the latter question stems from the acidic chemicals used in the superfinishing process. In this process, the refinement chemistry creates a coating on the gears that is continuously wiped off by the media. However, the media only removes the peaks, leaving the valleys of the metal surface untouched. Metallurgists often expressed concerns that the acidic chemistry had the potential to cause corrosion in the valleys of the metal surface. This was a reasonable concern, eight years ago, when the superfinishing process was being introduced to the aerospace gear industry.

To investigate this concern, Rolls-Royce provided REM with another gearshaft that had IGA for further evaluation (Fig. 18).

The gearshaft was sectioned, polished, and examined. SEM images confirmed the presence of IGA (Fig. 19).

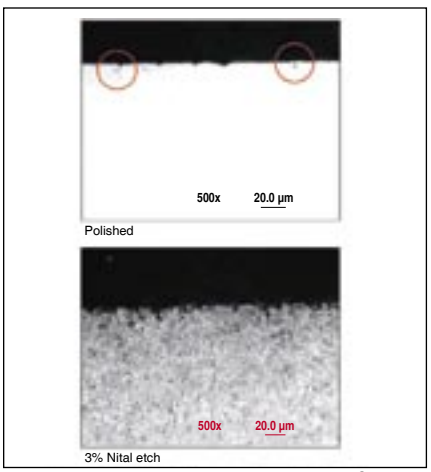

Figure 12—Photomicrographs of Area 1 at 500X magnification. Circles show several IGA cracks.

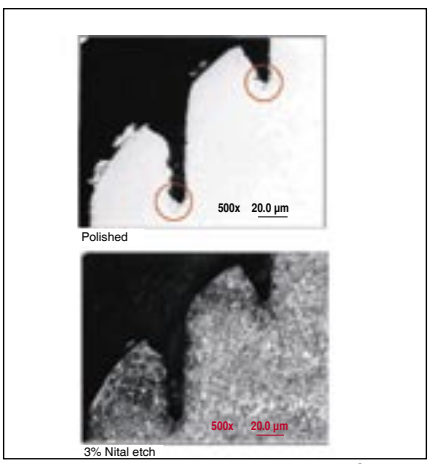

Figure 14—Photomicrograph of Area 3 at 500X magnification. Circles show visible IGA cracks in the valleys of the machining lines.

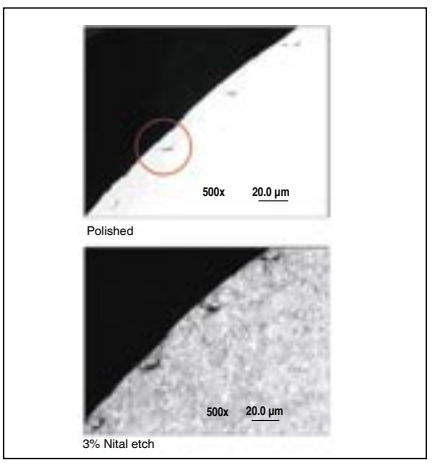

Figure 16—Photomicrograph of Area 5 at 500X magnification. Circle shows surface microcracks.

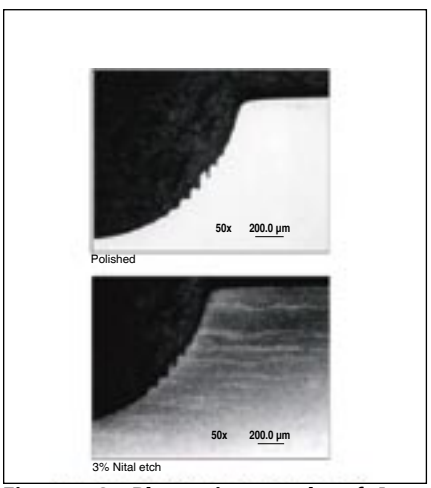

Figure 13—Photomicrographs of Area 2 at 50X magnification showing residual machining lines.

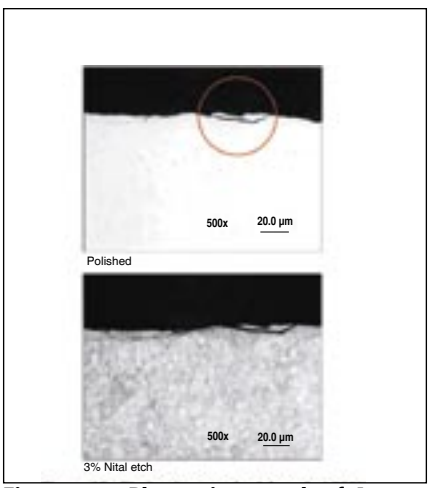

Figure 15—Photomicrograph of Area 4 at 500X magnification showing surface damage.

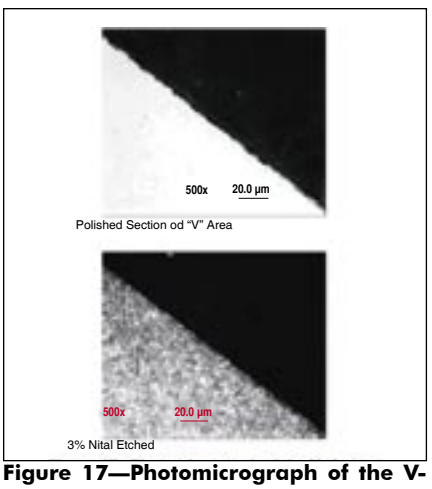

Figure 17—Photomicrograph of the V-Area of the superfinished V-Block at 500X magnification. No pitting or IGA was detected.

The maximum nominal depth of the IGA was 0.0002".

The gearshaft was then superfinished such that approximately 0.0002" of metal stock was removed. It was then sectioned, polished and examined for the final inspection. The SEM image clearly shows that the layer containing the IGA was completely removed (Fig. 20). The surface at 5,000X shows that it is extremely smooth. This proved that the superfinishing process is not only metallurgically safe, but is also capable of repairing damaged surfaces. However, the depth of the damage must not exceed the metrological tolerance limits of the gear teeth.

Conclusions

1. Gears are susceptible to IGA and corrosion during the manufacturing and/or storage processes.

2. Superfinishing using chemically accelerated vibratory finishing does not exacerbate IGA.

3. Superfinishing, in fact, can be used to remove corrosion, light surface damage and the IGA layer.

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3. This was an unpublished study completed by the Aerospace Research Bloc whose sponsors include Avio Group (Italy), Boeing (Mesa and Philadelphia), Curtiss Wright Controls, Honeywell International, Pratt & Whitney (East Hartford, CT and Quebec, Canada), REM Chemicals, Rolls Royce, Sikorsky Aircraft and Timken.
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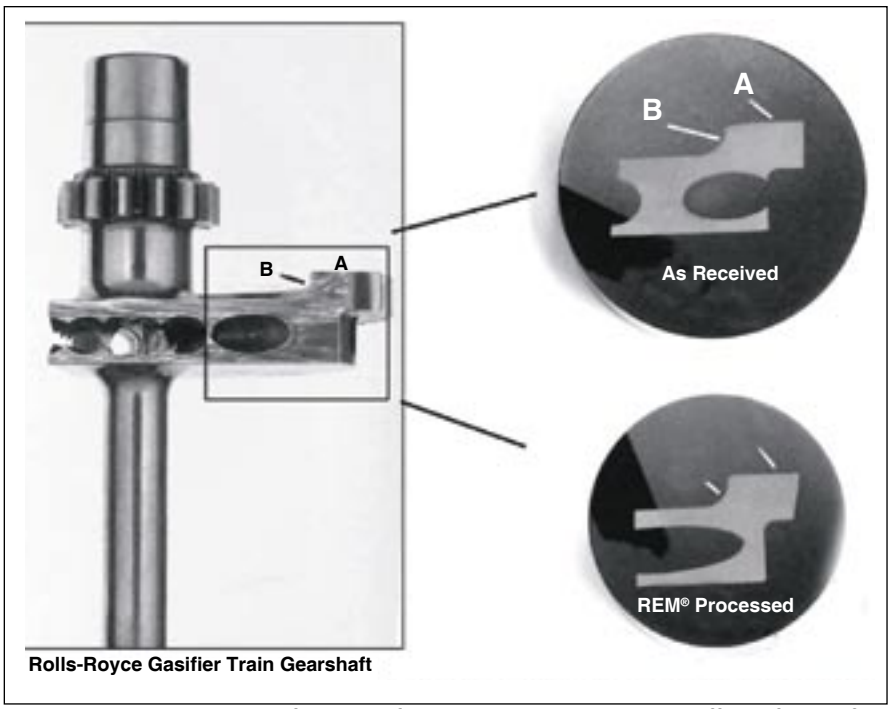

Figure 18—Cross-section of gearshaft studied to determine the effect of superfinishing on IGA. IGA was detected on areas A and B.

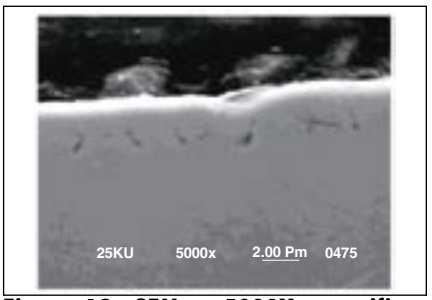

Figure 19—SEM at 5000X magnification, showing the presence of IGA. Circle shows a typical IGA crack on areas A and B. The nominal IGA depth is 0.0002".

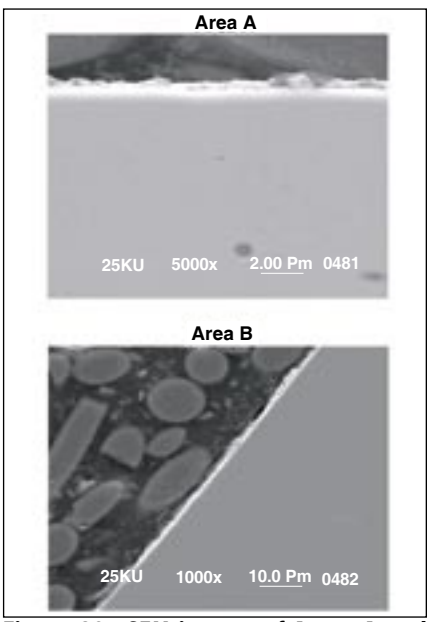

Figure 20—SEM images of Areas A and B showing that superfinishing removed the IGA.

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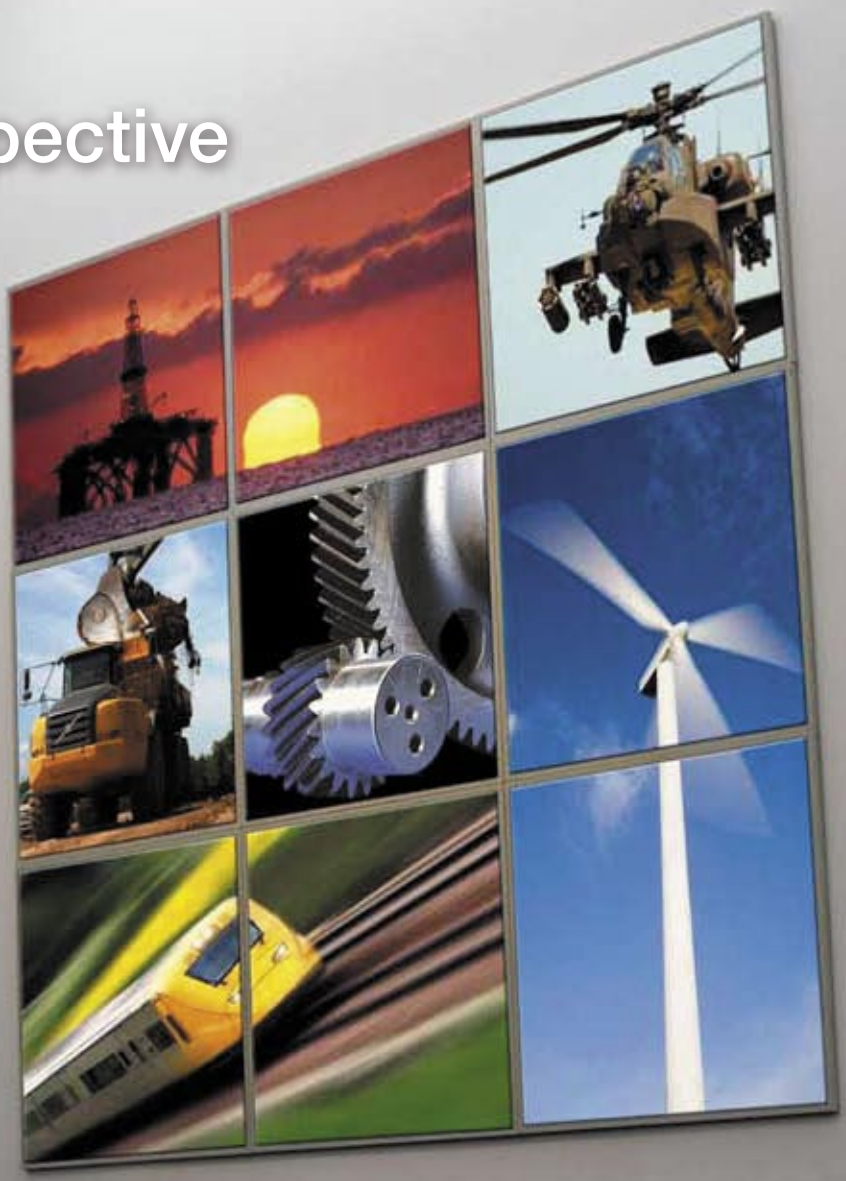
Gregory Blake *is a senior specialist, mechanical engineer, at Rolls Royce Corporation and holds the organizational position of product definition manager of gearboxes. He has 15 years of professional experience in the areas of gear manufacturing, design, product development and technology.*

The Gear:
An Industry Perspective



In this exhibition, the masters at Overton Chicago Gear show their full range of capabilities. Here, they reveal the full spectrum of custom works created for the marine, off-shore, locomotive, mining, wind energy, transportation and construction industries. Using the latest technologies, processes and equipment, the artists are known for the ability to continually meet the most demanding quality standards.

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Low Pressure Carburizing of Large Transmission Parts

Klaus Loeser and Bill Gornicki

Management Summary

Often, the required hardness qualities of parts manufactured from steel can only be obtained through suitable heat treatment. In transmission manufacturing, the case hardening process is commonly used to produce parts with a hard and wear-resistant surface and an adequate toughness in the core. A tremendous potential for rationalization, which is only partially used, becomes available if the treatment time of the case hardening process is reduced. Low pressure carburizing (LPC) offers a reduction of treatment time in comparison to conventional gas carburizing because of the high carbon mass flow inherent to the process (Ref. 1).

By increasing the carburizing temperature, a further significant increase in productivity is obtained, which is not possible in gas carburizing systems to this extent due to furnace component and process limitations (Ref. 2). By adding micro-alloy elements such as aluminium, niobium and titanium as well as properly adjusting the nitrogen content, modern case hardening steels have become sufficiently fine-grain resistant even in temperatures above 1,000°C (1,830°F) (Ref. 3). Today's vacuum carburizing systems are suited for heat treatment in temperatures above 1,000°C.

Introduction

The combination of fine core resistant case hardening steels and suitable high temperature vacuum processes will lead to increased productivity especially in the large transmission industry, i.e., wind energy. Therefore, low pressure carburizing in combination with high pressure gas quenching (HPGQ) as applied in a vertical vacuum furnace platform offers the potential for heat treating large transmission parts.

Conventional Case Hardening of Large Gears

LPC and HPGQ processes are becoming more established in the case hardening of transmissions for automobiles and commercial vehicles. Until now, however, these processes were irrelevant in the treatment of large transmissions due to the lack of suitable furnace concepts for this process technology for large transmission parts with diameters of 600 mm (24") and more.

Therefore, large transmission parts are generally gas carburized in atmosphere pit furnaces and subsequently hardened in separate oil or polymer quench baths via open air transfer (Fig. 1). Direct hardening, being the most economic case hardening process, is generally performed on smaller

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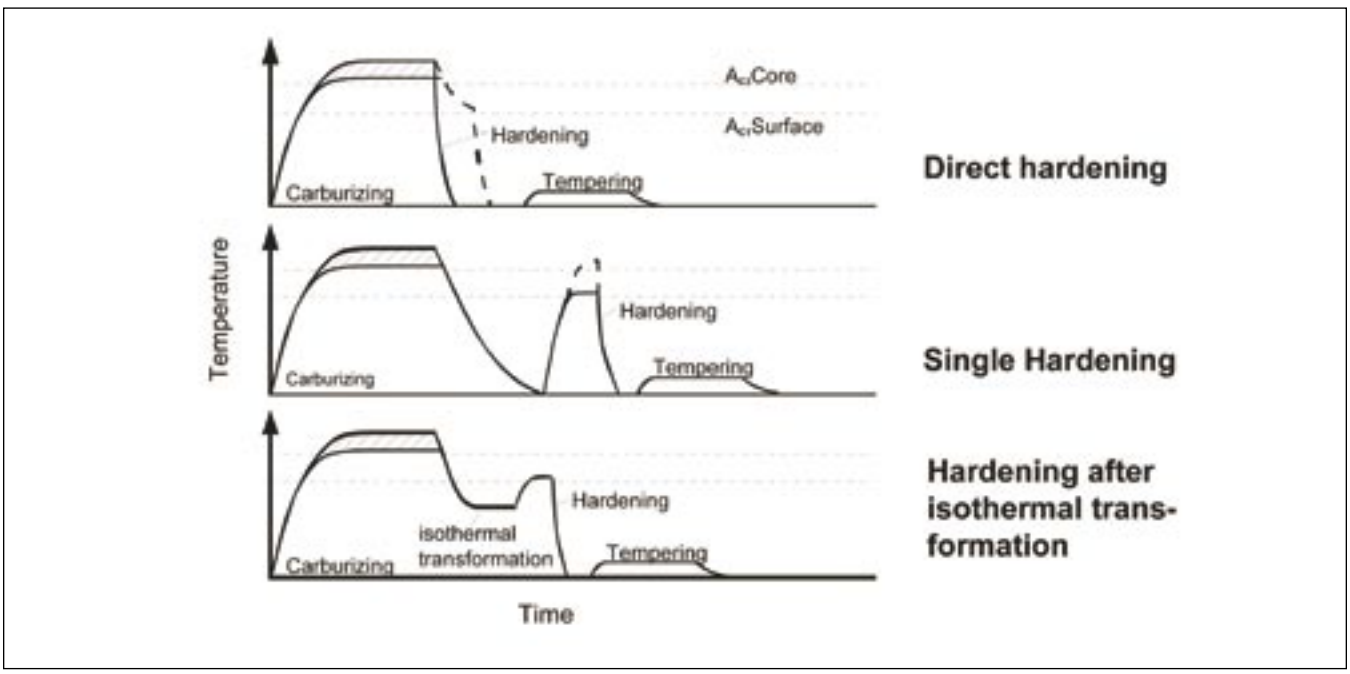

Figure 1—Atmospheric case hardening methods for large transmission gears.

gear wheels, i.e., the parts are quenched directly from carburizing temperature or after lowering to hardening temperature. Compared with single quench hardening, treatment time can be reduced by up to 20%. The reduced distortion allows for relatively small allowances for grinding, resulting in reduced production costs and improving gear tooth quality. Disadvantages include a slightly coarse structure and a higher residual austenite content. For larger gears, generally direct hardening after isothermal transformation or single hardening is performed, resulting not only in a significantly finer grain structure, but also in increased distortion. Due to long-term exposure in the specific atmospheric conditions during gas carburizing, the parts show a significantly higher amount of intergranular oxidation (IGO), which might lead to a soft surface layer and/or reduced fatigue properties during later service.

For hardening, the charge carriers loaded with transmission parts are removed manually from the pit furnace and submerged into liquid quench baths via air. This hot transfer may lead to increased part distortion as a result of warpage of change carriers through repeated use. Additionally, heavy smoke, unshielded flames and the immense thermal interference with the entire furnace surroundings carry a high risk potential to the operator of the facility.

LPC/HPGQ Processes for Large Gears

Low-pressure carburizing. While case hardening depths of 0.4–1.5 mm (0.016– 0.06") are common for automobile transmission parts, values ranging from 2 to 5 mm (0.08–0.2"), depending on the gear module, are standard for large transmission parts. This leads to a treatment time of many hours up to several days. Therefore, for economic reasons, the advantages of LPC should also be used for large transmission parts, preferably at high carburizing temperatures of up to 1,050°C (1,920°F). Suitable fine grain resistant steels are available in the market, thus eliminating the possibility of coarse grain formation, which might lead to uneven distortion, poor static and dynamic mechanical properties and reduced toughness. For example, significant savings in process time can be achieved in the case hardening of large steel chains (Ref. 5) by increasing the carburizing temperature as shown in Figure 2. In case of standard low pressure carburizing that is directly hardened after carburizing at 950°C (1,740°F), a process time including heating and carburizing of 35 hours is necessary to achieve 3 mm (0.12") case depth. A drastic reduction in process time can be obtained by increasing the carburizing temperature to 1,050°C (1,920°F). Although the load needs to be reheated after carburizing for grain refinement to a temperature of 870°C (1,600°C) for three hours, the total process time could be reduced to 18 hours. Further time savings are possible with fine grain resistant case hardening steels allowing for direct hardening from 1,050°C (1,920°F). Slow cooling, reheating and oil or polymer quenching in a controlled atmosphere or vacuum furnace might be an alternative choice to LPC.

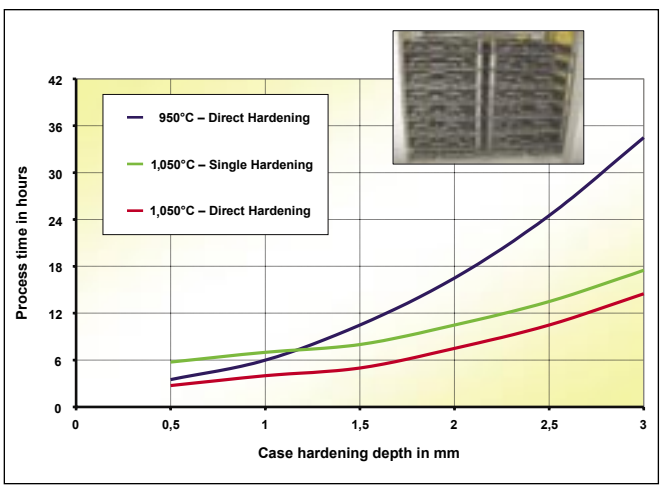

Figure 2—Process time depending on case hardening depth for different case hardening processes and temperatures (Ref. 5).

High-pressure gas quenching. HPGQ in combination with LPC is now commonly used to harden new transmission gears in the automotive industry. The steady increase of quench pressure and gas velocity and the continuous development of the processing technology allow increasing the quench intensity in such a way that even low-alloy case hardening steels can be successfully hardened (Ref. 4).

Compared with liquid quenching, "dry" quenching possesses many important ecological and economical advantages. The quench gases used, such as nitrogen and helium, are inert and leave no residue on the workload; therefore, an investment in washing machines and fire protection systems is not required. The use of gas recovery systems reduces gas consumption and lowers the operating costs in heat treatment. The most important difference to liquid quenching is the absence of phase transformations during quenching with gas, which secures a homogeneous heat transfer. A further advantage is the possibility to adjust the quench intensity by changing the gas pressure and the gas velocity to meet respective requirements, thereby creating the basic conditions to minimize quench distortion during quenching.

Quenching also plays an important role in obtaining the required strength properties. As mentioned earlier, automotive transmission parts made of low-alloyed case hardening steels are being successfully quenched using a specially-developed gas quench technology. In the field of large transmissions, however, higher quench intensity is required because of the parts' larger cross sections. Since a further increase in quenching intensity of the current gas quench technology would exceed technological and economical limits, the use of this technology for large transmission parts only makes sense if case hardening steels with a high hardenability are used.

Today, a number of case hardening steels—23MnCrMo5, SAE 9310, SAE 4320 or Ovako 277—are available which are well suited for gas quenching of large parts because hardenability-enhancing elements such as nickel, chrome, molybdenum and manganese are added. Further to the addi-

tion of alloying elements, the suitable pre-treatment of material during steel production also enhances hardenability. Following the change in pre-treatment from "FP (ferrite/pearlite-annealed)" to "quenched and tempered," considerably higher core hardness values were obtained in samples consisting of material 18CrNiMo7-6 when subsequent case hardening and gas quenching were performed.

Furnace Technology for LPC of Large Gears

In addition to a suitable carburizing and quench technology, the case hardening of large transmission parts requires a suitable furnace technology. Vacuum pit furnaces with integrated gas quenching are especially suited. For many decades, these plants have been successfully used to vacuum harden, anneal and braze large parts, particularly in the aviation and tooling industries. The furnaces' working space dimensions range from 600 to 2,000 mm (24" to 80") in diameter and are up to 2,000 mm (80") high. Charging is either from the bottom by means of a lowerable charge table or from the top via crane, depending on the design. The heating chamber is insulated with graphite board and electrically heated with graphite rods to a maximum temperature of about 1,250°C (2,300°F). This type of insulation possesses a relatively low thermal mass and is therefore rapidly heated. The excellent insulation properties guarantee a low thermal loss and high temperature uniformity. This heating chamber design delivers optimum performance as proven in the low pressure carburization of automobile transmissions.

The furnaces are equipped with an integrated gas quench system, consisting of a gas fan, a heat exchanger as well as the appropriate gas guiding systems. For high-alloyed materials used in the aviation industry, a quench pressure of 2 bar is generally adequate. The tool industry, however, uses quenching at pressures up to 20 bar. The integrated gas quench system does not have the quenching intensity of a separate cold quench chamber. However, it does eliminate the transport of hot parts, which are very prone to distortion. Depending on the application, various quench methods can be realized. Figure 3 shows a typical pit furnace with a bottom loading design used for heat treating of tools. Gas quenching is performed by vertical gas flow from top to bottom or bottom to top. To achieve a uniform quench throughout the load, the gas flow can be reversed during the quench. As another example, Figure 4 shows a pit furnace concept that can be loaded from the top. Quenching in this furnace is done by using vertical graphite tubes arranged in a circle in the heating chamber. The tubes feature several radial nozzles where the quench gas is dispersed uniformly to the parts. Additionally the system is equipped with a rotating charge table, which evens hardening scatter band, thereby reducing quenching distortion.

The combination of high temperature vacuum carburizing and high pressure gas quenching in connection with suitable vacuum pit furnaces opens up new perspectives for economic and low-distortion case hardening of large transmissions,

continued

Figure 3—Bottom loader for LPC of large parts with integral gas quench.

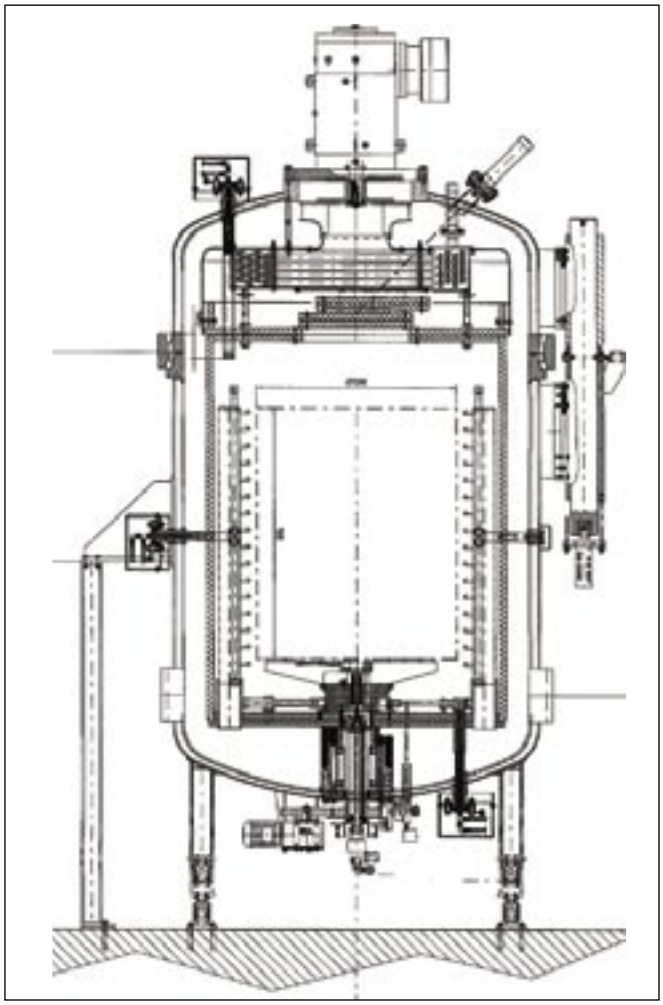

Figure 4—Top loader concept with integrated nozzle cooling for LPC of large transmissions.

made possible by the parallel development of fine grain resistant and high hardenability case hardening steels (Fig. 5). As in conventional case hardening processes, it is possible to perform direct hardening with or without isothermal transformation as well as single hardening. If it is not possible to successfully gas quench the material, the parts may be rapidly carburized in the vacuum furnace, cooled in gas and subsequently quenched in the conventional pit furnace using an oil quench. This technology features a number of other advantages such as uniform and rapid carburizing without IGO as well as homogeneous, low-distortion quenching.

The energy consumption is low because the furnace employed is only heated during the process. Heating and gas absorption during idle phases are not necessary. The process gas consumption is minimal because of the pulsed carburizing technology with acetylene in vacuum. Figure 6 shows the carbon profile of 18CrNiMo7-6 material after carburizing at 1,050°C (1,920°F) to a case depth of 2.5 mm (0.1"), as calculated with the simulation software *VC-Sim*. To carburize large gear components with a total surface of 15 m^2 (160 ft^2) to that case depth, a net carburizing time of only 8 minutes and an acetylene volume of only 2.25 m^3 (80 ft^3) are necessary.

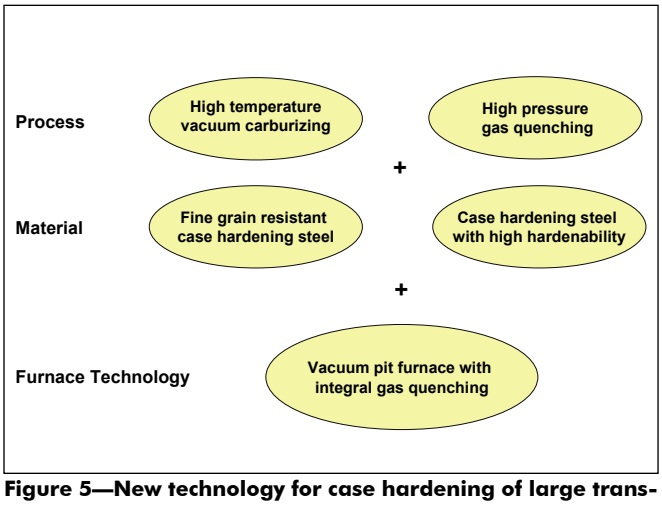

Figure 5—New technology for case hardening of large transmission gears.

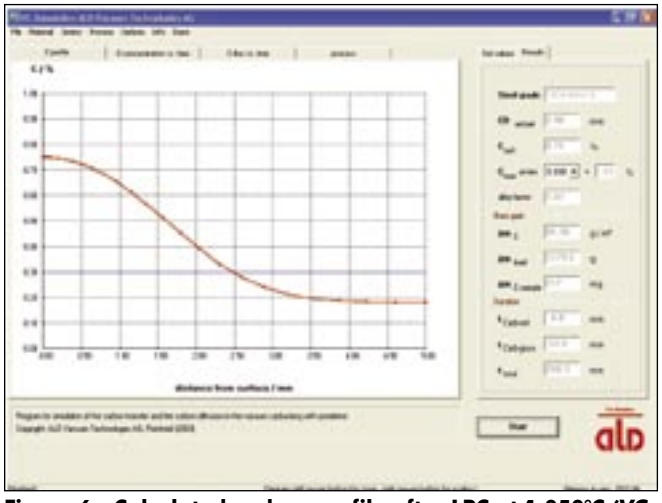

Figure 6—Calculated carbon profile after LPC at 1,050°C (*VC-Sim* software).

The furnaces show only slight thermal and gaseous emissions and are fully automated. Following the quench process, the parts are dry, clean and bright. The minimized distortion enables significant reduction in subsequent grinding processes, which leads to reduced hard machining costs and case depths.

Conclusion

Case hardening using vacuum carburizing and subsequent high pressure gas quenching has become widely established in the heat treatment of automobile parts in the recent years. However, the advantages of this technology are not limited to small transmission parts and low case hardening depths. The combination of high temperature vacuum carburizing and high pressure gas quenching in connection with suitable vacuum pit furnaces and suitable case hardening steels will hopefully open up new perspectives for the economic and low-distortion case hardening of large transmissions found in wind energy transmission components.

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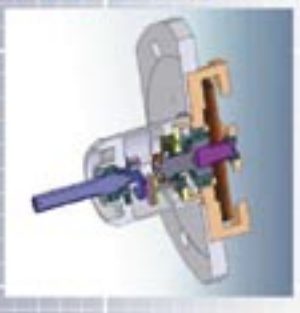

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Tooth Fillet Profile Optimization for Gears with Symmetric and Asymmetric Teeth

A. Kapelevich and Y. Shekhtman

Management Summary

The gear tooth fillet is an area of maximum bending stress concentration. However, its profile is typically less specified in the gear drawing and hardly controlled during gear inspection in comparison with the gear tooth flanks. This paper presents a fillet profile optimization technique for gears with symmetric and asymmetric teeth based on FEA and a random search method. It allows achieving substantial bending stress reduction in comparison with traditionally designed gears. This bending stress reduction can be traded for higher load capacity, longer lifetime, lower noise and vibration and cost reduction.

Introduction

Historically, gear geometry improvement efforts were concentrated on the working involute flanks. They are nominally well described and classified by different standard accuracy grades, depending on gear application and defining their tolerance limits for such parameters as runout, profile, lead, pitch variation and others. Working involute flanks are also modified to localize a bearing contact and provide required performance at different tolerance combinations and possible misalignment as a result of operating conditions (temperature, loads, etc.). Their accuracy is thoroughly controlled by gear inspection machines. The gear tooth fillet is an area of maximum bending stress concentration. However, its profile and accuracy are marginally defined on the gear drawing by typically very generous root diameter tolerance and, in some cases, by the minimum fillet radius, which is difficult to inspect. In fact, tooth bending strength improvement is usually provided by gear technology (case hardening and shot peening to create compressive residual stress layer, for example) rather than gear geometry.

The gear tooth fillet profile is typically determined by the generating cutting tool (gear hob or shaper cutter) tooth tip trajectory (Fig. 1), also called the trochoid. If the cutter parameters are chosen or designed to generate the involute flank profile, which must work for the specific gear application and satisfy certain operation conditions, the fillet profile is just a byproduct of the cutter motion. The fillet profile and, as a result, bending stress are also dependent on the cutter radial clearance and tip radius. The standard radial clearance usually is $0.25/P$ or $0.20/P + 0.002"$, where P is the standard diametral pitch. The standard cutter tooth radius for the coarse-pitch gears is $0.3/P$. For fine-pitch gears the standard cutter tooth radius is not standardized and can be as low as zero (Ref. 1).

Unlike the contact Hertz stress, the bending stress does not define the major dimensions of the gears, such as pitch diameters or center distance. If the calculated bending stress is too high, in many cases, the number of teeth can be

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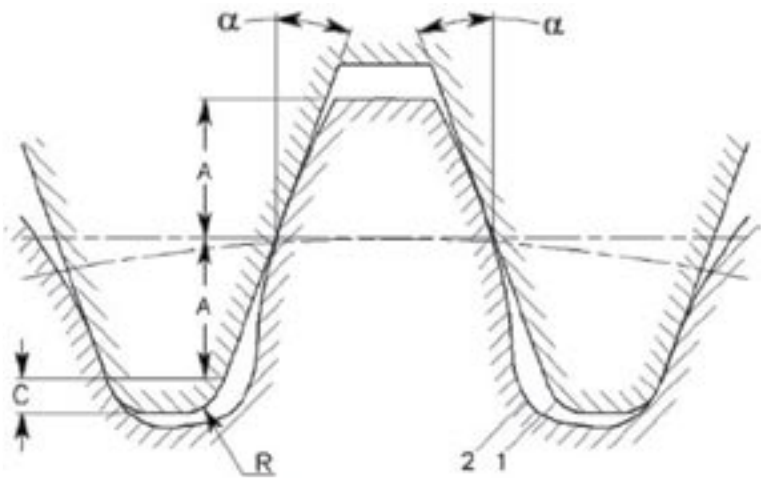

Key

1	Cutter tooth tip
2	Gear tooth fillet as a trajectory of the cutter tooth tip
α	Rack profile (pressure) angle
A	Addendum
C	Radial clearance
R	Cutter tip radius

Figure 1—Gear tooth fillet generation by the rack cutter (gear hob).

reduced and the coarser diametral pitch (larger module) can be applied to keep the same pitch diameters, center distance, and the same (or close) gear ratio. This makes the gear tooth physically larger and reduces bending stress to an acceptable level. Of course, this increases specific sliding and reduces contact ratio and gear mesh efficiency, but this is better than broken teeth.

There are two general approaches to reducing bending stress for the given tooth size. One of them is to alter the generating cutter tooth tip—the most common application of this approach is to use a rack with full tip radius. Another approach is to alter the gear tooth fillet profile—the most common solution here is the circular (instead of trochoidal) fillet. Further development of both these approaches is based on a mathematical function-fitting technique where the cutter tip radius or the gear tooth trochoid fillet profile is replaced by a parabola, ellipsis, chain curve or other curve, reducing the bending stress (see for example References 2 and 3). Bending stress reduction achieved by such fillet profile improvement is varied and greatly depends on the cutter or gear tooth parameters. The resulting tooth fillet profile must be checked for interference with the mating gear at various gear (and center distance) tolerance combinations.

This paper presents the Direct Gear Design fillet profile optimization technique, which allows for a substantial bending stress reduction in comparison to traditionally designed gears. It also describes how bending stress reduction can produce other gear performance benefits.

Optimization Method

Direct Gear Design (Ref. 4) defines all gear geometry parameters without using the pre-selected basic or generating rack. It is applied for custom gears and allows for the separation of the active involute flank and tooth fillet design.

The flank profiles are designed first to satisfy primary performance requirements, such as maximum load capacity with acceptable contact stress level, maximum gear mesh efficiency (minimum specific sliding), etc. The tooth fillet design is based on completely defined involute flank parameters. The initial fillet profile is a trajectory of the mating gear tooth tip in the tight (zero backlash) mesh. For practical purposes, this trajectory is defined at the minimum center distance (including both gears' runout), maximum tooth thickness, and maximum outer diameter of the external mating gear (for an internal mating gear, the minimum inner

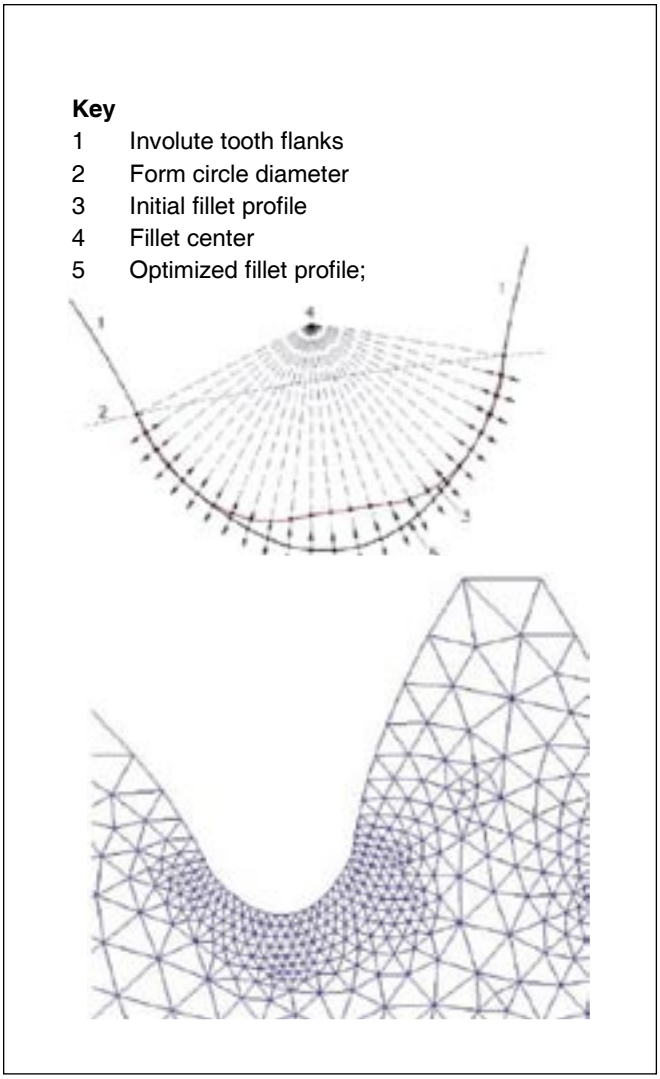

Figure 2—Fillet profile optimization.

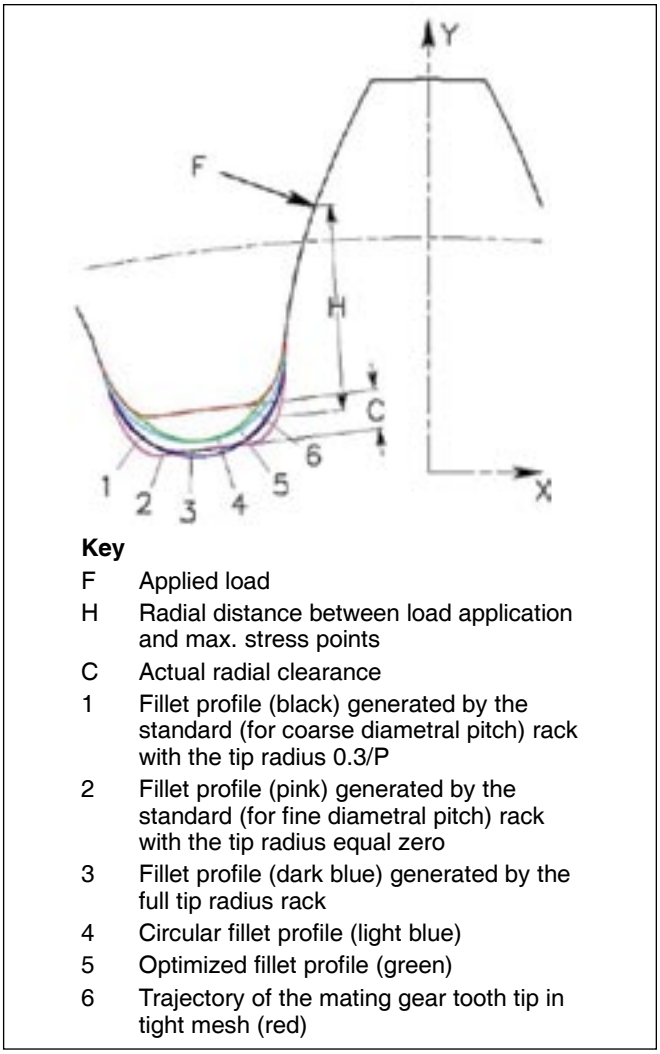

Figure 3—Standard gear tooth with different fillets; X and Y coordinates at the center of the gear.

diameter is used). This allows the exclusion of interference with the mating gear tooth.

The fillet optimization consists of three major components (Ref. 5):

- Trigonometric functions for fillet profile approximation;
- FEA for stress calculation;
- A random search method to define the optimal set of the trigonometric functions' coefficients, which allows them to reach the minimum bending stress.

The trigonometric functions are selected in such a way that the first and the last FE nodes of the initial fillet profile are placed on the form diameter circle (Fig. 2) and cannot be moved during the optimization process. The rest of the initial fillet FE nodes are moved along the beams that pass through the fillet center. The center of the fillet is the center of the best-fitted circle. The bending stresses are calculated for every new fillet profile configuration. The adjustment of the optimizing variable parameters is defined based on the successful (leading to stress reduction) and unsuccessful (leading to stress increase) iteration steps and some random vector. The number of iteration steps (or optimization time) and minimal iteration steps are limited. The random nature of this method does not yield absolutely identical results for the same set of gear parameters and number of iteration steps. The program was adjusted so that the maximum bending stress difference between repeated calculations does not exceed 2%. The fillet shapes for these cases are also slightly different.

Optimization Results

As an example of the fillet profile optimization, different fillets were constructed for the gear pair with the standard involute tooth profile and the following parameters (Fig. 3):

- Number of teeth of both mating gears—24;
- Diametral pitch—12;
- Generating rack profile (pressure) angle—20°;
- Addendum coefficient (also known as normalized addendum coefficient)—1.0;
- Face width of both mating gears—1.0";
- Operating torque—200 in-lb.

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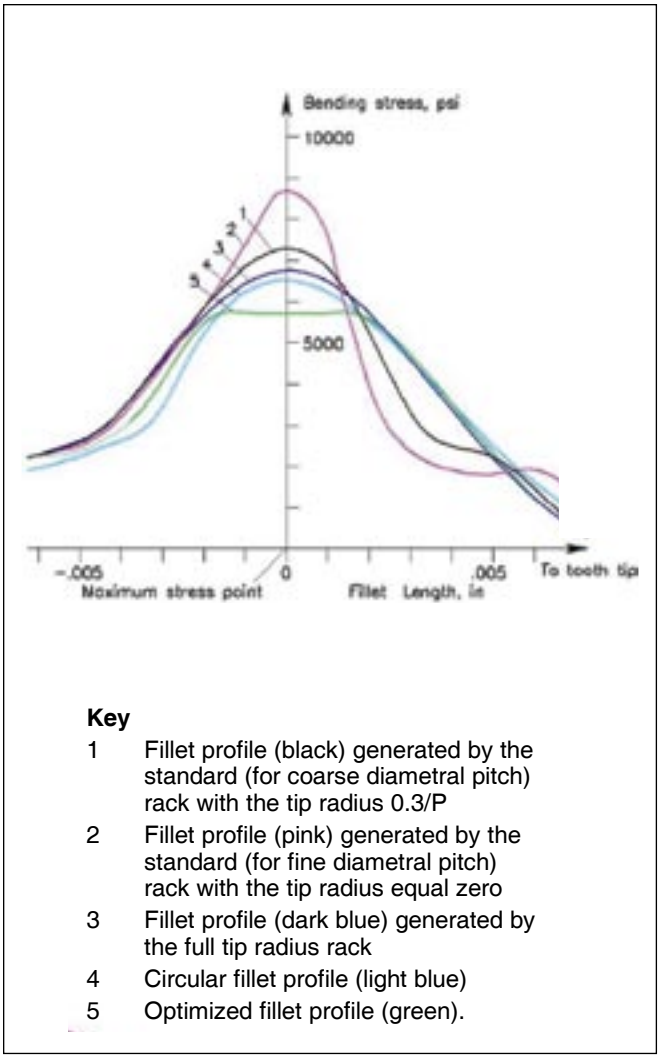


Figure 4—Bending stress distribution chart along the fillet profiles.

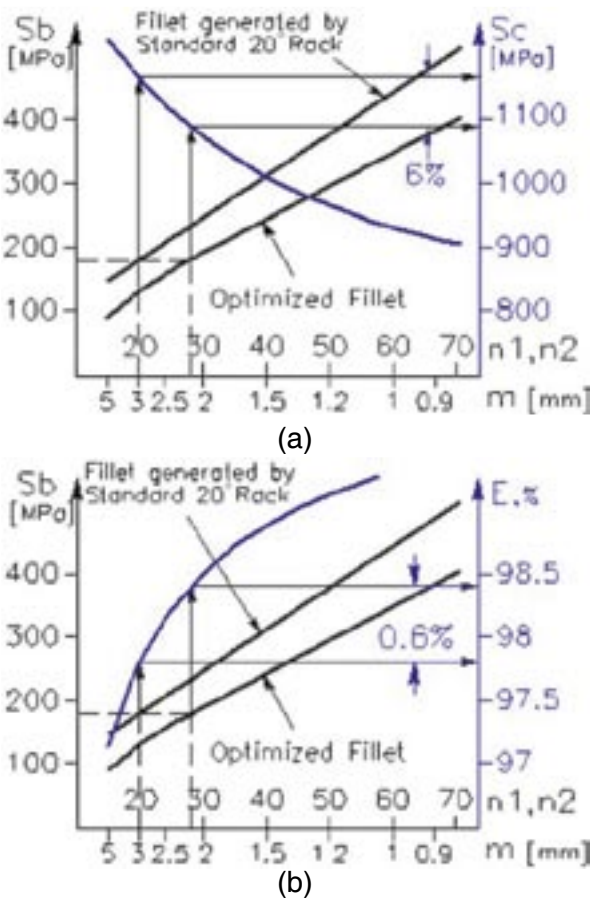


Figure 5—a = contact stress reduction; b = increased mesh efficiency.

Table 1 presents the FEA of the different fillet profiles. It also indicates that the optimized fillet has the largest curvature radius at the maximum stress point and the shortest radial distance from this point to the load application point. The isogram charts illustrate the bending stress distribution. Figure 4 also shows the bending stress distribution along the different fillet profiles. It clearly indicates bending stress, which is evenly distributed along the large portion of the fillet profile. Other fillet profiles have significantly greater maximum stresses that are sharply concentrated.

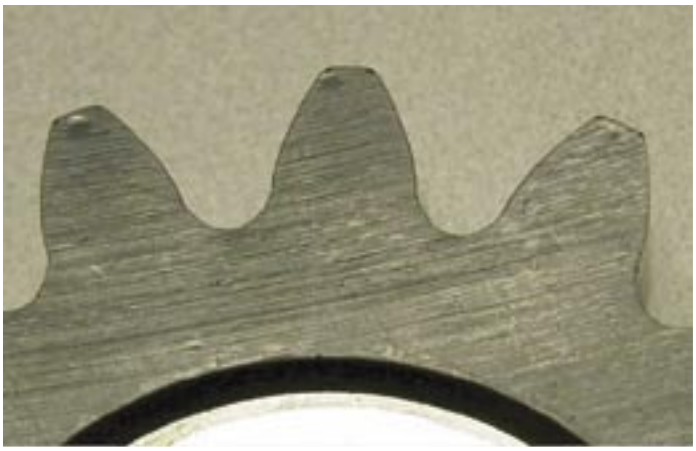
Benefits of Fillet Optimization

If load capacity of the gears with conventional (trochoidal or circular) fillet profiles is limited by the maximum bending stress, the fillet optimization increases gear load capacity proportionally to the bending stress reduction. However, very often, gear load capacity, and consequently gear drive size and weight reduction, is limited by the tooth surface durability, which greatly depends on the contact stress. In this case, the bending stress reduction provided by the fillet

continued

Table 1. FEA of different fillet profiles

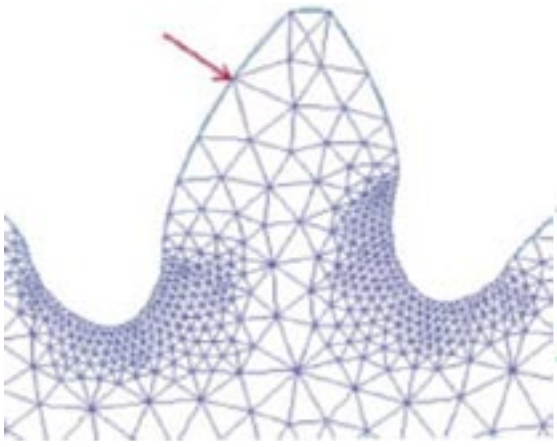
	Rack cutter with tip radius R=0	Rack cutter with tip radius R=0.3/P	Rack cutter with full tip radius	Circular fillet profile	Optimized fillet profile
Fillet profile number at Figure 3	2	1	3	4	5
Bending stress isograms					
X-coordinate of load application point, in	-.0593	-.0593	-.0593	-.0593	-.0593
y-coordinate of load application point, in	1.0167	1.0167	1.0167	1.0167	1.0167
X-coordinate of maximum stress point, in	-.0825	-.0858	-.0868	-.0822	-.0813
Y-coordinate of maximum stress point, in	.899	.9026	.9026	.9158	.9234
Fillet curvature radius at the maximum stress point, in	.0231	.0399	.047	.0483	.1093
Radial distance between load application and maximum stress points, in	0.1157	0.1118	0.1117	0.0989	0.0915
Radial clearance, in	.0208	.0208	.0246	.0165	.0159
Maximum bending stress, psi	8686	7287	6602	6412	5731
Relative stress difference %	+19.0	0	-9.4	-12.0	-21.4



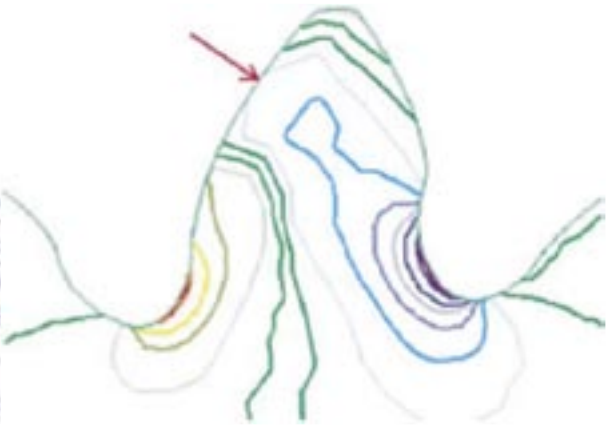
a) Polyurethane die cast gear for industrial application

b) Metal machined gears for automotive application

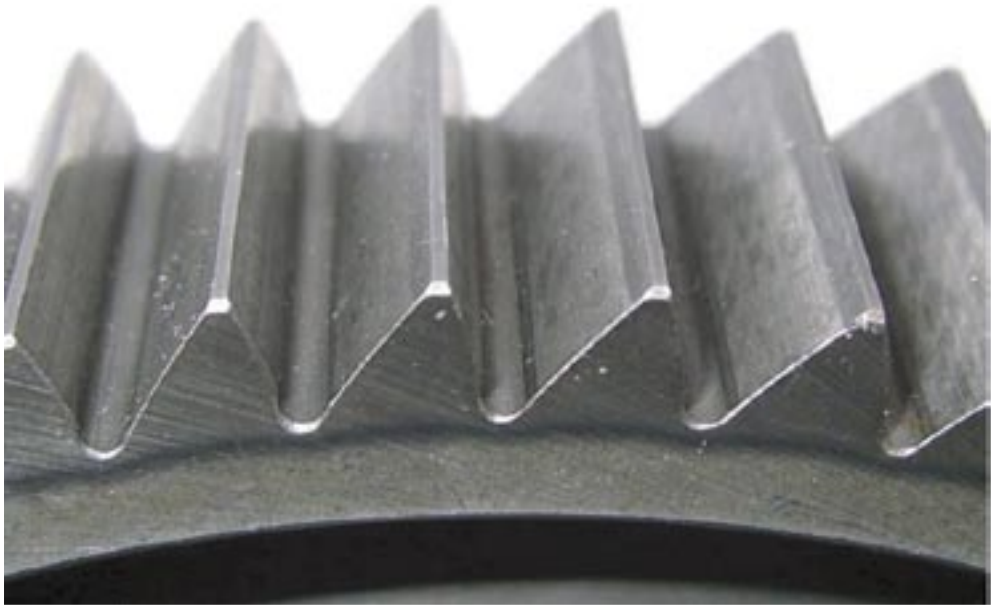
Figure 6—Examples of custom gears with optimized fillet profile.



a) FEA mesh



b) Stress isograms



c) Experimental gear for aerospace application

Figure 7—Asymmetric gear with an optimized fillet profile.

optimization can be converted into the contact stress reduction. Figure 5a presents the charts of the bending (black) and contact (blue) stresses, calculated for the gear pairs with the standard involute profiles. These gears have gear ratio 1:1, the constant center distance a_w = 60 mm, the face width of both gears b = 10 mm, and the driving torque T = 50 Nm. The number of teeth varies from 12 to 75 and module varies accordingly from 5 mm to 0.8 mm to keep the constant center distance. The bending stresses are presented in two charts; one for the gears with the standard (generated by 20° pressure angle rack) trochoidal fillet profile and another one for the gears with the optimized fillet profile. For example, a bending stress level of 180 MPa is considered acceptable. This level is achievable for the 20-tooth gears with the standard fillet or for the 28-tooth gears (with finer module). However, the 28-tooth gears have a higher contact ratio and, as a result, lower contact stress. The fillet optimization allowed converting potential bending stress into the 6% contact stress reduction by using the gears with greater number of teeth. This 6% contact stress reduction doubles the life of steel case hardened gears with a high number of load cycles.

Similarly to the conversion of the bending stress reduction into contact stress reduction and longer life, the fillet optimization allows achieving higher gear mesh efficiency. Figure 5b presents the charts of the bending stresses (black) and gear mesh efficiency (blue) for the same gear pairs. In this example, the finer module gears with greater number of teeth and the optimized fillet, which have the same maximum bending stress level, provide less specific profile sliding and, as a result, 0.6% higher gear mesh efficiency in one gear pair. This can be very beneficial for a high-power, multistage gear transmission because this will reduce heat generation, required lubrication system, etc.

The potential benefits of the bending stress concentration reduction by the tooth fillet profile optimization can be extended. This allows using a gear with a greater number of teeth and finer module that generates less noise and vibration. It is likely possible to increase the hydrodynamic oil film thickness and reduce the flash temperature, because of the reduced profile sliding.

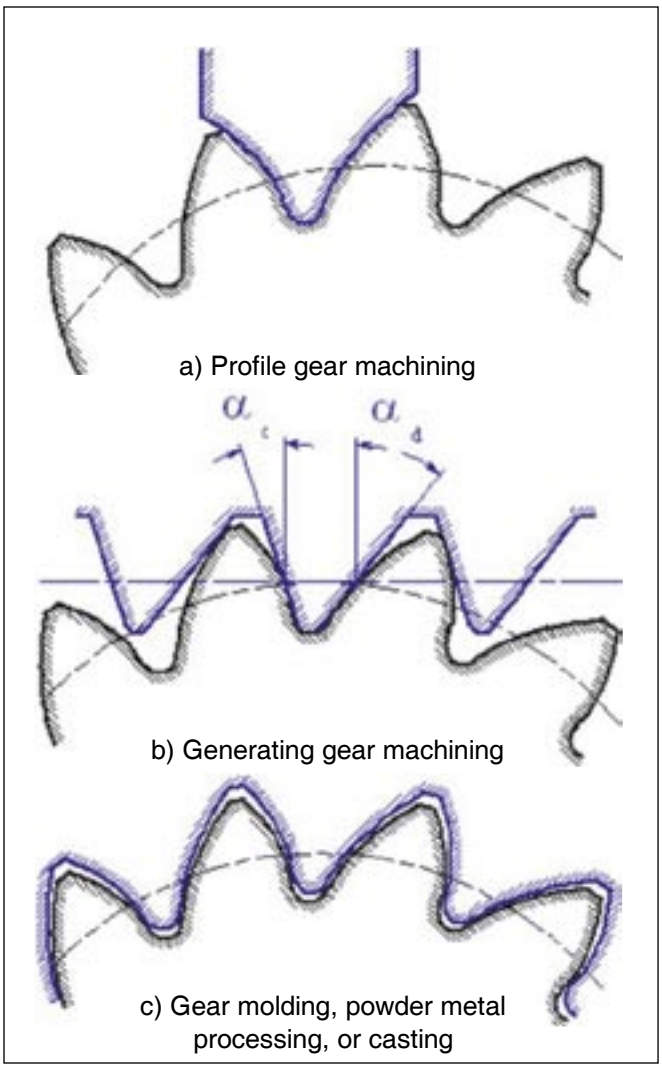


Figure 8—Tooling profiles.

Application of Fillet Optimization for Symmetric and Asymmetric Gears

The fillet profile optimization is for custom gears. In previous paragraphs, the optimized fillets were constructed to the standard involute tooth flanks only to compare them with the fillet profiles of the standard gear teeth and demonstrate possible bending stress concentration reduction. The authors have no intention of recommending using fillet optimization for standard gears. The benefits of the standard gears include their universality and suitability to the majority of non-critical gear applications. They are available off-the-shelf; their design validation is simple and typically does not require special testing.

In custom gears, nonstandard gear geometry, including an optimized fillet profile, is necessary to guarantee required performance. Custom gears are used for extreme and highly competitive applications like aerospace and racing drives, automotive gear transmissions, etc. Forming gear technology, like plastic and metal injection molding, powder metal processing, precision gear forging, extrusion and die casting allow for extending the implementation of nonstandard gears with the optimized fillet profile to many custom gear applications. Examples of such gears are presented in Figure 6.

Many gear applications, like for propulsion drives, have one main direction for the torque transmission. The design intent of asymmetric gear teeth is to improve performance of the primary drive profiles at the expense of the performance for the opposite coast profiles. The coast profiles are unloaded or lightly loaded during a relatively short work period. The main advantage of asymmetric gears is contact stress reduction on the drive flanks, resulting in higher torque density (load capacity per gear size).

Another important advantage is the possibility to design the coast flanks and fillet independently from the drive flanks, managing the tooth bending strength and stiffness, and load sharing.

Asymmetric gear geometry (Ref. 6) is not defined or

limited by any standards. This makes asymmetric gears naturally suitable for tooth fillet optimization. Figure 7 presents an asymmetric gear with an optimized fillet profile. The tooth fillet profile optimization is applicable for all kinds of involute (and non-involute) gears including spur, helical, bevel, face, worm gears, etc. The fillet profile is optimized in the normal section of the tooth, and then it can be protruded or swapped to define the complete gear tooth.

Tolerancing, Tooling and Inspecting the Tooth Fillet Area

No matter how the custom gear tooth profile might be different from the standard one, accuracy of the custom gears defined on the drawing is typically based on the existing standards. The gear tooth fillet optimization makes this area as important for gear performance as the involute flanks. Its specification on the gear drawing should be addressed accordingly. Unfortunately, modern gear standards do not define the fillet profile accuracy. As a temporary solution, the fillet profile tolerance (deviation from the nominal fillet profile) can be defined in relation to the involute profile tolerance, which is well defined in the gear standards. Based on limited experience with implementation of optimized fillet profiles, their tolerance can be defined as 1.0 –2.0 multiplied by the involute profile tolerance.

Custom gears with optimized profiles require custom tooling. For the profile machining process (Fig. 8a) the tool profile is the same as the space profile between the neighboring teeth. For a generating machining process like gear hobbing (Fig. 8b), the tool profile is defined by reverse generation, where the designed gear forms the tooling rack profile. The pressure angles, in this case, are selected to provide better machining conditions. For gear molding, powder metal processing, and casting (Fig. 8c), the tool cavity profile is the same as the whole gear profile, adjusted for warpage and shrinkage.

A crucial phase in custom gear development is gear inspection. The involute flank profile is inspected by a variety of available gear measuring machines and devices, which are not specifically designated to control the fillet profile. However, some of them, like CMMs, could be reprogrammed for the fillet profile inspection. Optical inspection devices like ToolScope (or Smart-Scope) are also suitable for this purpose.

Conclusions

- The article presented the Direct Gear Design tooth fillet profile optimization method;
- Tooth fillet profile optimization provides significant (10–20%) bending tress reduction in comparison with traditionally defined tooth fillet profiles;
- The bending stress reduction provided by the fillet optimization can be converted into other gear performance benefits, such as contact stress reduction and increased gear mesh efficiency;
- The article presented implementation example of the gears with the optimized fillet profile;
- The article considered approaches to the tolerancing, tooling and inspection of the gears with an optimized fillet profile.

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4. Kapelevich, A.L., "Direct Design Approach for High Performance Gear Transmissions," *Gear Solutions*, December 2007, 22–31, presented at the Global Powertrain Congress 2007, June 17–19, 2007, Berlin, and published in the *Global Powertrain Congress Proceedings*, Vol. 39–42, 66–71.
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Dr. Alexander L. Kapelevich *is the owner of the consulting firm AKGears, LLC, developer of modern Direct Gear Design methodology and software. He has thirty years of experience in gear transmission development.*

Dr. Yuriy Shekhtman *is an expert with a 40-year experience mathematical modeling and stress analysis . He created a number of computer programs based on FEA and other numerical methods. Dr. Shekhtman is a software developer for AKGears.*

EMO Milano—Just in Time for an Investment Renaissance

This fall in Milan the international machine tool manufacturing community will stand at a pivotal juncture in the road back to growth. Many economists predict the global economy to jump-start into an anxiously-awaited recovery, which means there may be no better time to invest in new machinery.

"Despite the complex world market situation, EMO Milano 2009 is a not-to-be-missed appointment for trade operators, says Alfredo Mariotti, director of the event. In short, the main protagonists of the world scene will be present at the event, even with impressively large exhibition spaces.

"In any case, if the third quarter of the year coincides with an inversion of trends, as several international economic analysis institutes suggest, EMO Milano 2009 will be the right moment to plan investments in instrumental goods, and whoever attends the show will certainly benefit," Mariotti says.

Known as the "machine tool world exhibition," EMO is promoted by the European Committee for the Cooperation among Machine Tool Industries (CECIMO), and it's held in Milan only once every six years; the show takes place every other year, running twice in Hannover, Germany before returning to Italy. This year is the first it's being held at the new Fiera Milano convention center, spanning a total gross surface area of 345,000 square meters.

The event is noted for its strong international appeal, with 70 percent of exhibitors coming from outside of Italy, representing 34 countries. They cover all areas of the industry: metalcutting, metalforming, components, tools, robotics and automation. Exhibitors include Bosch Rexroth, Bourn and Koch, Gleason, Koepfer, Reishauer, Höfler, Klingelnberg, SAMP, Liebherr, Kapp, Niles, Praewema, Wenzel, Fanuc, Heidenhain, Siemens, DMG and Mori Seiki.

The event in Italy draws a different appeal for exhibitors than 2007's show in Germany or other machine tool shows such as Hannover Fair.

"For us, the Italian edition of EMO is more important than the German event," says Mario Stroppa, managing director of Gildemeister Italiana (Brembate BG). "At the edition held in Hannover, 60 percent of visitors are German; on the contrary, half the number of visitors at EMO Milano are international."

Gildemeister will showcase its new gear cutting technology on non-gear-dedicated machining centers. The German company launched sales efforts earlier this year on the up-and-coming gear technology, and they intend to have fine-tuned the software component that is critical to the process. They will have the latest developments on display at EMO, along with seven machines making world debuts, which is likely a huge opportunity for Gildemeister to attract the international gear community's attention.

Another benefit Milan holds over the German edition is the access to different geographic markets. "I feel that the Italian edition of EMO is the best approach to markets in Southern Europe and the Mediterranean," says Paulo Egalini, managing director of Mandelli Systems, Gruppo Riello Sistemi (Minerbe VR). "The growing relevance of the Milan edition is confirmed, in any case, by the fact that Italian constructors are continually closing the gap in market share compared to German competitors."

In hall 7 stand G06, Renishaw will be displaying a full range of metrology products, which includes machine tool touch probes, CMM probes, laser calibration systems, machine tool performance analysis systems, optical encoders, magnetic encoders and probe styli.

The world's machine tool manufacturers will display their latest technology at EMO Milano from October 5–10 (courtesy of Fiera Milano).

Renishaw probes will be on display at EMO 2009 (courtesy of Renishaw).

Representatives will also be discussing Renishaw's new retrofit service for CMMs, which includes *MODUS*, Renishaw's first metrology software, as well as a new high-speed application for valve seat and guide measurement.

The MTConnect Institute is demonstrating the MTConnect Standard similarly to how it was presented at IMTS last fall in Chicago. An application will request data from sample devices over the Internet. Participants include Bosch Rexroth, Mahr GmbH, Agie Charmilles, Monnier + Zahner Ltd., Optical Gaging Products, Inc. and System Insights, Inc.

It's no news that sales for much of the products on display at EMO Milan has stagnated this year, but exhibitors seem eager to show the world that research, development and innovation have continued to march forward. Exhibitors and organizers express great optimism that once October 5 rolls around, manufacturers will be better positioned to make those investments they've been cautiously holding off on all year.

EMO Milano takes place October 5–10, 2009 at the Fiera Milano convention center in Italy. For more information, visit *www.emo-milan.com*.

CALENDAR

September 30–October 2—Fundamentals of Gear Design. UWM School of Continuing Education, Milwaukee, WI. This beginning knowledge course is presented by Raymond Drago and the University of Wisconsin School of Continuing Education. It presents basic modern gear system design and analysis with emphasis on proper selection, design application and use, as opposed to fabrication. Topics include a short history, basic gear nomenclature, types of gears, gear arrangements, theory of gear tooth action and failure modes and prevention. Cost is $1,095. For more information, contact Murali Vedula, program director, (414) 227-3121 or *mvedula@uwm.edu*.

October 6–8—Wisconsin Machine Tool Show. Wisconsin Exposition Center, West Allis, WI. The 11th installment of the biennial Wisconsin Machine Tool Show is the largest show specifically targeting tooling and metalworking in the Midwest this year. Held on the grounds of the Wisconsin State Fair Park, part of the greater Milwaukee area, the show features free technical seminars to complement the 200,000-plus square foot exhibition hall. Displays, demonstrations, products and services are presented by local, national and international companies. Admission is free with pre-registration. For more information, visit *www.machinetoolshow-wi.com* or contact Expo Productions, Inc. at (800) 367-5520 or *expo@exepc.com*.

October 19–23—International Lean Conference. Northern Kentucky Convention Center, Covington, KY. On the southern side of Cincinnati, 2,500 lean practitioners from around the world will gather for the Association for Manufacturing Excellence (AME) flagship, annual conference. The conference consists of eight keynote speakers, 60 presentations, 30 workshops and 40 plant tours. There are also 70 vendors chosen by AME as learning center exhibitors, sharing lean-based products and services. A dozen special interest sessions are designed to provide a deeper understanding of lean issues in highly specific subjects, such as lean accounting and nanotechnology. Group rates are available. For more information, visit *www.ameconference.org* or call (224) 232-5980 x223.

October 26–29—Furnaces and Atmospheres for Today's Technology. Holiday Inn Express, Meadville, PA. This annual event hosted by Seco/Warwick allows industry specialists to present the latest improvements in heat treat furnaces and provide practical information for companies new to heat treating. The format this year has been changed to present information on support technologies and industry trends. Speakers will address the history and progress of the technology while providing information on process development over the past year. Topics include furnace selection and application, fundamentals of heat transfer, nature of vacuum, leased atmospheres, alloy applications, temperature control, heating elements and power control units. Dan Herring, aka the "heat treat doctor," is the keynote speaker. For more information, visit *www.secowarwick.com/F&A.html*, or contact Gary Armour at (814) 332-8558 or *garmour@secowarwick.com*.

October 27–29—Shot Peening/Blast Cleaning Workshop and Trade Show. Albuquerque Embassy Suites Hotel, Albuquerque, NM. Sponsored by Electronics Inc. of Mishawaka, IN, this annual event identifies a higher level of shot peening performance and raises professional standards while highlighting a company's educational commitment. In three days, attendees receive intensive instruction on every aspect of the shot and blast cleaning industries. The workshop is attended by design engineers, machine operators, maintenance and quality engineers, foremen and supervisors. The workshop is recognized by the Federal Aviation Administration (FAA), and qualified students have the opportunity—though not required—to take the FAA exam, which documents participants' knowledge in shot peening fundamentals. For more information, visit *www.shotpeener.com* or call (800) 832-5653.

November 3–5—AWEA Supply Chain Workshop. Cobo Center, Detroit, MI. Held in conjunction with the American Wind Energy Association (AWEA) Small and Community Wind Conference and Exhibition, the Supply Chain Workshop attracts representatives from a range of markets to discuss the wind industry's need to fortify and expand its supply chain. This will help keep up with growing demand while increasing domestic manufacturing of wind turbines and components. Topics include the anatomy of a turbine, wind industry overview, major component sourcing and value chain services, how to enter the wind industry through funding contracts and retooling as well as case studies. Workshop attendees have the opportunity to attend the other conference's sessions and exhibition hall. For more information, visit *www.smallandcommunitywindexpo.org/supplychain.cfm*.

November 18–20—AWEA Wind Energy Fall Symposium. Hilton Bonnet Creek Resort and Spa, Orlando, FL. Wind energy professionals in every area of the industry will meet to learn about the wind business overall, discuss current challenges and opportunities and network. Some of the issues discussed include the latest legislation, financing, constraints on supply chain and transmission as well as expanding infrastructure. There is a pre-conference seminar on the fundamentals of wind energy designed for industry newcomers. The main symposium program provides detailed presentations, interactive discussion and topical information on a range of topics. For more information, visit *www.aweafallsymposium.org*.

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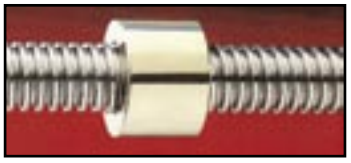

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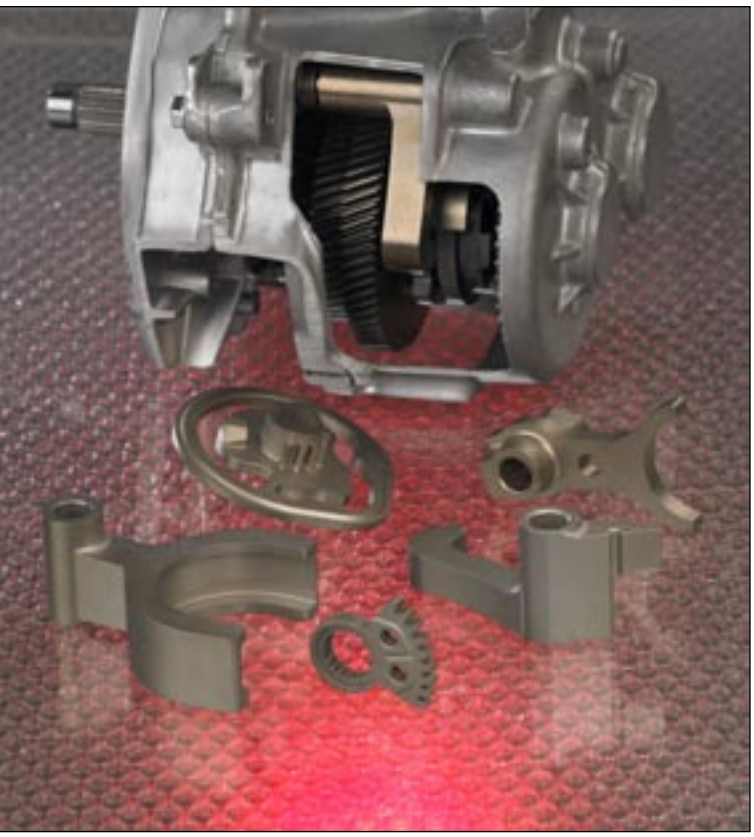

This assembly of five PM steel parts is used in an ATV transmission and was recognized by the MPIF.

The Metal Powder Industries Federation (MPIF) presented FMS Corporation with the Outstanding Powder Metallurgy Parts Grand Prize in the lawn and garden/off-highway category for a complex assembly of five PM steel parts used in the transmission of an ATV.

The assembly consists of two shift forks, two sector gears and a park pawl. Four of the parts are made from PM sinter-hardened steel to a density of 7.2 g/cm^3 with a minimum ultimate tensile strength of 110,000 psi. One of the sector gears is made from 4300 steel with tensile strength of 160,000 psi and a 30 HRC minimum hardness. The parts were produced using the standard press and sinter process.

The Outstanding PM Parts Awards are presented each year at the MPIF annual trade show PowderMet. John F. Sweet, president of FMS Corporation, took home the award for its "high level of complexity and high quality requirements. The level of complexity allows for many different dimensions to be held," he said.

"Innovation is the key. It was a good application of powder metallurgy in a new market."

FMS has won the award in different categories seven times since 1998. Of all FMS's winning parts, this one had the highest number of components in an assembly. "We have produced other assemblies," Sweet says. This was certainly the highest level of complexity we have taken on as a company."

He says, "The entire development took over a year."

The customer, Team Industries of Bagley, MN, settled on FMS and the PM process due to cost savings, which they estimated at 60 percent. "They considered machining and casting and were convinced that the powder metal method would be the most cost effective," Sweet says.

FMS specializes in powder metal component parts with full CAD/CAM gear design and inspection capability. Sweet touts the benefits of using PM for transmission parts compared with traditional machining methods. "The cycle time is lower, and there is little or no material waste. It's a very efficient process," he says.

He notes that PM is the fastest growing metalworking process, with gear manufacturing as an area that has expanded significantly in use, and the technology has improved. "The powder metal process continues to make inroads in the manufacture of gears in an efficient way," Sweet says. "Where it was once thought of as strictly a cost cutting measure to be used with low performance gears,

powder metallurgy continues to advance in material performance, and today we can compete in most high performance [applications], even 8620 carburized steel."

American Broach

LAUNCHES NEW DIVISION, WELCOMES GM

Leon Kozlov is the general manager of the American Gear Tools division of American Broach and Machine.

Ken Nemec, president of American Broach and Machine Company (ABM), recently announced the creation of the American Gear Tools (AGT) division. AGT designs and delivers hob, shaper, shaving, milling, straight, spiral and bevel cutters and spline rolling racks. Engineering and inspection services, troubleshooting support, application enhancements and gear cutting tool regrinding services are the focus of the new division.

Leon Kozlov, formerly vice president and chief engineer of Barit International, joins AGT as general manager, as of September 8. Kozlov has more than 30 years of experience in the design and development of gear cutting tools.

"Not only has American Broach and Machine started a new division, we have hired a ringer," Nemec says.

The new division is a way for ABM to "complete the circle," Nemec says, and meet all the tooling needs of its gear producing customers.

continued

Correction.

Regarding the technical paper appearing in our June 2009 issue, "The Effect of Start-Up Load Conditions on Gearbox Performance and Life Failure Analysis and Case Study," some revision is warranted.

The article uses the term "spalling," whereas the preferred nomenclature is "flake macropitting," as defined in ANSI/AGMA 1010-E95 (Ref. 1). Flake macropitting starts with a crack that extends from a surface origin in a fan-shaped growth pattern to form a triangular crater. Tip-to-root interference is a common root cause of flake macropitting.

Also, Figure 12 and associated text claim macropits grow in the slide direction. Actually, macropits grow opposite to the slide direction.

Reference

1. ANSI/AGMA 1010-E95, "Appearance of Gear Teeth—Terminology of Wear and Failure," AGMA (1995).

—The Editorial Staff

"Leon is a great addition to ABM, adding even more depth and knowledge to the ABM team in Ypsilanti, MI. Leon speaks, reads and writes several languages including English and Russian. Leon is a degreed engineer, and his specialty is gear cutting tool design and application," Nemec says.

American Broach and Machine is exhibiting at Gear Expo in booth 716 and has extended an open invitation for visitors this fall to its Ypsilanti, MI facility to welcome Kozlov and tour the plant.

Gear Technology

ADDS AQUEOUS PARTS CLEANING SYSTEM

An environmentally friendly ultrasonic, aqueous-based parts cleaning system has joined the shop floor at Rancho Cucamonga, CA-based Gear Technology.

"This state-of-the-art system cleans machined components prior to first-article inspection points during the machining process and before final shipments are made to our customers," says Tom Marino, president of Gear Technology. "The multiple-tank process removes even the smallest particles and is capable of processing up to 6,000 parts per month.

"With in-house and environmentally responsible parts cleaning, we ensure our customers' precision machined gears and assemblies are shipped completely free of foreign object contamination and are received ready to use."

Halifax Rack and Screw

Invests in New Equipment

The Cincinnati North America distribution center for Halifax Rack and Screw Cutting Company of Cincinnati, OH and Brighouse, England has invested in 14.5 degree and 20 degree pressure angle gear racks in four-, six- and 12-inch lengths. The investment takes the form of two new pieces of gear rack manufacturing equipment and a stock inventory for the North American market. The equipment allows for quick turnarounds on standard and modified rack for clients in this region.

"HRS invested more than one million Euros in new state-of-the-art equipment last year for our Brighouse production facility," says Rich Easley, North American sales manager for HRS. "This investment ensures our continued ability to supply the highest quality gear racks and screws at competitive pricing. Our inventory additions will support the stimulus programs in U.S. construction."

continued

Halifax Rack and Screw's facility in Cincinnati, OH has invested in two pieces of gear rack manufacturing equipment and an expanded stock inventory.

Barit

CHANGES OWNERSHIP, EXECUTIVE MANAGEMENT

Yuriy Ardashnikov is chief engineer for Barit International.

Dennis and Edward Moldavsky have purchased 20-year-old gear cutting tool provider Barit International Corporation. Dennis Moldavsky was formerly Barit's director of sales and is now the CEO. Edward Moldavsky is the president. The new executive positions were assumed in May, and the company remains at the Northbrook, IL headquarters.

Barit was founded in 1989 by Alexander Polevoy. "When Rita (Polevoy) mentioned she was thinking about retiring and wanted to find a buyer for the company, I knew this was a great opportunity for my family to grow and improve an already successful family-owned business," Dennis Moldavsky says.

The Moldavskys' first course of action as new owners was to hire chief engineer Yuriy Ardashnikov, who has 22 years of experience in the industry, from designing geared power transmissions and mechanical drives to manufacturing support and quality control management. He brings Barit expertise in diesel engines, machine tools and custom gearing.

Vision

DOUBLING FLOOR SPACE

Vision Quality Components Inc. is moving to a facility twice as large as its previous space in the Clearfield Technology Park in Clearfield County, PA. Since opening its doors in January 2003, Vision has leased 10,000 square feet of space at the industrial park, and the new facility is only a few minutes from the former one, off Interstate 80 in Pennsylvania.

The new building is owned by Vision. It features 2,000 square feet of office space and 18,000 square feet of manufacturing space, so Vision can expand manufacturing capacity. Vision currently manufactures spur gears, helical gears and precision pump gears using the powder metallurgy process.

Triumph Group

AWARDED BELL HELICOPTER CONTRACT, PROMOTES MANAGEMENT

A multi-year supply agreement was made between the Triumph Group and Bell Helicopter. Under the agreement, the gear systems operations, located in Park City, UT and Macomb, MI will provide the main transmission assemblies for the 429 helicopter.

The agreement includes manufacturing, assembly/integration and testing of the transmissions in addition to design and engineering the test equipment.

continued

NEWS

The initial agreement spans five years with five one-year contract extension options. The estimated value exceeds $363 million over the next 10 years.

"We are extremely pleased that Bell Helicopter chose Triumph to be a strategic supplier to this program," says Richard C. Ill, chairman and CEO for Triumph. "We believe Triumph's experience in providing cost effective solutions, our capacity to integrate complex bills of material and our commitment to meet or exceed stringent quality control requirements enabled us to win this business. We view this award as a significant milestone in our excellent relationship with Bell Helicopter and look forward to supporting this program."

In other news from Triumph, Jeffry D. Frisby, group president of Triumph Aerospace Systems Group, was named president and chief operating officer of the company. Ill previously held the post and was promoted to chairman. David Kornblatt was promoted from senior vice president to executive vice president, and he remains the company's chief financial officer.

"Jeff Frisby has made significant contributions to the growth of our aerospace business," Ill says. "He is a proven member of our leadership team and has played a key role in making Triumph what it is today."

Frisby has served as group president of the Triumph Aerospace Systems Group since 2003. He first joined the company in 1998, as president of Frisby Aerospace, Inc. when it was acquired by Triumph. He was group president of the Triumph Control Systems Group until the Aerospace Systems Group was formed in April 2003.

Frisby is a member of the board of directors at Quaker Chemical Corporation, and he is on the advisory council to the Wayne Calloway School of Business and Accountancy at Wake Forest University. He is an active member of the American Society of Mechanical Engineers, where

he served on the industrial advisory board.

"I am proud to have been part of the Triumph success story over the years and am honored to have been selected as President and COO," Frisby says. "I believe we are well positioned to take advantage of the challenges and opportunities in the aerospace industry today and I look forward to working with Rick, Dave and our operating companies to develop, coordinate and execute strategies that will sustain and grow our business."

GE

FORMS GEAR VENTURE WITH CHINESE PARTNER

GE Drivetrain Technolgies, a unit of GE Transportation, has formed a joint venture company with Chongqing XinXing Fengneng Investment Co., Ltd. to produce large- diameter gears for the wind turbine industry.

Chongqing XinXing Fengneng is the majority owner, and the gears will be manufactured in a new facility in Chongqing, China. Initially, the business will manufacture the gears for GE Drivetrain Technologies' wind turbine gearbox production facility in Shenyang, China. GE Drivetrain and A-Power Energy Systems announced the facility's development as part of a joint venture agreement made in January 2009.

"As a supplier to some of the world's leading automotive and motorcycle companies, Chongqing XinXing brings a world-class manufacturing mentality to the production of wind turbine gears," says Tim Schweikert, president of GE Technology Infrastructure in China.

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When children are asked what they want to be when they grow up, the answers are undoubtedly diverse. Some immediately respond with doctor, lawyer or firefighter while others take a more creative approach with answers like spy, princess or superhero. The Addendum Staff has yet to come across a youngster that seems committed to a career in gear manufacturing.

The Discovery Center Museum, located in Rockford, IL is hoping to change this. With 250 hands-on exhibits, a planetarium, a news studio and an outdoor science park, the children's museum has a little bit of everything to educate young minds and highlight the appeal of science, manufacturing and engineering careers.

Two exhibits, particularly, hold interest to those reading this magazine. The *Gears Gears Gears* exhibit allows visitors to start a set of gears in motion and observe how the gears change speed, direction and force. The *Gear Wall* consists of a variety of colorful gears that children can arrange properly to spin a propeller extending above the wall.

"With both exhibits, visitors can observe things like how each gear affects the turning direction of the gear it engages as well as what happens when a large gear turns a small gear and vice versa," says Christopher Bernd, outreach coordinator. "Teachers can also bring their students to the Discovery Center for a special field trip featuring a class about simple machines."

The most exciting revelation might just be how interested the kids seem to be once they start work on the exhibits. "Our youngest visitors get a kick out of watching the gears on our *Gear Wall* and realize they caused the movement," Bernd says. "We often see children or whole families working together, adjusting gears, to make everything on the wall move."

In addition, the museum takes programs on the road to schools, daycares, libraries and park districts that focus on gears and pulleys.

"In our outreach programs, children love experimenting with the sequence and combination of gears. I often hear groans of protest when it's time to clean up and move on," Bernd says.

Along with gears and pulleys, the museum focuses on engineering and the benefits for children to get interested at an early age. For years, the Discovery Center has collaborated with local libraries, colleges and the Illinois Society of Professional Engineers to celebrate National Engineers Week in February. Activities include bridge building competitions, college and high school career nights and a program called "Discover Engineering."

Visitors can arrange the gears on the *Gear Wall* to spin a propeller (courtesy of the Discovery Center Museum).

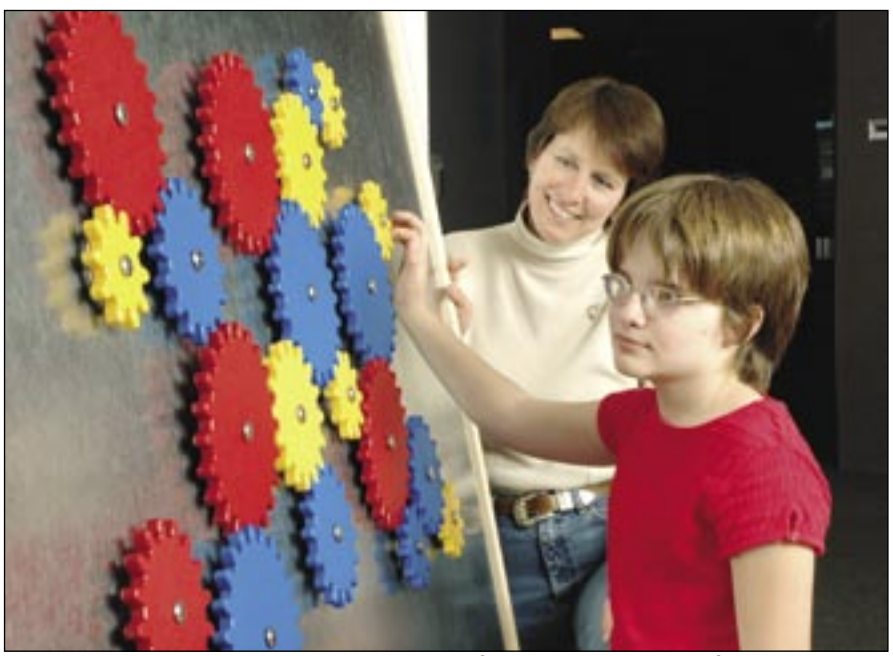
"This is where we invite local engineers and businesses that incorporate engineering and engineering technology in the products they produce, for what could be described as a hands-on expo for families," Bernd says.

This fall the museum is bringing several gear heads to Rockford, including Grant Imahara and Kari Byron from the Discovery Channel hit show *Mythbusters*. An electronics wizard, Imahara often makes the robotics for the show while Byron is the resident sculptor and model-maker. The two will be at the museum on Saturday October 3, for a 90-minute discussion focused on audience questions.

In the future, the museum plans to continue taking its exhibits on the road and getting the message out on career opportunities in manufacturing and engineering.

"If children can understand the process to produce something, they will likely appreciate the product more," Bernd says. "And an appreciation of that can lead to curiosity and learning."

For more information on the Discovery Center Museum, visit *www.discoverycentermuseum.org*.



How do gears change speed, direction and force? Children learn first hand at the *Gears Gears Gears* exhibit (courtesy of the Discovery Center Museum).

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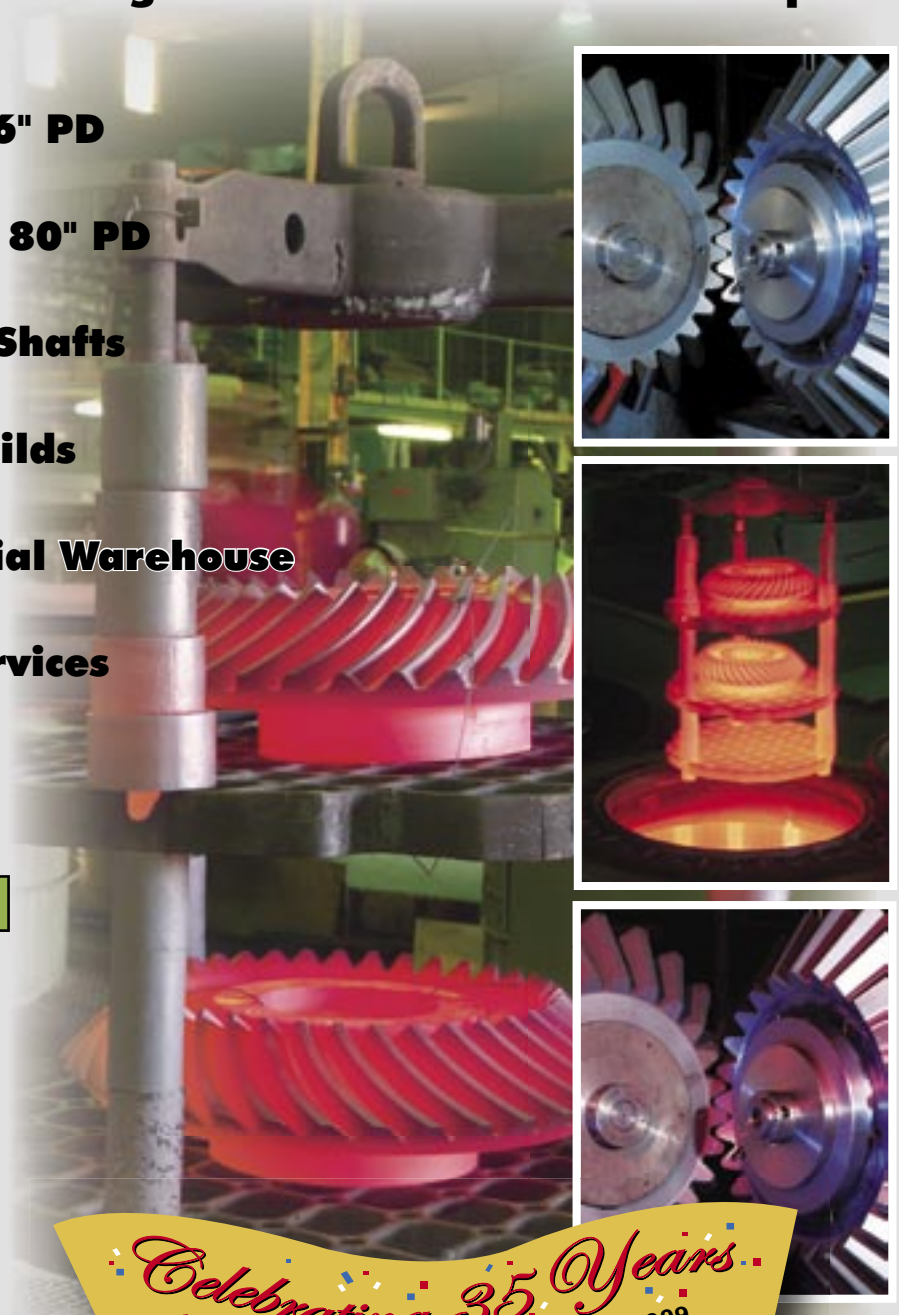

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