March/April 2007

GEAR TECHNOLOGY

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The Journal of Gear Manufacturing

PLASTICS

- Plastic Gear Standards: A Balancing Act
- Can't Get No Respect?

Technical Articles

- Transmission Error Testing
- Rolling Contact Fatigue: Part II
- Asymmetric Tooth Bending Stress

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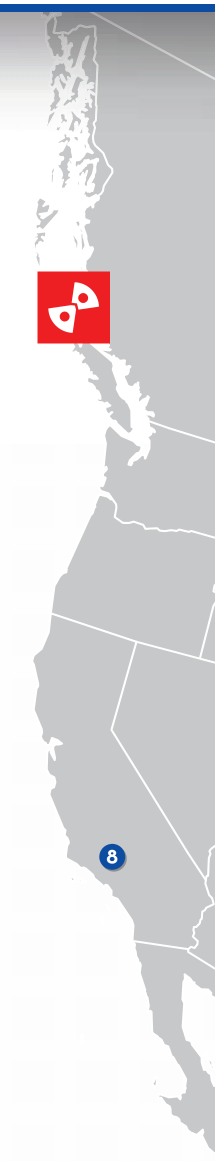

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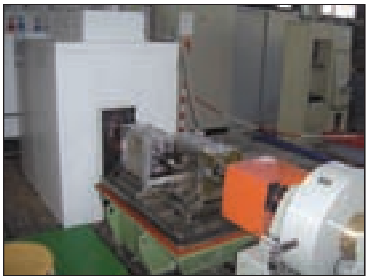
TECHNICAL ARTICLES



Vol. 24, No. 2. GEAR TECHNOLOGY, The Journal of Gear Manufacturing (ISSN 0743-6858) is published 8 times per year by Randall Publishing, Inc., 1425 Lunt Avenue, P.O. Box 1426, Elk Grove Village, IL 60007, (847) 437-6604. Cover price $7.00 U.S. Periodical postage paid at Arlington Heights, IL, and at additional mailing office (USPS No. 749-290). Randall Publishing makes every effort to ensure that the processes described in GEAR TECHNOLOGY conform to sound engineering practice. Neither the authors nor the publisher can be held responsible for injuries sustained while following the procedures described. Postmaster: Send address changes to GEAR TECHNOLOGY, The Journal of Gear Manufacturing, 1425 Lunt Avenue, P.O. Box 1426, Elk Grove Village, IL, 60007. ©Contents copyrighted by RANDALL PUBLISHING, INC., 2007. No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording, or by any information storage and retrieval system, without permission in writing from the publisher. Contents of ads are subject to Publisher's approval.

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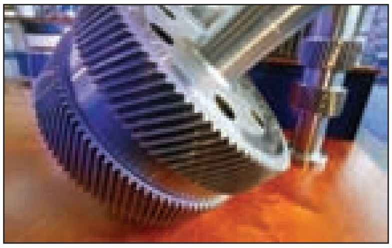

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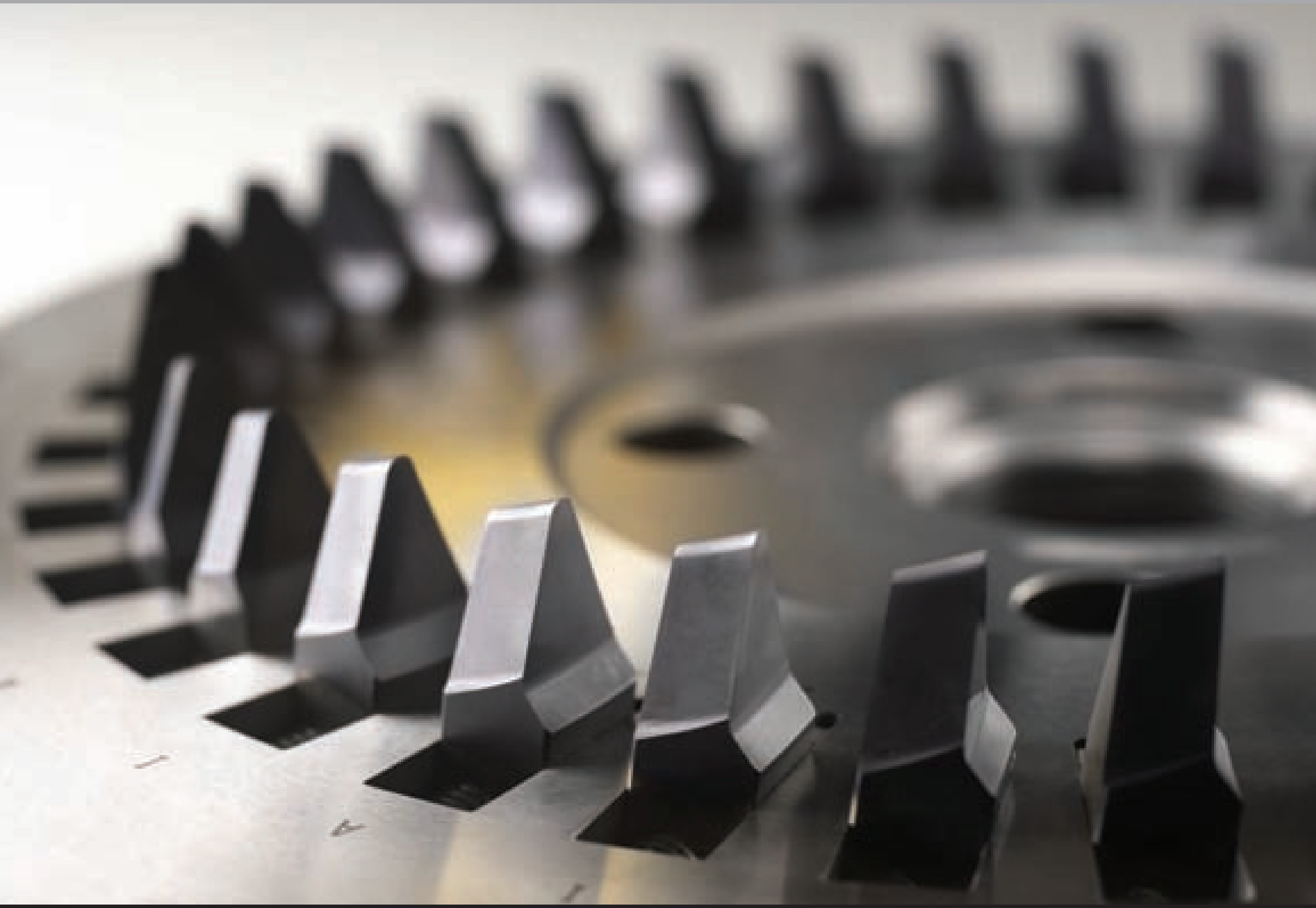

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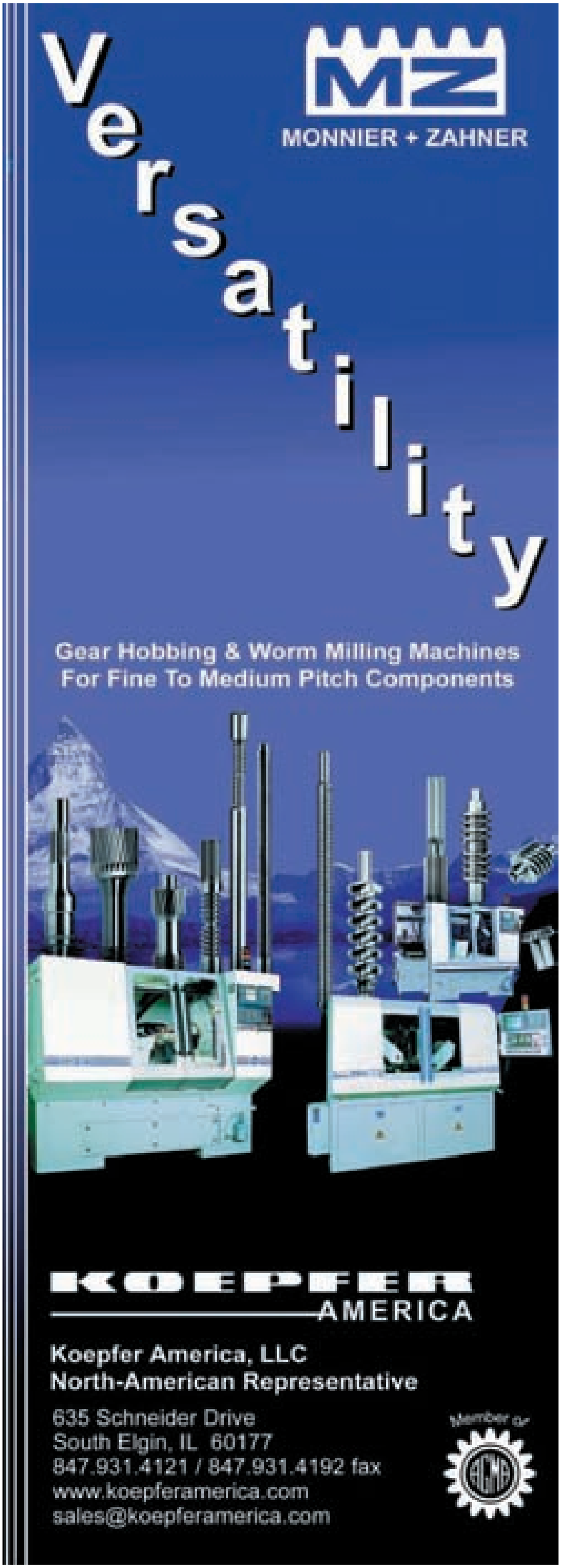

GEAR TECHNOLOGY

VOL. 24, NO. 2

Randall Publishing, Inc.
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Elk Grove Village, IL 60007
Phone: 847-437-6604
Fax: 847-437-6618

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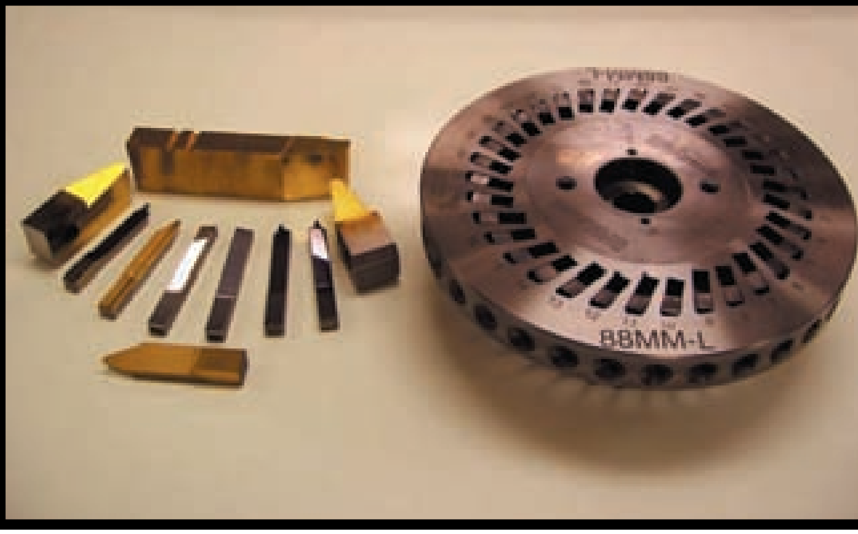

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Moving Into High Gear

In February, we launched a new magazine, *Power Transmission Engineering* (*PTE*). While most of you have probably already seen it, those of you who haven't can read the first issue online at *powertransmission.com*.

PTE is to the broader power transmission market what *Gear Technology* has been to the gear industry for the past 23 years.

As with *Gear Technology*, our goal with *PTE* is to educate and inform. To that end, we'll feature the highest-quality technical articles, combined with features, news and other information designed to help *power transmission* product consumers and users save money, be more productive and produce higher-quality products. But *PTE* goes beyond *Gear Technology*: in addition to gears, we'll also cover bearings and brakes, couplings and clutches, sensors and speed reducers. In short, all the types of components that help make things move, and which many of you already make, buy and use.

This is not completely new territory for us. We've been involved with this broader market for the past 10 years as publishers of the online buyers guide at *powertransmission.com*. Since 1997, *powertransmission.com* has grown to become one of the most visited and well respected industrial resources on the Internet. The site now receives more than 80,000 USER SESSIONS per month. Real people from all over the world use it every day to find suppliers of *power transmission* products.

We process dozens of sales leads per day for our *powertransmission.com* visitors and advertisers, including many of you who are readers of *Gear Technology*. Requests come for all types of products, and we forward those requests to the appropriate companies. Sometimes the requests are small—like the one from a recent visitor who needed a power take-off for his tractor. Sometimes the requests are quite large—like the one from a visitor who needed to overhaul or replace the gearboxes for a coal pulverizing plant. Sometimes our visitors are just in the design stage, looking for components they can build into their finished products. Other times, they're end users who have an immediate need to repair or expand their factory, assembly line or industrial plant.

Over the past 10 years, we've found that the people using the site wanted and needed additional information about these products, so we've added short editorial items like the news sections, which we update every day with products, calendar items and industry news.

But our visitors needed more in-depth information. *Power Transmission Engineering* was the next logical step.

There are, of course, other magazines serving the power transmission marketplace, but none of them with the depth or quality of information we publish. If you find the information in *Gear Technology* important and of interest—and many of you have told us you have saved every issue—we're confident you'll also like and need *Power Transmission Engineering*.

The February issue of *PTE* was a digital-only issue, and we'll be using the same electronic format for the rest of this year. But two issues—April and August—will also be printed magazines, delivered to 15,000 buyers of power transmission products, mostly in the United States—many of the same people who have already used *powertransmission.com*.

We're using this combined print-and-electronic strategy for a number of reasons. With *powertransmission.com*, our roots in this market have always been digital. Also, publishing issues online allows us to hold our advertising costs down while still allowing us to demonstrate to the marketplace the types of articles and information we'll publish. But at the same time, we understand the power of print, and we expect that by this time next year, *PTE* will be a print publication every issue.

Of course, much of that depends on you and your reaction to the new magazine.

If you think you can use this kind of in-depth information on bearings, motors, clutches, couplings and similar products, please sign up for a free subscription at *www.powertransmission.com/subscribe.htm*. If you're in the USA, Canada or Mexico, you can choose either the electronic or printed issues. Subscribers outside North America can sign up for the digital version.

Also, if you manufacture or sell *power transmission* products and you're interested in reaching serious buyers, then you can download the media kit at *www.powertransmission.com/mediakit07.pdf*. Or call our sales manager, Ryan King, at (847) 437-6604. *powertransmission.com* and *Power Transmission Engineering* provide you with a print-and-electronic advertising combination that's aimed specifically at your customers.

Finally, if you have technical articles, feature story ideas or news that you think might be appropriate for either of our magazines or our websites, please call us or send an e-mail to *publisher@geartechnology.com*. We're interested in anything that helps educate the industry, and we'd like to help you share your story. If we're reaching your customers and potential customers, your articles can help them be better informed buyers. A sales engineer is too expensive to be an educator. Besides, that's our job.

Michael Goldstein

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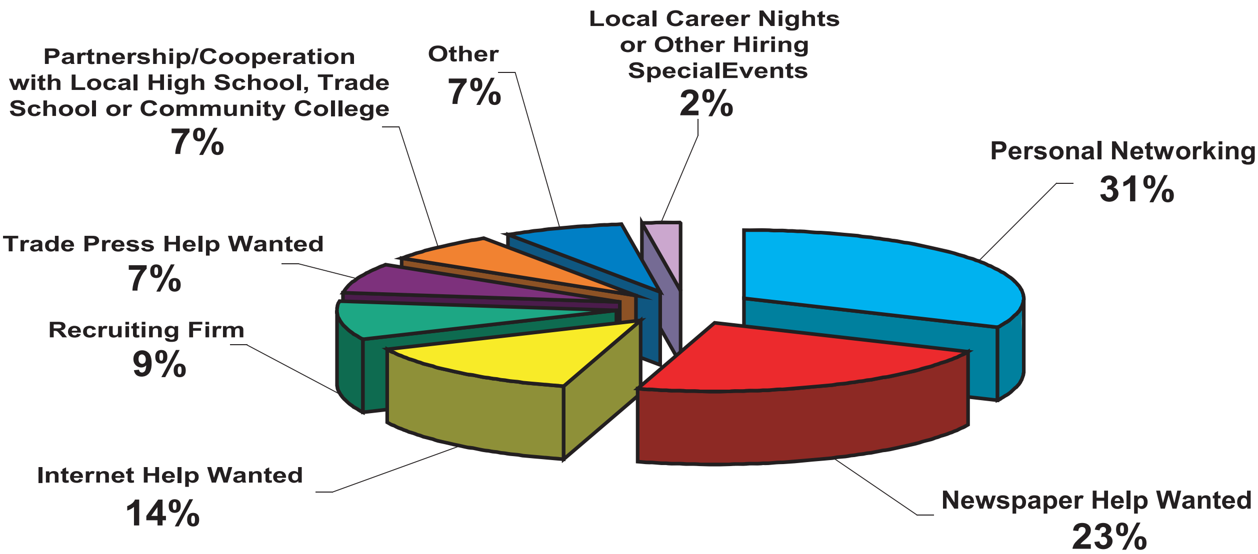

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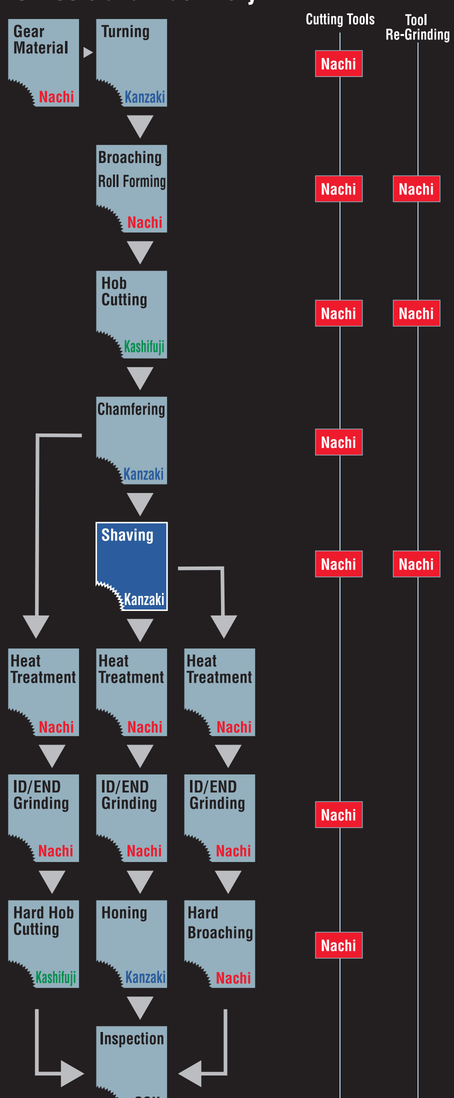
Gear Cutting Process Task Assignments for Tools and Machinery



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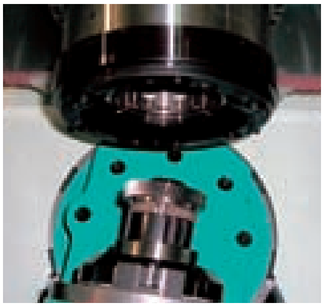

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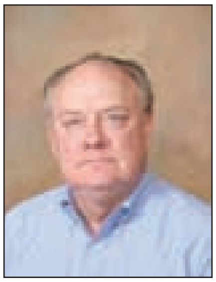
Zan Smith

Plastic Gear Standards: A Balancing Act

David Sheridan and Zan Smith, Ticona Technical Polymers

Creating standards for plastic gears calls for a deft touch. The challenge is to set uniform guidelines, yet avoid limiting the creative solutions plastic offers gear designers.

Few standards and guides exist for plastic gears. This is not surprising given that they have only been used for about 60 years compared to hundreds of years for metal gearing. Another reason lies in plastic's great variability. This class of materials encompasses diverse resin families, each offering many choices in the nature of the polymer and the ability to enhance performance with fibers, fillers and functional additives. In addition, a polymer's mechanical properties can shift significantly with temperature and other environmental factors within the typical operating range of a gear set.

At this time, just two American Gear Manufacturers Association (AGMA) plastic gear standards exist: ANSI/AGMA 1006-A97, Tooth Proportions for Plastic Gears, and its metric version ANSI/AGMA 1106-A97. They were developed in 1997 and set standardized tooth profiles for spur and helical gears. Some other national bodies have also created plastic gear standards. British standard BS 6168 looks at non-metallic spur gears and has many similarities with the German document VDI 2545. There may be plastic gear standards from other countries that are unknown to the authors.

In recent years, AGMA has published two information sheets as plastic gear design guides. One, AGMA 920-A01, Materials for Plastic Gears, offers help in selecting polymers for injection-molded and cut gears based on understanding material behavior and molding considerations for dimensions and gear-related properties. The other, AGMA 909-A06, Specifications for Molded Plastic Gears, applies to injection-molded external and internal spur and helical gears. AGMA also has documents underway on test methods and inspection for plastic gears.

Need for New Standards

Among the many possible plastic gear standards that remain to be developed, two would be especially useful: one for load ratings and the other for quality measurement.

The lack of a universal approach for calculating loading in plastic gears leads designers to translate metal gear stress calculations to plastic. Analytical methods used for metals are appropriate as long as the analysis properly considers the geometric and mechanical variations of plastics. A finite-element approach is best used only after the geometry has been optimized analytically. The challenge in standardizing such calculations, however, is that plastic gear property profiles vary from polymer to polymer, and properties change with additives and operating environment factors, such as lubricant, temperature and moisture.

British standard 6168:1987, Specification for Non-Metallic Spur Gears, is a rating standard for several generic families of plastic spur gears. The German document, VDI 2545, Zahnräder aus thermoplastichen Kunststoffen (Gear Wheels Made from Thermoplastics) is a widely referenced document from 1981 and is the predecessor to BS 6168. A shortcoming of these rating documents is that they cover a limited set of materials, so designers must often rely on material suppliers for guidance on material selection and properties for any given application.

The accuracy of plastic gears in the United States is usually stated using AGMA Standard 2000-A88, Gear Classification and Inspection Handbook, Tolerances and Measuring Methods for Unassembled Spur and Helical Gears (Including Metric Equivalents). This is commonly referred to as the AGMA "Q number" system. This system was developed with cut metal gears in mind. But plastic has different attributes than metal when it comes to accuracy; for instance, plastic may do a better job on tooth-to-tooth consistency, but not as good on runout.

One issue with plastic gears is that tolerance levels may vary by feature on a gear. At this time, the Q level for a plastic gear is commonly assigned based on the worst feature. This does not do justice to the performance of many gears. One solution would be a plastic gear accuracy system that allows quality to be expressed as tolerances on various features, e.g., the runout, pitch, profile and lead that meet a gear's application requirements. Many plastic gear designers simply assign tolerances without reference to any accuracy standard.

Beyond Standards

Having a solid body of standards for the use of plastic in gears is essential in fostering the use of such gears. Equally important, however, is the need to educate those who design gears in how to make the best use of this material and understand the peculiarities of an injection-molded part with regards to tooling and processing. For instance, designers need to move beyond the belief that they must adhere to the standard tooth forms defined in metal gear manufacturing standards.

Designers would be better off if they treated standard tooth forms as starting points and then optimized their designs to satisfy the requirement of a finished gear set. This approach makes sense because cavities for plastic gears must be cut to non-standard dimensions to accommodate differential shrinkage. Customizing the mold for shrinkage opens the door to incorporating optimized tooth forms for an application at little or no added cost.

Plastic's variability is one of its great strengths and underpins the design freedom it allows. But this variability also complicates the job of standardization. Moving forward there is a need for new global standards that account for this variability, such as those for material-specific load ratings and flexible accuracy ratings, to support gear manufacturers anywhere in the world.

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EXPANDS TOROID TOOL LINE

Dapra Corporation recently added 12 new shell mills in ODs from 2" through 8" to its high-performance Toroid cutting tool line.

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Dapra's new octagonal inserts have eight-sided geometry for general face milling capabilities. Their 45-degree lead angle provides increased feed capacity for face milling, profiling, and helical interpolation and chamfering.

In order to simplify the matching of the various-shaped inserts with specific cutter bodies, Dapra provides "R-value" designations, which can be found on each cutter body. Compatibility can be achieved by matching the insert and cutter body "R-values," the company says.

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Slater Tools

INTRODUCES ROTARY BROACHING TOOL HOLDER

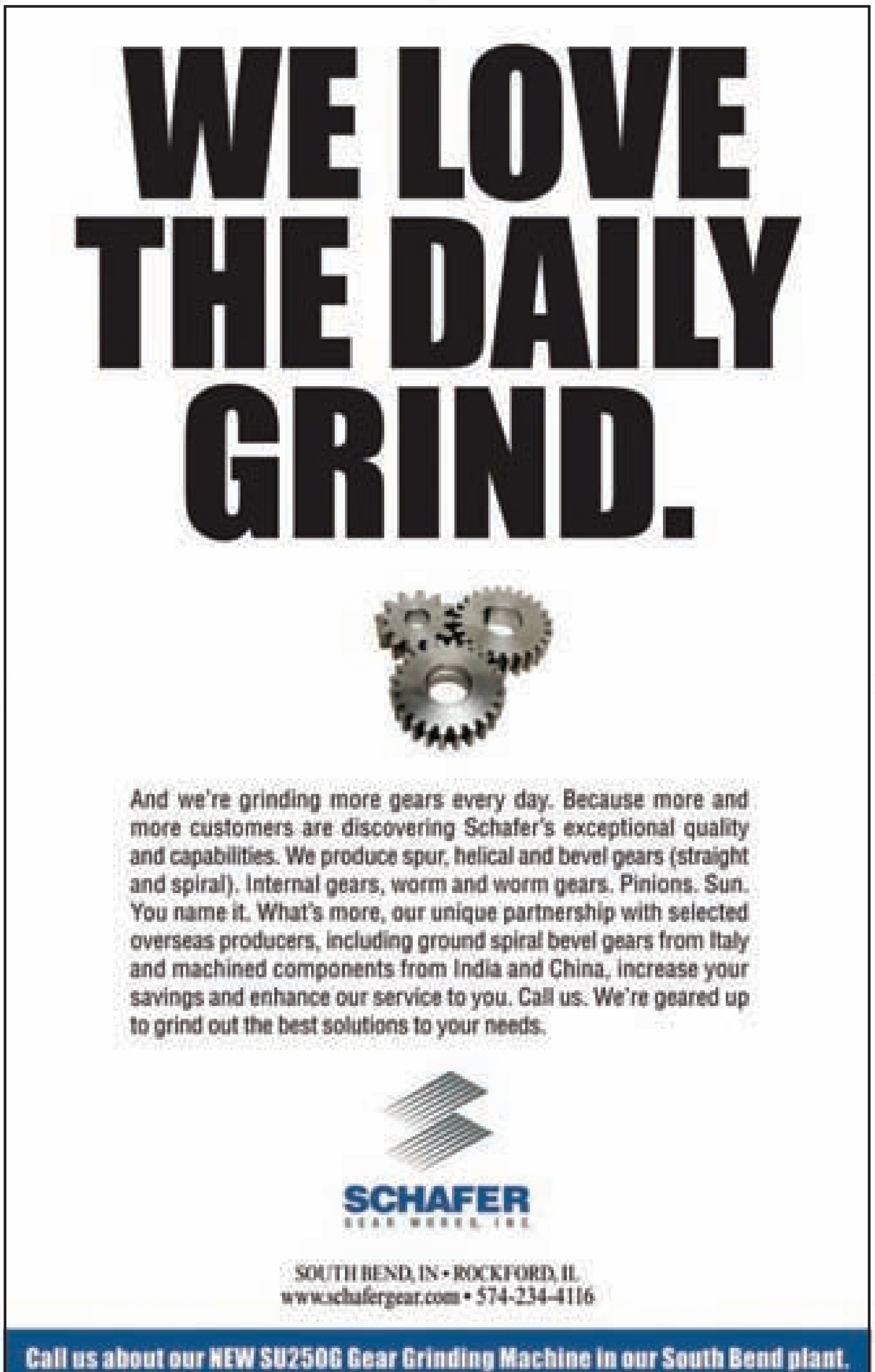
Slater Tools Inc. released a new, adjustment-free rotary broaching tool holder designed for Swiss-type machines.

Slater's new adjustment-free design allows the operator to use the tool holder without the need for centering. According to Slater's press release, the new rotary broaching tool holder's design is the smallest in the industry, eliminating interference and clearance problems, and providing easy access to the grease fitting.

Slater's new tool holder uses the standard 1.25" length rotary broaches, available from stock. This length allows for deeper broaching than current non-adjustable rotary broaches and tool holders. The adjustment-free rotary broaching tool holder is used for any type CNC, Swiss, or manual turning, milling, drilling or screw machine.

Rotary broaching—also called hex broaching or wobble broaching—uses a precision tool to produce an internal form inside a pre-drilled hole. The result is a polygon form, which matches the shape of the broach. For instance, a square broach measuring 1/4" produces a square hole of the same size. Broaches are available from Slater Tools Inc. as squares, hexagons, splines, serrations and other polygon forms.

For more information:
Slater Tools
44725 Trinity Dr.
Clinton Township, MI 48038
Phone: (586) 465-5000
Internet: *www.slatertools.com*



Rex Cut's Mounted Points

REACH DEEP INTO CHANNELS WITH LITTLE VIBRATION

A line of mounted points available in various shapes and sizes to fit into channels and other contoured spaces for repairing and maintaining molds and dies is introduced by Rex-Cut Products.

The Rex-Cut® mounted points feature multiple layers of non-woven cotton fiber and aluminum oxide or silicon carbide abrasives that are pressed and bonded into a variety of industry-standard shapes and sizes. According to the company's press release, the points are suitable for mold and die repair and maintenance, and are capable of reaching deep into channels and provide controlled operation with little vibration.

Offered in very fine- to coarse-grain sizes and two bonds—MTX, where more metal removal is required and GFX for light metal removal, cleaning, and polishing—Rex-Cut mounted points deburr, grind, and finish without changing the part geometry. They are suitable for use on aluminum, mild, stainless steel, titanium and other exotic and highly alloyed parts.

For more information:
Rex Cut Products
960 Airport Rd.
Fall River, MA 02722
E-Mail: *bobc@rexcut.com*
Internet: *www.rexcut.com*

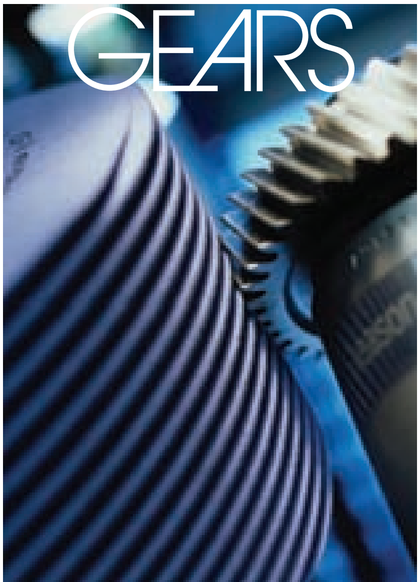
Hardinge

DEBUTS TURNING CENTER AT WESTEC

Hardinge introduces its SR-Series multi-tasking turning center, utilizing a three-jaw chuck.

According to the company's press release, Hardinge developed the SR-Series as an extension to its line of turning centers, positioning it as a heavy-duty chuck and bar turning center that can be configured with many multi-tasking capabilities to machine

GROUND GEARS



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With up to 25% more torque and horsepower, and 24% more speed than previous Hardinge turning centers, the SR-Series turning centers will cut tough materials and handle deep interrupted cuts while maintaining overall part accuracy.

The SR 150, 200 and soon-to-be-released 250 all feature superior vibration damping, accomplished through the use of heavy-duty, linear roller guides mounted to a HARCRETE-reinforced cast iron base.

This platform allows the user to tackle tough work almost vibration-free while reducing expenditure.

According to Jeff Ervay, Hardinge North American turning product manager, "The range of SR-Series 'chuck and bar models' offers a precision machine to a whole new audience for Hardinge, having best-in-class torque and horsepower that makes these machines really stand out in their category. The SR machines allow unmanned operation, high throughput, and 'done-in-one' capability in a high-

production or job shop environment, plus the ability to perform these operations on hardened material."

Displayed as a prototype at IMTS 2006, the first ever production version SR-Series machines will be introduced in Machinery Sales' booth 3316 at the WESTEC 2007 Exposition & Conference Center in Los Angeles March 26-29.

For more information:

Hardinge Inc.
Phone: (800) 843-8801
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Schunk

RELEASES NEW ELECTRICAL MINIATURE HIGH-SPEED PARALLEL GRIPPER

Schunk Workholding's miniature high-speed parallel gripper (MHP) is the two-finger counterpart to the centric gripper SMG.

According to the company's press release, the new gripper with electromechanic drive achieves short cycle times and is also equipped with end-position dampening and integrated electronics for optimized control. A longer tool life is assured by maintenance of the end positions without power, which avoids an overload due to continuous power.

For fast applications, Schunk recommends the MHP. The angular position of the gripper head is unlimited and continuously adjustable to the individual gripping situations. Moreover, the roller bearing gripper jaws, with their thread holes, offer various attachment possibilities for universal gripper fingers. For simple and universal adjustment in applications and installations, a connection extension is available as an additional accessory.

For more information:

Schunk Workholding
211 Kittyhawk Dr.
Morrisville, NC 27560
Phone: (919) 572-2705
E-mail: *info@us.schunk.com*
Internet: *www.schunk.com*

Ingersoll Cutting Tools

INTRODUCES INSERT AND TOOLING FAMILY

Ingersoll Cutting Tools introduces its Hex-Turn family of inserts and holders.

According to the company's press release, the 12 cutting edges of these hexagonal, negative-geometry inserts can reduce production costs.

Each corner of the insert features wiper geometry to enhance surface finish, even at high feed rates. The 45° lead angle allows high feed rates with low cutting forces. A 120° included angle provides a strong insert design and improved resistance against notching.

The external and internal tool holders utilize Ingersoll's T-type clamping system. Internal holders feature directional coolant control.

For more information:

Ingersoll Cutting Tools
707 Fulton Ave.
Rockford, IL 61103
Phone: (815) 987-6000
Internet: *www.ingersoll.com*

Holroyd's Plated CBN on High-Rigidity Edgetek Machines

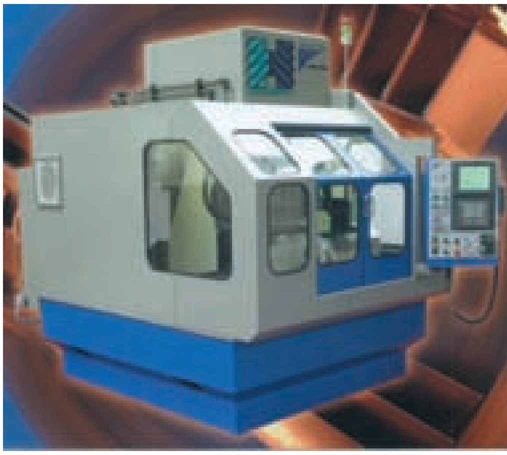
REDUCES PROCESS TIMES WITH SINGLE LIFT AND SETUP

Holroyd's Edgetek machines are produced with high-power/high-speed spindles that optimize the use of plated CBN wheels at surface speeds of up to 9,000 m/min. This enables them to achieve high depths of cut and optimized metal removal rates exceeding those of more conventional machines, such as CNC lathes, milling and machining centers and grinders.

In addition, the Holroyd Edgetek machines are manufactured with a polymer granite base.

The polymer base typically weighs 3 tons and has no resonant frequency. As a result, it enables higher precision machining to be achieved.

Combining the stiffness and damping capability with the Edgetek's ultra-high-speed machining capabilities and plated CBN wheels, the machines reduce cycle times in many crucial industry sectors. In one example, the cycle times for producing automotive parts manufactured from sintered metals were reduced from 70 seconds per component to just 22 seconds. At the same time, the Edgetek's plated CBN technology achieves a reduction from $1 to just 3.3 cents per component. This is the result of the Edgetek machine producing a much larger number of



components between tool changes: 15,000 as opposed to the 50 achieved with conventional milling and turning machines.

In another UK application, a single five-axis Edgetek machine is slashing process times with single lift and set-up. The Edgetek is replacing seven conventional milling and grinding

continued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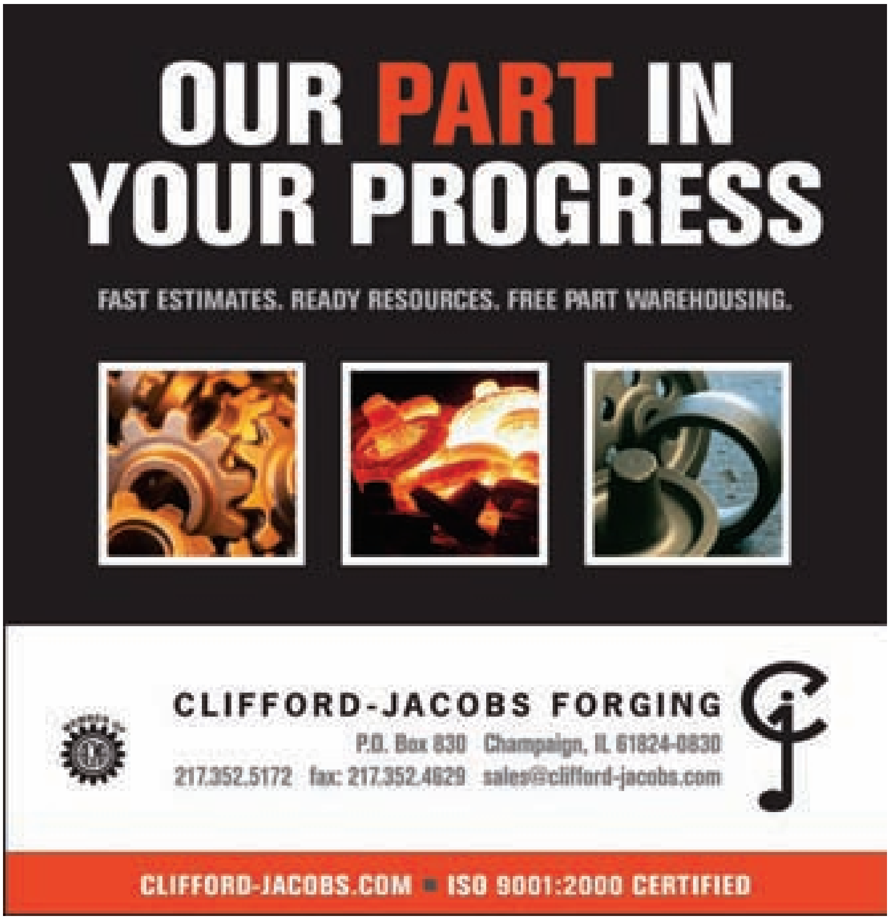

machines, providing a reduction in the throughput time for a complex finished part from 8 hours to just 12 minutes. "This application epitomizes lean manufacturing technology," said Holroyd's sales director, Neil English. "It provides the opportunity to begin with a hardened blank, and then produce a completed part in a single setup, using plated CBN wheels."

"It is not the cost that is driving the trend toward plated CBN, but the productivity," says English. "Smaller production runs and more setups means that many companies no longer have the luxury to amortize the cost of bonded wheels, and the long non-productive set-up times associated with them, over extended production runs. Plated technology fills the need for high metal removal rates with short set-up times and eliminates the need for dressing."

The flexibility of the Holroyd Edgetek design, and the variety of machine types and multi-axis configurations available, enables the machines to provide higher levels of precision and productivity in the manufacture of gears, sprockets, rotors and impellers, medical instruments, hand tools, air foils and nozzle guides, airframe actuation components, ducting supports, and mechanical seals. The machines serve a broad spectrum of industry types, including power generation, automotive, aerospace, medicals, tools and general engineering.

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Injection-molded gear manufacturers like ABA-PGT are at the leading edge of plastic gear manufacture.

Plastic Gears—

A Growing Industry Still Seeking Respect

Jack McGuinn, Senior Editor

Mr. McGuire: *I want to say one word to you. Just one word.*
Benjamin: *Yes, sir.*
Mr. McGuire: *Are you listening?*
Benjamin: *Yes, I am.*
Mr. McGuire: *Plastics.*

—From the 1967 film, The Graduate

Forty years ago, the plastics industry was practically in its embryonic phase when that classic movie line was delivered to Dustin Hoffman's befuddled, just-graduated, in-search-of-a-career character, Benjamin Braddock. Today, although still in its infancy, plastic gear manufacture has made significant gains in the gear industry, with plastic gears now being used in applications never thought possible. And yet, while envelope pushing by plastics suppliers, gear manufacturers and end-users alike guarantees that plastic gear market share will continue to grow, there nevertheless remains a level of skepticism. A number of product designers and parts specifiers with industrial applications remain unconvinced that gears produced from plastic are capable of matching the high-temperature, high-power functionality of metal gears. But talk to any number of relevant players in the plastics industry—gear molders and suppliers—and they will tell you that when decisions are made regarding gear materials for high-capability, high-performance applications, plastic gears are getting a bad rap.

Zan Smith, an engineering associate with Florence, KY plastics supplier Ticona, says the plastic industry must at times overcome misperceptions, in relation to other materials.

"I think sometimes the use of plastic is avoided because there is a lack of understanding about its effectiveness," he says. "There are some applications where plastic would probably be the preferred material, but OEMs fail to consider it because they are unfamiliar with its performance capabilities." He adds that, in recent years, the plastics industry has done a good job of promoting the benefits of plastic and shifting

"Lights Out" manufacturing provides cost-effective packing and shipping at ABA-PGT's Vernon, CT plant.

attitudes about the use of plastics in challenging situations, such as in gears.

Over the years, plastic gears have indeed proven themselves time and again, and are certainly here to stay in significant numbers. While estimates vary and are—at best—just that, industry experts point to some very healthy numbers regarding the size of the plastic gear market.

"On a sales revenue basis, we believe approximately 10% of gears sold are plastic," says Thomas E. Grula, account manager for DuPont. "On a number of gears sold basis, the figure is much higher; but we have no good estimate."

Richard Wheeler, president of Manchester, CT-based plastic gear molder ABA-PGT, Inc., breaks down the data a bit further.

"According to a market survey completed in 1997 by the market research firm Freedonia Group, the demand for plastic gears in the U.S. was projected to grow more than 10% annually, to roughly $1.5 billion in 2000 and to $2 billion in 2005," he says. "Plastic gears are produced by OEMs (captive molders), custom molders and gear molders. Based upon rough estimates, the gear molders produced approximately $100 million in 2000, or less than 7% of the $1.5 billion in plastic gears shipped in 2000."

What's in a Name?

Generating those numbers are a variety of applications in which plastic is the gear material of choice—including, but by no means limited to—office and lawn equipment; automotive interior, exterior and under-the-hood components; and pumps. The list grows with each new advancement in plastics engineering. But before going further, perhaps a primer in plastics terminology would be helpful. While there is no shortage of names out there for what in the end is universally known as "plastic," there are distinctions to be made.

"'Plastic' is a good term to use, and the most convenient," says Grula. "However, a better term may be polymer-based materials. The term 'plastic' is short for thermoplastic, which implies that the material is melt-processable. Some key material in the growth of gears produced from polymer-based materials may not be melt-processable; they may require other fabrication techniques, such as sintering. This is especially true in the area of materials with improved heat resistance."

Ticona's Smith relates a humorous experience he had at his local optometrist that lends some perspective to the confusion in terminology.

"(The optometrist) asked me if I wanted polycarbonate or plastic lenses,

continued

and I said, polycarbonate is plastic….he said, 'No it's not.' And I asked, Well, what is plastic? And he gave me some spec number or something he thought was plastic, but he insisted polycarbonate was not plastic. And it was much better than having glass or plastic."

Automotive Inroads. And More.

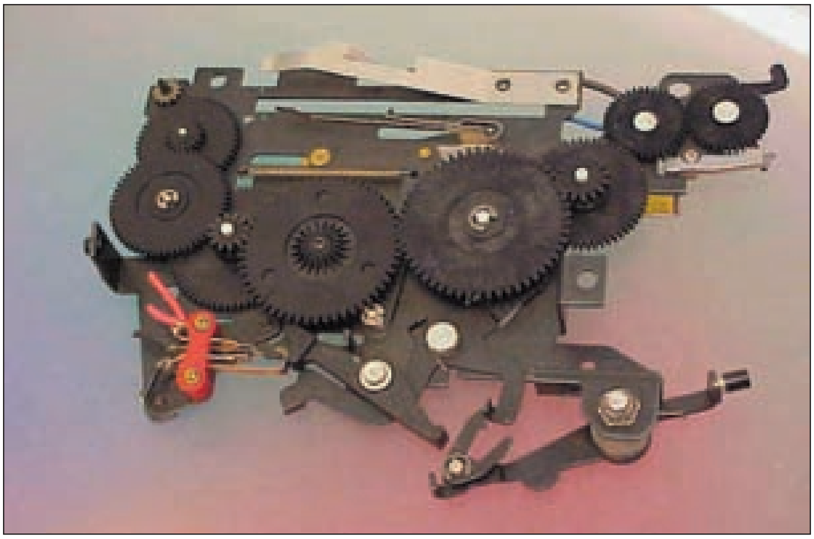
Funny anecdotes notwithstanding—and whatever one calls it—the use of plastic gearing is growing.

"Any opportunity where operating environment permits the use of plastic gears, the conversation is being made," says Edward Butler, vice president of engineering for Seitz Corp in Torrington, CT. "Temperature, stress, and chemical attack, which may be present in the application, need to be design considerations for plastic gears. Plastic gears are an inexpensive solution to steel gears, and offer such benefits as reduced noise generation as well as improved lubricity, which can be added to plastic material."

Grula echoes Butler's optimism for expanded application opportunities.

"Automotive applications are a high-growth area for plastic gears, and the continued development and proliferation of power-actuated accessories is a key driver."

He adds, however, that those opportunities will also require more than newly engineered plastics. "Greater penetration in under-the-hood applications will require continued advances not only in materials technology, but in gear design and processing technology as well."



Plastic gears are found in all kinds of applications. Shown here is an ABA-PGT gear set for a device that makes change for paper money in vending machines.

Plastic gears are now common in automotive applications such as this seat position sensor from ABA-PGT.

Ticona's Smith supports that statement, pointing to fundamental design changes in how automobiles are built. Those changes are leading to the increased use of plastic gears that will be required to function in an extensive temperature range.

"Power steering is getting away from hydraulics, and you're beginning to see electric power steering with plastic gearing being involved there," he says. "And there's movement towards electric in the braking system, and there may well be an opportunity for plastic gearing in that area."

There are, according to Smith, efforts already underway in that regard in both Europe and the U.S.

Too, the home appliance market has for years been fertile ground for plastic gears. What is new is the fact that plastic gears are now being seen in heavy home appliances such as washing machines.

Lack of True Benchmarks a Standard Complaint

If there is one thing that retards further expansion of plastic gears in higher-performance environments, it is the lack of well-defined global or even North American standards. Considerations such as load and stress conditions, tolerances, inspection, calculation software, fatigue testing and other due diligence common to gearing—both plastic and metal—are all areas that will require more clarity and consistency in order to enable expanded acceptance of plastic gears.

David Sheridan, senior design engineer for Ticona, is one of many in the industry who believes such clarity is long overdue. And it must allow for the apples-and-oranges differences from metal gears inherent in injection-molded plastic gears.

"There is definitely a need for something different from what is out there, specifically in the plastic gear industry. But the issue really is that gear feature tolerances—within a certain quality level—were originally established by the metal gear machining capabilities.

And injection molding is really a different beast, and it has different capabilities and properties. So for some features you can get tighter tolerances for molded plastic gears, and for some features you get worse tolerancing."

The nature of the "different beast" that is injection-molded gearing does indeed require outside-the-box calculation by gear designers that goes beyond, for example, available standardized ISO testing data for materials. Even the most promising, leading-edge thermoplastics may go unused for gears if the need for effectively precise standards is not realized.

"For gear designers to get the precise data that they require to optimize plastic gear design and functionality—and, thereby, expand into new markets and end-use applications—the gear industry needs to develop an agreed upon method to test molded plastic gears under specific load and stress conditions," says Grula. "This is true even for existing materials, where much of this data does not exist. It is likely even more important as newer, higher-performing materials are developed."

He goes on to say that plastic-specific gear testing is "difficult" due to the many different variables facing gear designers in the interpretation and implementation of the test data. "This is an area in which the AGMA Plastic Gearing Committee is working," he adds.

Grula's frustration with this dilemma serves to support Zan Smith's thoughts regarding the skepticism plastic gears must overcome. He points out how that skepticism adversely affects not only plastic gear manufacturers, but also end-users' bottom line.

"Today, gear designers typically have to rely on material performance data derived from standardized (ISO) testing, provided by material suppliers to be used across all applications," he says. "The problem is that this data is not specifically relevant to gears, so the resultant gear designs and material selections are often unnecessarily conservative, leading end-users to reject plastic-based gear systems that may offer the best, most cost-effective solution."

Much of the need for new standards derives from the physical properties of plastic, especially in the injection molding process. Seitz Corp.'s Butler is another who maintains that more robust, plastic gear-specific calculation standards are a must for optimal gear design.

"The ability to calculate contact stresses, bending stresses and tooth deflection is essential to good gear design," he says. "Approximation of these calculations from 'cookbook' calculations is still widely used; however, actual modeling of the gear meshes in an FEA package allows better evaluation of the dynamics of the gear mesh, resulting in better feature design."

For ABA-PGT's Wheeler, test-and-verify is a good way to prevent costly, uninformed assumptions in plastic gear design, especially when a newly engineered plastic is part of the equation. A trap designers often fall into, for example, is in extrapolating narrowly derived performance standards to plastic gear design.

"Plastics don't behave like metals, so it is always difficult to model plastics. You can't just pull data and trust it," he says. "Plastic tensile strength standards—such as ASTM D638-03 (ISO 527-1)—give an approximation only. ASTM test bars, which all suppliers use, fall far short of a gear in determining actual performance.

"Better is to get the wear and strength data from actual gear testing. Some, but not many, of the material suppliers are working on compiling that data."

According to some in the industry, plastic gear design and certifiable standards suffer from too much off-the-shelf thinking when attempting to nail down truly accurate tolerancing. As is often the case, it is a question of quality levels.

"The reason (tolerancing) is hampered," says Ticona's Sheridan, "is that the quality level that's assigned to a plastic gear is determined by its widest-toleranced feature, so recognizing that there needs to be something different

is key. One of the proposed solutions is some kind of plastic gear accuracy system that allows specific tolerancing for specific features, instead of lumping it all together under one grouping and relying on the lowest common denominator."

Given plastic gearing's brief history, and the wider range of material choices plastic provides, the stakes are higher when attempting to qualify a certain plastic for a high-performance application. It is almost as if plastic is literally held to a higher standard than metal in that process.

"Plastic has been around for only 60 years, compared to metal where they've had a long time to figure out what's right and wrong, and even so they're still tweaking," says Smith. "So usually, when the metal guys are working on something they're looking at a relatively—especially in the high-performance stuff—few materials. So you can practically write a standard for a specific grade of metal.

Photo courtesy DuPont/Winzeler Gear.

"Whereas in plastics, we have all kinds of different polymer bases with all kinds of different additives we can put in to modify it. And then we can mix and match all kinds of different materials in the same gear set and a different housing. So you can have three or four different materials in the same application."

Beyond standards, plastic gears present other hurdles for material suppliers and gear makers. Lubricity, thermal expansion and contraction effects on mesh geometry, flexing and creep, parallelism of gear housings relative to stiffness, fatigue endurance and reliable calculation methodology are among the more important issues.

But one "hurdle," according to Grula, can in fact lead to a beneficial result in a number of ways. He points out that the teeth of plastic gears—by their very nature—flex back and forth repeatedly when in operation, which in fact results in significant load sharing between the teeth. This characteristic explains why plastic-molded gears often exceed their expected performance level.

"Other areas where gears made from polymer-based materials can significantly out-perform metal gears are in noise reduction, corrosion and chemical resistance, reduced weight, design freedom/combined functionality, and also cost."

Experience Counts. And Saves Money.

The last, key ingredient in plastic gearing—as far as the customer/end-user is concerned—is where to go to have them manufactured. It depends in many ways upon the difficulty of the application. For commodity-type, simple gear sets, most injection molders are a reliable resource. But if gear quality—low noise and vibration, optimal repeatability of positioning tolerances and long product life—is paramount, an experienced gear injection molder is the best resource, says Mark Thompson, ABA-PGT's business development director for molding.

"Plastic gear quality is usually determined by measurements of concentricity, roundness, involute profile, tooth spacing errors, axial hourglass or taper, helix angle and size, i.e., arc tooth thickness, outside and root diameters."

Another distinct reason for not going on the cheap with a generic molder is that elephant in the room—the lack of reliable, universal inspection standards.

"Plastic gear quality is sometimes determined by analysis of material integrity, for which no common inspection methods have been developed," says Don Ellis, an ABT-PGT gear engineering team leader. "Some of the common areas that affect the quality of plastic gears are crystallinity (strength), voids (internal stress risers), cold welds, residual stresses and location (alignment of fibrous reinforcement along the tooth profile)."

He adds that to prevent part variation, it is vital that the injection molder have extensive experience and knowledge in gear making as they pertain to controlling: material conditioning; time and temperature (must be held to the recommended processing parameters to prevent the material from degrading, which would result in reduced material properties); time and pressure settings for injection; temperature/injection rate; and mold cycle time. And while non-gear molders may well be aware of all these concerns, it is typically their lack of a gear-specific information database that results in taking several bites of the apple before a gear is manufactured with the required precision.

So, if you are a gear designer or parts specifier, which will it be—plastic or metal? It is your decision, of course, but make sure you do your homework before you buy.

Another tale from Zan Smith explains why.

"I remember seeing a machine shop machining a bevel gear that was relatively low in volume. And when I asked why they were machining instead of injection molding it, the shop owner

Not your father's metal gear shop. (Photo courtesy ABA-PGT.)

said that his customer required the accuracy of machining. This was only a couple of years ago and he had been doing it that way for 20 years, and his customer is probably unaware that the accuracy of the plastic gear industry has changed so much in 20 years that he can probably get a more accurate (and cheaper) plastic part than from the guy machining it. But everyone was happy, although that was clearly an application that could have been replaced by injection molding."

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Transmission Error and Noise Emission of Spur Gears

Piermaria Davoli, Carlo Gorla, Francesco Rosa, Fabrizio Rossi and Giuseppe Boni

Management Summary

Transmission error (TE) is recognized as one of the most important causes of gear acoustic emissions. There are many ways to reduce it in the design of the gear teeth, but the effectiveness of any action needs to be validated through experimentation with real parts. In this paper, a test rig for TE measurement is described and some TE experimental measures are discussed.

Introduction

According to Munro (Ref. 1), the idea of "transmission error" was introduced first by Harris (1958) and, some years later, by Niemann and Baethge.

Nevertheless, before the analytic definition of TE, it was universally recognized that tooth deformation under load during mesh affects the meshing kinematics, thus causing impacts between mating teeth, which are the main source of the acoustic emission of the transmission. Profile modifications (e.g., "K profiles") were born from this recognition and are widely applied today, but these modifications are often based on empirical rules, or they are selected according to similar successful experiences. Therefore, the practice of applying profile modifications to reduce gear noise and vibration was introduced before the definition of TE, as confirmed by papers in the 1940s by H. Walker and D.W. Dudley, who proposed to use it "to reduce noise, friction and wear" (Refs. 2–5).

Today there are many theoretical and computational tools which can predict the transmission error of a gear during the design stage. These tools allow the designer to introduce appropriate profile modifications to reduce TE, not empirically, but on the basis of consolidated theories.

Nevertheless a precise correlation between gear TE and noise is still lacking, and much research continues because of the great number of phenomena involved. Due to the unavoidable approximations introduced by numerical models and to the difficulties in reproducing the desired tooth profile through machining processes, it is not easy to choose the best modification for decreasing acoustic emission.

In order to develop a theoretical model closer to reality, experimental tests are necessary to understand why sometimes profile modifications, designed to reduce noise, have such different effects from those predicted.

What is Transmission Error?

Let us consider the driven gear of a set: TE is the difference between its actual position and that corresponding to the ideal case of perfect meshing conditions (Refs. 1, 6).

There are many reasons for the presence of TE in gears. One is unavoidable: gears are subject to torques, which cause forces on teeth, thus modifying their geometry by bending.

Another unavoidable effect, which would exist even if tooth deflections were negligible, results from machining errors (profile and pitch error, eccentricity, etc.) and assembling errors, which modify the ideal geometry of the gear.

Therefore real teeth—deformed under load, affected by machining and mounting errors—are subject to different working conditions from the ideal ones. In particular, the different geometry of the teeth at the beginning of the mesh causes impacts.

Transmission error is the indicator of all these effects and is defined in this way:

$$TE = \theta_2 - \frac{z_1}{z_2} \cdot \theta_1$$

where

θ_1 = angular position of pinion
θ_2 = angular position of gear
z_1 = number of teeth of pinion
z_2 = number of teeth of gear

The measure of TE is complex, not only because it is influenced by many factors, but also because it is often very small. For this reason, it is necessary to have very accurate measurement instruments, and also a test rig which allows the isolation of TE from all other phenomena. This enables the measurement of TE caused only by meshing, without the influence of other effects like compliances, manufacturing and assembling errors of the test rig, drive irregularities, dynamic effects, etc.

Test Rig and Measurement System

The most important feature of a test rig for TE measurement is stiffness: torsion and bending stiffness of the shafts, stiffness of bearings and of the casing.

If the stiffness of all these parts is much greater than that of the elements involved in meshing (teeth and gear blank stiffness), we can see and measure the phenomenon in its "pure" form. But if the parts of the test rig have stiffness of the same magnitude, many effects mix together and influence the final measure. Thus the results are not easily interpreted, and the TE is difficult to evaluate quantitatively.

A test rig specifically designed to measure TE has been constructed by the authors, with the aim of obtaining the maximum stiffness compatible with the dimensions of the layout of the test rig. Its features are described in Reference 7. The most important characteristics are the following:

- Three-phase asynchronous motor controlled by inverter, with maximum power of 100 kW, maximum torque of 500 Nm and maximum speed of 3,800 rpm.
- Two eddy current brakes.
- Variable center distance of gears.

A schematic and photo of the test rig are shown in Figures 1 and 2. Gears are mounted overhung to allow a quick setup, but the overhang is kept as low as allowed by the gear face width and bearing dimensions. The shafts are supported by two heads, which can be positioned and adjusted in any direction on the support plane. In this way, it is possible to set the desired center distance, with the limits defined in the design step, and misalignments, both in the plane of the shaft axes and in the orthogonal one. The misalignment in the plane of the axes is driven by a pin centered on the gear middle face, while the misalignment in the orthogonal plane is set by means of shims; appropriate reference marks, machined during the manufacturing, allow an accurate measurement of the position.

As explained in a previous paper (Ref. 8), the TE measurement system designed for this test rig is based on optical encoders, chosen for their high accuracy and preferred to other measurement systems based on radial and tangential accelerometers. The two encoders measure gear positions θ_1 and θ_2; these measurements, properly elaborated, let us calculate TE.

On the basis of the TE definition, its measure requires the independent measurement of the two angles θ_1 and θ_2. It is fundamental that errors and measurement uncertainty are lower than quantities to be measured. Since the TE of high-quality gears (those generally involved in applications which need this kind of measurement) amounts to seconds of a degree, the measurement system must have a higher degree of precision.

For this reason, two high-resolution Heidenhain encoders with 18,000 divisions have been chosen. The high number of angular divisions enables a high resolution. One angular division corresponds to 72" of degree, and it can be further divided if the acquisition system can identify, without aliasing, the sinusoid generated by the encoder corresponding to the passage of an incision. This involves an upper threshold of drive shaft angular velocity, which depends on the maximum acquisition frequency of the used data acquisition board. Signals are acquired along with a reference phasing signal, which enables the correlation of the angular positions of the two gears, which in turn allows the creation of TE diagrams, always starting from the same meshing teeth of pinion and wheel.

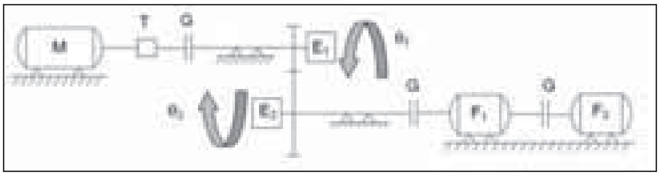

Figure 1—Schematic layout of the test rig for TE measurements: M = motor; T = torque meter; F_1 & F_2 = eddy current brakes; G = couplings; and E_1 & E_2 = optical encoders.

Figure 2—The test rig.

Experimental Results

Two series of experimental tests have been completed. In the first one, a gear set with profile modifications on

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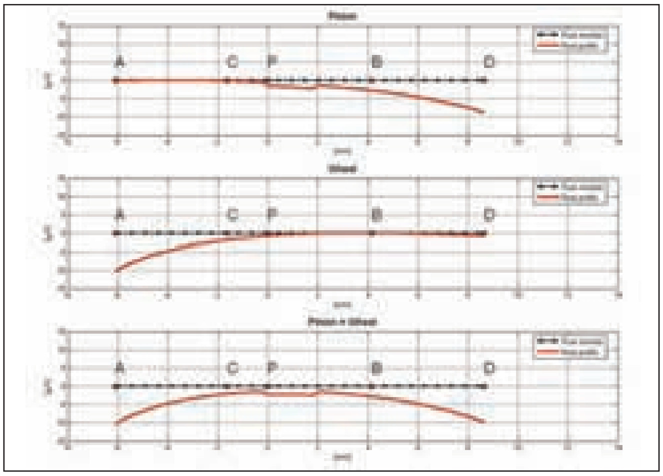

Figure 3—Profile modifications of the first gears.

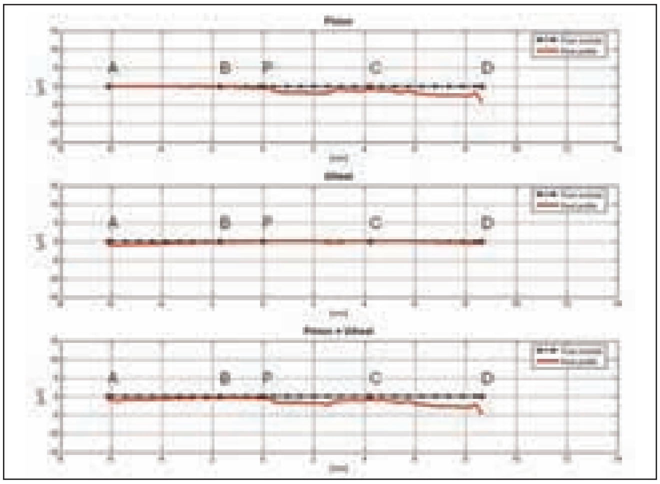

Figure 4—Profile modifications of the second gears.

Table 1—Gear set parameters.	
GEAR SET	
Module m (mm)	3.5
Pressure angle α (°)	20
Helix angle β (°)	0
Center distance a (mm)	160
Addendum for unitary module H_a	1
Dedendum for unitary module H_f	1.36
Ratio ε_α	1.43
Tooth quality for DIN 3961	7

Table 2—Pinion parameters.	
PINION	
Number of teeth z_p	34
Pitch diameter d_p (mm)	119
Profile correction $x_p \bullet m$ (mm)	+ 2.5
Face width b_p (mm)	15

pinion and wheel tooth tips (Fig. 3) has been tested. In the second one, a gear set having the same macro-geometry, but with an almost null profile modification on both pinion and gear (near to pure involute profile), has been tested (Fig. 4). Tables 1–3 report the macro-geometry data of both gear sets, which therefore differ only in profile modifications. TE and acoustic emission measurements have been performed for both gears.

The manufacturing process of the gears is the following:

1. Blank Turning.
2. Hobbing.
3. Case carburizing and case hardening.
4. Generation grinding.
5. Grinding of the hole and of the reference axial plane, with a single positioning on the machine and using the gear teeth as reference.

The signals are acquired by the two encoders and, after the elaboration of the signals by means of a specially developed software program, TE diagrams are calculated.

Figure 5 shows TE measured on the first gear set (with profile modification) as a function of pinion position and applied torque. We can clearly see that measured TE has the two typical components: a constant one, growing with the applied torque (because it corresponds to gear tooth mean deflection under load) and a variable one, corresponding to stiffness variation and manufacturing errors.

By virtue of a frequency spectrum that has been calculated for every TE measurement (Fig. 6), we can recognize the different components of the signal: the low-frequency harmonic (one per revolution) caused by gear eccentricity, the harmonic at mesh frequency with its multiples, and spectral components at lower frequencies than mesh frequency.

The amplitude of the first spectral component (mesh frequency) depends on applied torque, as we can clearly see in Figure 7. Therefore, an accurate study of profile modifications can reduce TE in correspondence with a chosen value of applied torque, reducing acoustic emission at the source.

Noise measurements on the same gear set considered for TE are shown in Figure 8. We can see a close correlation between sound pressure level (SPL) and TE in that the torque values that minimize TE also minimize acoustic emission.

If we plot SPL spectrum at a given torque at different motor speeds (Fig. 9), we can see mesh frequency and its multiples shifting on the frequency axis. These diagrams are also called "waterfall" diagrams.

By properly filtering the SPL signals (Fig. 10), we can highlight the phenomenon of sidebands, which consists of harmonics at the following frequencies:

$$f_{sb} = a \cdot f_z \pm b \cdot f_{s1,2} \quad \forall\, a, b \in \mathrm{N}$$

where

f_z = mesh frequency
$f_{s,1}$ = input shaft frequency
$f_{s,2}$ = output shaft frequency

Table 3—Wheel parameters.	
WHEEL	
Number of teeth z_r	55
Pitch diameter d_r (mm)	192.5
Profile correction $x_r \bullet m$ (mm)	+ 2.151
Face width b_r (mm)	14

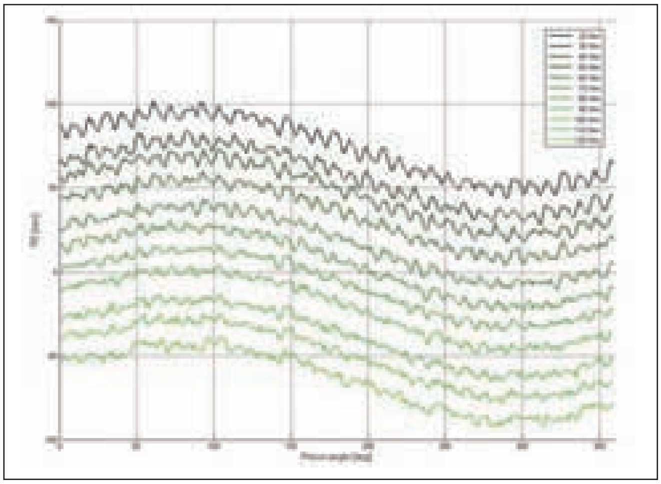

Figure 5—TE versus applied torque (first gear).

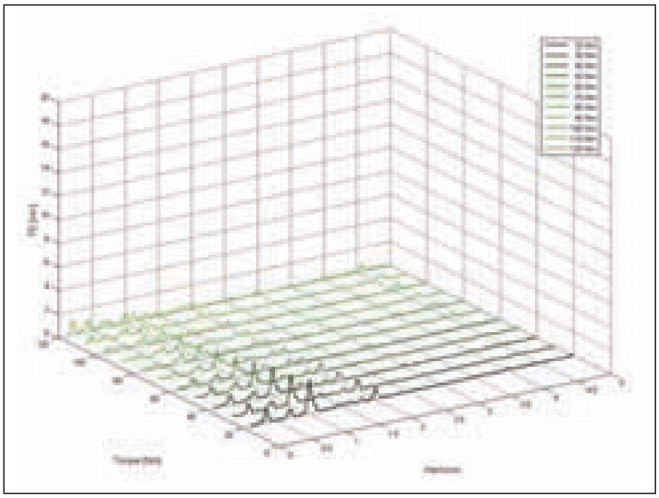

Figure 6—TE spectrum versus applied torque (first gear).

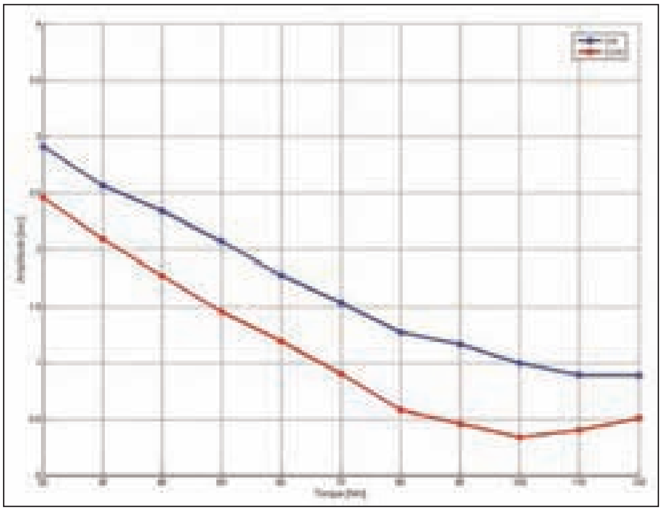

Figure 7—Spectral component of TE at mesh frequency versus applied torque (first gear).

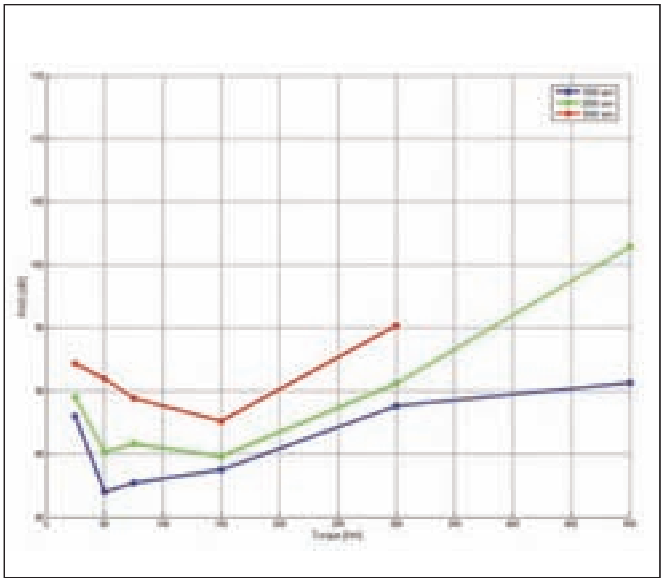

Figure 8—SPL versus speed and torque (first gear).

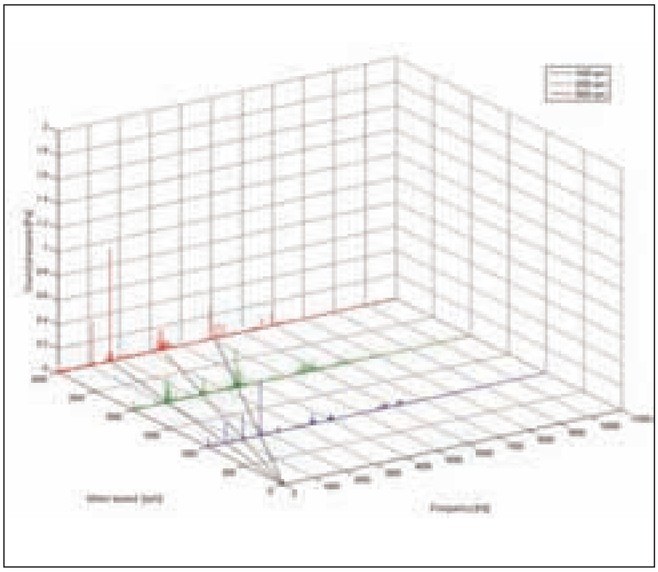

Figure 9—Sound pressure waterfall diagram (first gear).

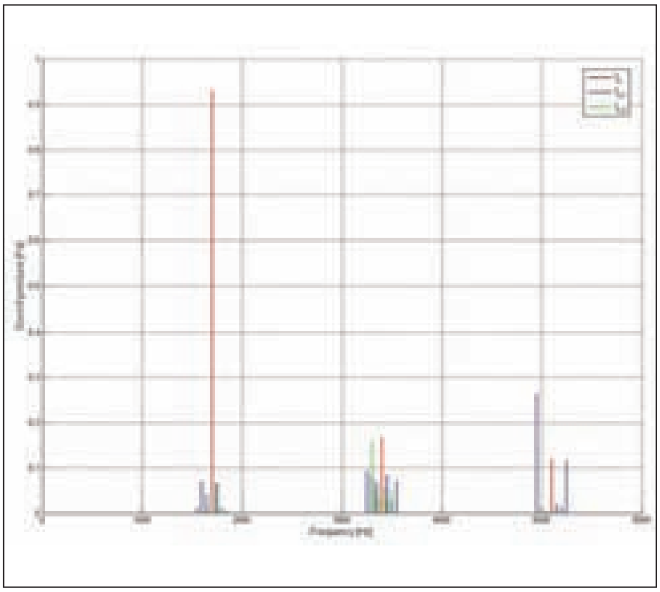

Figure 10—Sidebands (first gear).

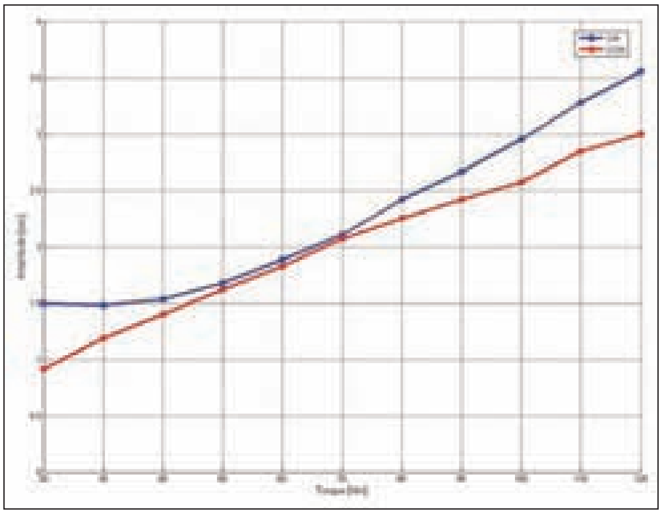

Figure 11—Spectral component of TE at mesh frequency versus applied torque (second gear).

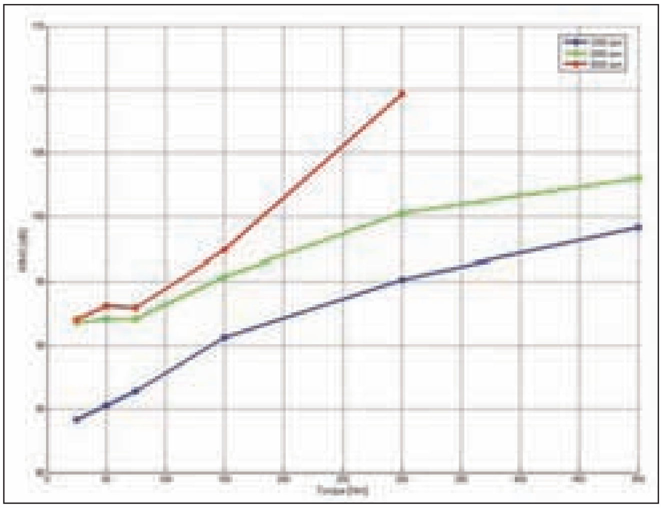

Figure 12—SPL versus speed and torque (second gear).

The same measurement procedure has been applied to the second gear set, but with no profile modification. SPL values are shown in Figure 12. We can clearly see that acoustic emission increases linearly with applied torque, and its trend follows that of the amplitude of the harmonic at mesh frequency (Fig. 11), as observed for the first tested gear.

Conclusions

Measuring TE is necessary to validate profile modifications, defined during the design phase, in order to reduce acoustic emission. TE measurement is complex and requires an appropriate test rig; otherwise experimental results can be influenced by other phenomena, which can hide the component due to tooth deformation.

On the basis of an accurate analysis of the experimental results—and with the help of theoretical simulations—profile modifications can be improved, allowing for a solution that minimizes TE at the desired torque.

A mix of theoretical simulation and experimental validation seems to be the right way to design quieter gears and transmissions.

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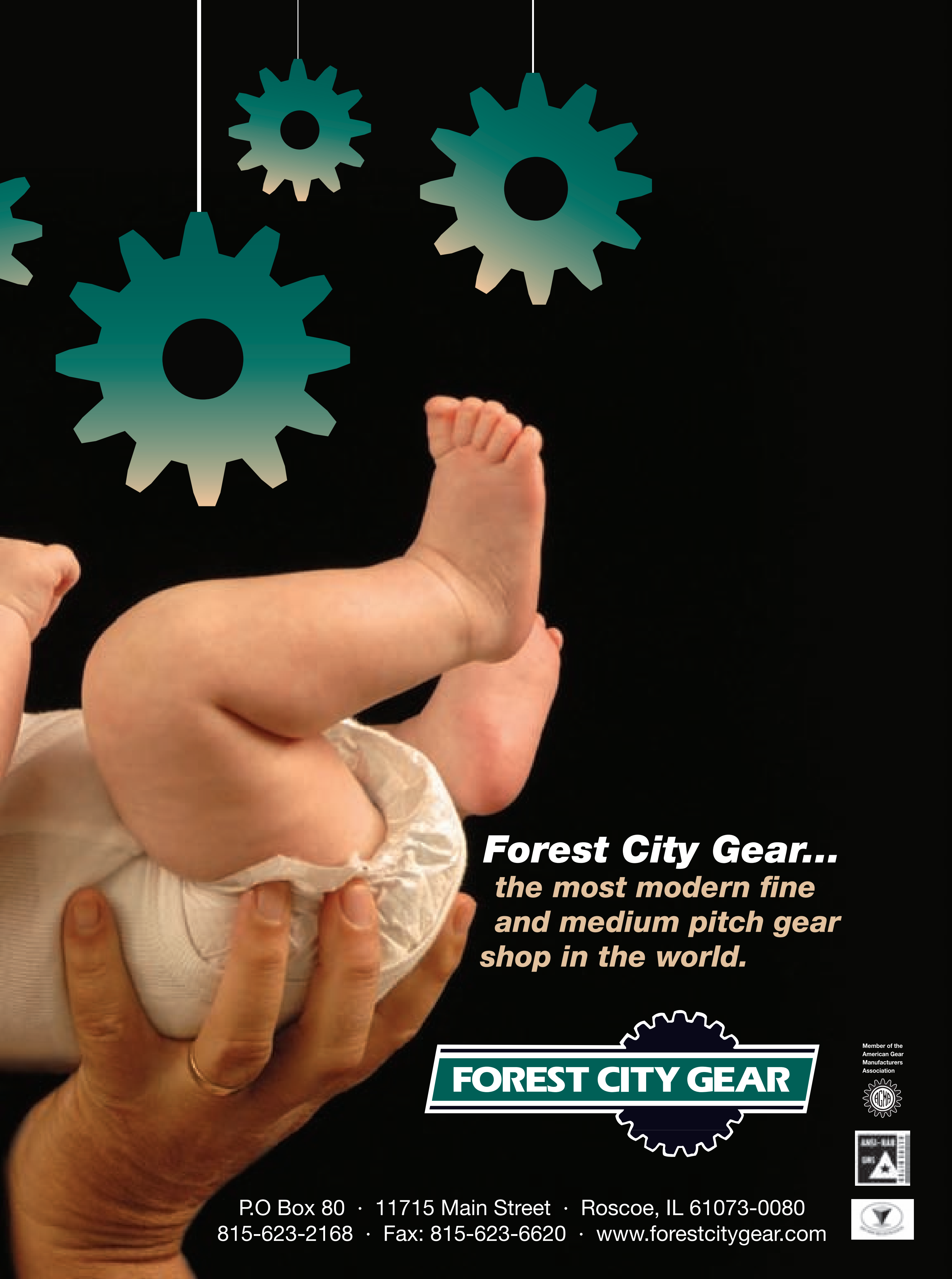
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EFFECTS ON ROLLING CONTACT FATIGUE PERFORMANCE—PART II

Dr.-Ing. Gottfried Hoffmann and William Jandeska, Ph.D.

Management Summary

This is Part II of a two-part paper that presents the results of extensive test programs on the RCF strength of PM steels and discusses the effects of some important material and process variables. (Part I was published in the January/February 2007 issue of *Gear Technology*.) The results here are compared to those of wrought steels presented in Part I of this paper. Also, a procedure will be introduced that accelerates tests for systematic studies of the effect of individual material/process parameters on rolling contact fatigue (RCF) strength of materials. This procedure combines testing under full EHD lubrication with eddy current technology and microstructural analysis to indicate crack initiation and growth

PM Processes for Gear Manufacturing

Powder metallurgy processes are often chosen for their cost-reducing potential. Manufacturing near-net or net shape parts with excellent reproducibility, minimizing or even avoiding secondary machining operations, and high utilization of materials and energy are the main driving forces to convert from wrought or cast to PM materials. However, when PM parts are being considered and PM materials are being selected, designers need to take into consideration the role of the inherent porosity and its effect on static and dynamic properties. The lack of a complete understanding of the porosity-property relationship requires extensive tests of PM parts under real operational loading conditions to avoid premature failure of parts and structures (Ref. 29).

The PM industry is aware of this problem and seeks to provide its customers with the required material data and to develop new technologies that reduce porosity either within the whole part or in certain, highly-loaded areas such as the surface (Refs. 29–34). These developments are necessary to expand the use of PM products within the automotive and other industries. Future expansion of PM technology is expected in manufacturing highly loaded gears in automotive transmissions by powder forging or surface densification of PM pre-forms (Ref. 35). To successfully replace wrought steel in those applications, the PM industry has to prove that materials and processes are competitive or superior and can be used to reduce cost considerably without reducing the reliability of the products. Due to the fact that PM processes have a higher degree of variability than manufacturing processes for wrought materials, systematic studies of the effect of process parameters on final product properties are requested by the end-user.

Role of Porosity in PM Steels

It is common knowledge that the inherent porosity affects the mechanical properties of PM materials in two ways (Ref. 36):

1. Linear reduction of static properties such as ultimate tensile strength, yield strength, and Young's modulus (assuming maximum porosity of 10–15%, which is typical for structural parts).

2. Exponential reduction of dynamic properties such as elongation, fatigue strength and impact energy.

There is no doubt that porosity also plays a very important role and even may be the most determining factor in the RCF strength of PM steels. To understand the role of pores in RCF, one has to distinguish between subsurface failure and surface conditions, including the role of lubrication in RCF.

Subsurface Failure. Pores within the material act as nucleation sites for subsurface cracks. Surrounding material can be plastically deformed by the stress field and can yield into the open space provided by the pores. As with fatigue under tension, it can be expected that cracks grow from pore to pore (Ref. 37). Whether the reduction of stress intensity at the crack tip due to pores has a measurable effect on the growth rate has yet to be determined. In surface-densified PM steels, previously existing pores collapse under the compressive pressure of the densification and have the potential to form micro-cracks if not healed by subsequent sintering or heat treatment.

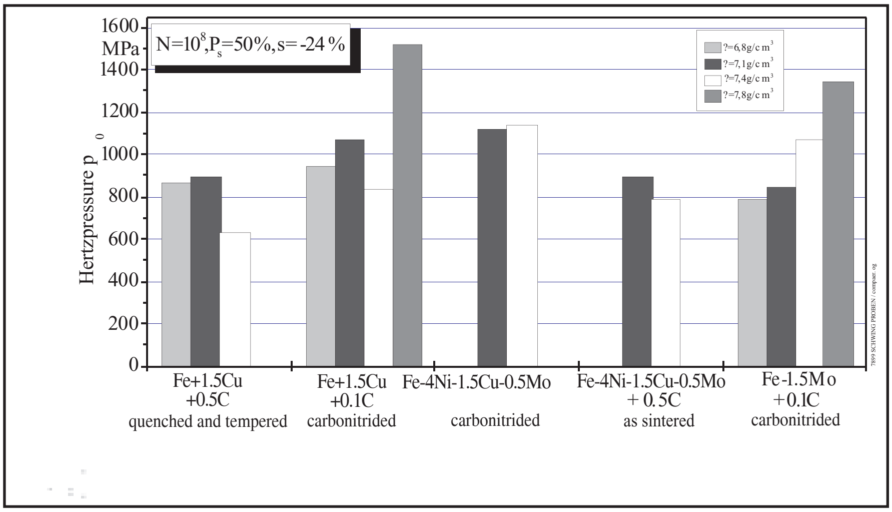

Figure 15—RCF strength of PM steels at different densities (Ref. 38).

Surface Condition Affected by Pores

High Porosity (Less Than 90% Theoretical Density.) In highly porous materials, the pores form an interconnected network throughout the material. The material behaves in a similar way to foam and is capable of absorbing a certain amount of lubricant. Like in porous bushings, pressure gradients due to the contact pressure within the material lead to the flow of lubricant from areas of high pressure to those of low pressure. If the pressure at the surface exceeds the resistance of the porous structure, the lubricant film in the contact zone becomes unstable and may collapse, causing excessive friction and wear. This critical oil pressure is affected by the number of pores, the connections between the pores, the shape and size of the pores, and the viscosity of the lubricant.

The connected pore structure, on the other hand, may have a positive effect on the RCF strength of the material. Assuming that the contact pressure does not exceed the critical pressure, the pore structure may act as a kind of damping buffer for pressure spikes that occur at high asperities and at the exit of the contact zone. Furthermore, the pores can provide lubricant and enhance the grip of the oil film at the surface.

Low Porosity (Greater than 95% Theoretical Density). At higher density, the pores become more and more isolated, and the interconnected network of pores is replaced by isolated, closed pores. Due to the fact that pores often represent the open space between powder particles and previous particle surfaces form grain boundaries in the sintered structure, grain boundaries usually lead to those pores. If pores are open to the surface, the effect is similar to dents in the surface. The damping effect of pressure spikes diminishes, and elastic deformation of the surrounding material can lead to high hydrostatic pressure within the pores, causing premature surface failure.

Experimental Test Results. There is only one test program that determined the RCF strength of PM materials at different densities under full EHD lubrication, with and without sliding, and line contact using the ZF-RCF test rig (Refs. 26, 38, 39). The results indicate a small increase or even a decline in RCF strength when the density is in the range at which the open pore structure changes into closed and isolated pores (Fig.15).

It shall be noticed that materials that show the largest drop contain copper that is added to the powder mixture as elementary powder. The copper particles melt before the sintering temperature is reached, leaving pores behind. Which role the additional pores play in the decrease of RCF strength is not understood yet. The reduced strength, however, may have some important consequences for porous PM materials used in RCF applications:

1. It may affect the trend in the PM industry to produce parts at higher densities. If a material is susceptible to surface failure due to isolated, open pores, it may be advantageous to avoid the close pore structure and to maintain an open pore structure.

2. To maximize RCF strength, full density processes are necessary, with special emphasis on surface topography and surface porosity.

In order to study the effect of open pores on failure mechanisms, a test program was performed using sinter-hardened PM steel to exclude any additional effect of case hardening (Ref. 40). The produced test specimens were randomly divided into two groups:

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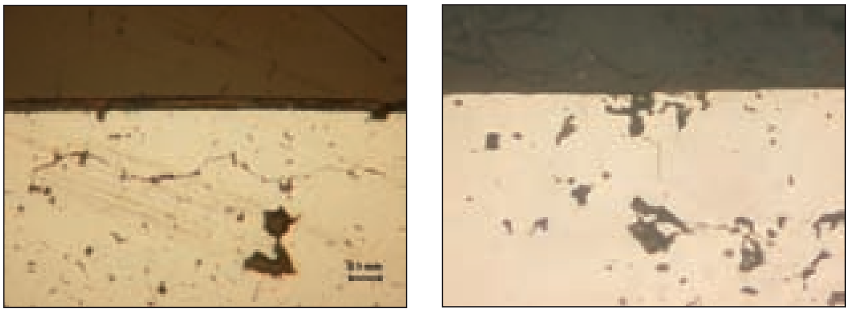
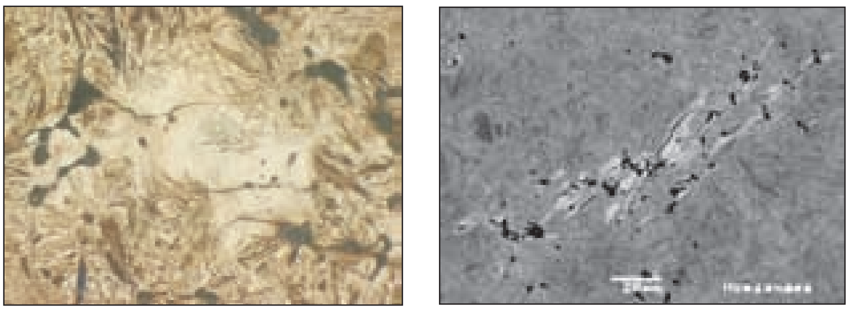


a) Impregnated. b) Not impregnated.

Figure 16—Failure mode in sinter-hardened PM Steel, density = 7.3 g/cm³ (40).



a) Sinter Hardened, Density = 7.35 g/cm³. (40) b) Surface Densified, Back Scattered Electron. (45)

Figure 17—Crack and crack growth in nickel-rich regions.

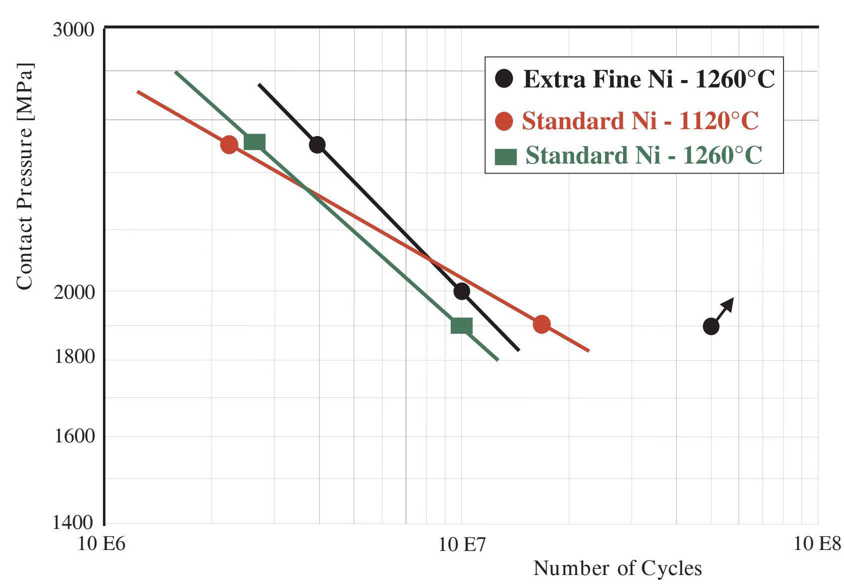


Figure 18—Effect of sinter temperature and nickel particle size on RCF of surface-densified PM steel FLN2-4405 (Ref. 43).

One group was tested in the as-sintered condition, the second group was resin-impregnated to fill all open surface pores. The microstructures in Figure 16 show that the impregnated samples fail by subsurface cracking. The non-impregnated sample, on the other hand, fails by mixed surface and subsurface cracking. The microstructure shows some cracks that clearly initiate from surface pores.

The tests show the importance of surface and subsurface porosity on the RCF strength of PM materials. Depending upon the RCF strength of the material and the shape and size of the subsurface pores, failure will be initiated at the weakest point. If the material has high resistance to RCF, surface pores can become the critical initiation sites for cracks. When the material has lower resistance, surface cracks and subsurface cracks may have similar chances to be formed.

More research must be done to determine the role of open and closed porosity on the RCF strength of PM steels.

The Role of Nickel

Nickel is a very important alloying element in powder metallurgy, due to its low affinity towards oxygen and positive effect on strength and heat-treated microstructure. If used by mixing elementary nickel powder with iron powder, homogenization takes place by volume diffusion, governed by Fick's second law of diffusion that leads to the equation (Ref. 41):

$$D \bullet t = \text{const} \qquad (2)$$

with

D = diffusivity

= $D_0 \bullet \exp(-Q / RT)$

Q = activation energy [J/mol]

R = gas constant [J/(mol • K)]

T = Temperature [K]

t = time [sec]

Furthermore, time for complete homogenization is affected by the particle diameter of the nickel powder imbedded in the iron matrix, and can be calculated using the solution of Fick's second law for these special boundary conditions (Ref. 41).

Standard nickel powder with an average particle size of 7.5 µm does not homogenize completely under typical industry-sintering conditions (1,120°C or 2,050°F/30 min), leaving small Ni-rich regions behind which form soft spots after heat treatment or carburizing (Ref. 42). Traditionally, the role of those soft spots has been regarded as beneficial for fatigue properties under tension loading (Ref. 43). Newer research has called this belief into question and identified those regions as nucleation sites for crack initiation with high crack growth rate, compared to pearlitic or martensitic microconstituents (Ref. 44).

Microscopical and SEM analyses (back-scattered electrons) of RCF test specimens also confirmed that, under compressive loading, Ni-rich areas are regions in which cracks preferably nucleate. They also grow within those regions before penetrating the matrix material that usually contains martensite or bainite, with spots of retained austenite (Fig. 17).

There are several methods to avoid costly Ni-rich areas in PM steels:

1. The use of pre-alloyed, iron-nickel powder.

2. The use of high-temperature sintering (higher than 1,200°C–2,200°F) or longer sintering time.

3. The use of fine nickel powder that would homogenize at standard sintering conditions.

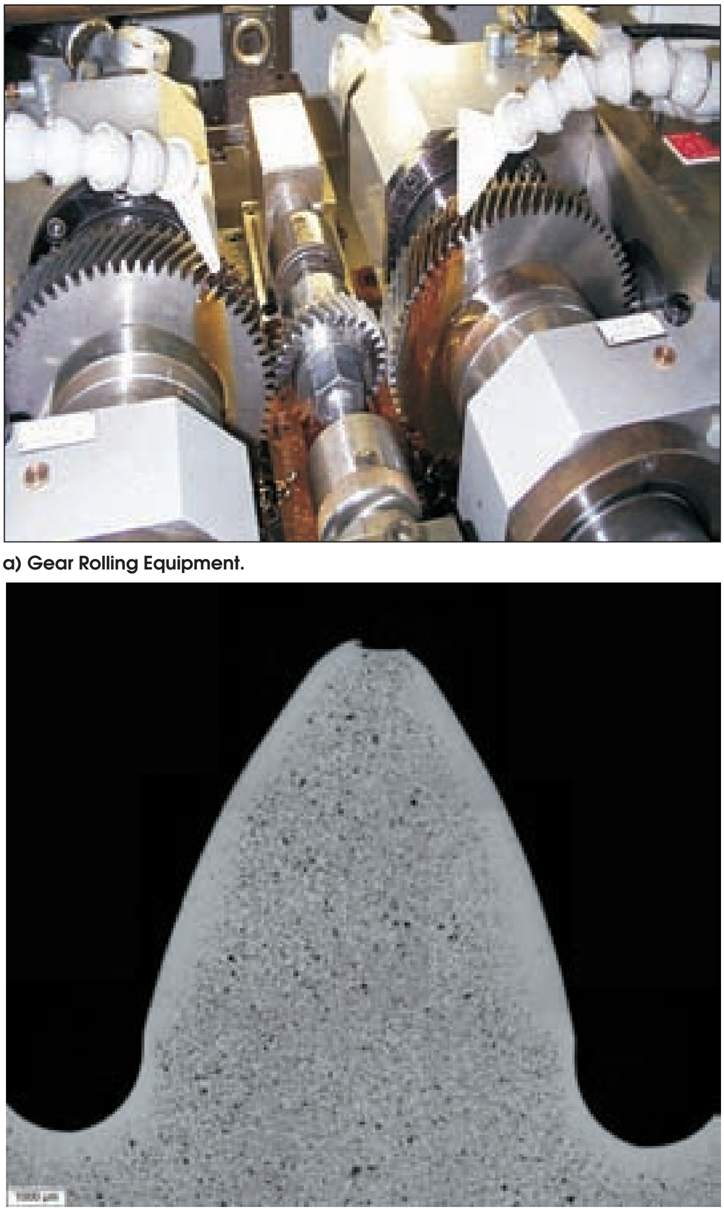
As can be seen from Figure 18, extra-fine nickel powder not only improves RCF strength at the higher load level, it also appears to affect the strength at high numbers of load cycles. Whether the improvements justify the additional costs remains to be seen.

Surface Densification Process for Highly Loaded Gears

Surface densification of PM pre-forms is a promising technology to produce the high-density surface necessary for highly loaded, helical automotive transmission gears. The technology must fulfill the requirements regarding load-carrying capacity and cost reduction to be competitive (Refs. 32–35). Figure 19 shows the equipment used for rolling the surface of a pre-form produced by the PM process to final specifications, and the cross-section of teeth produced by this process (Ref. 46).

A typical porosity profile is shown in Figure 20. It is commonly agreed upon that the depth of the densified zone is defined by the region at which the porosity is less than 2%. This adds another factor into the material-RCF strength correlation. There are two very important conclusions that can be drawn from the porosity profile:

1. The densification process must be treated as the case-hardening heat treatment: The depth of densification



a) Gear Rolling Equipment.

b) Surface-Densified Gear.

Figure 19—Surface densification of PM pre-forms (Ref. 46).

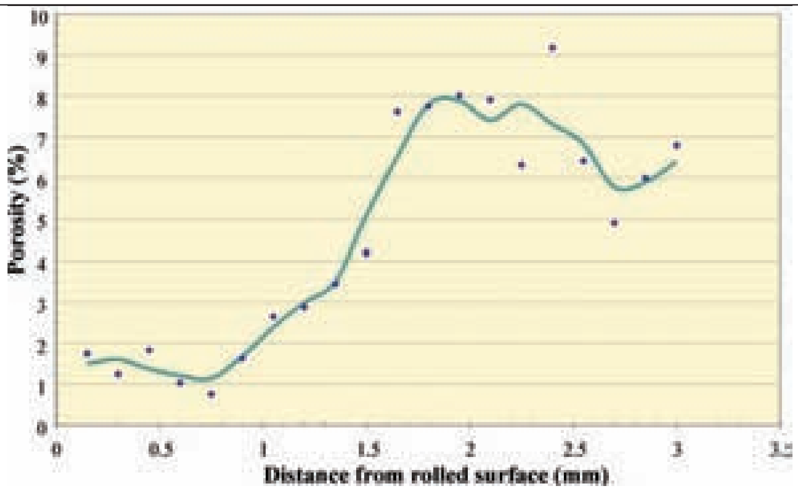


Figure 20—Porosity profile of surface-densified Ancorsteel 4300 (Ref. 47).

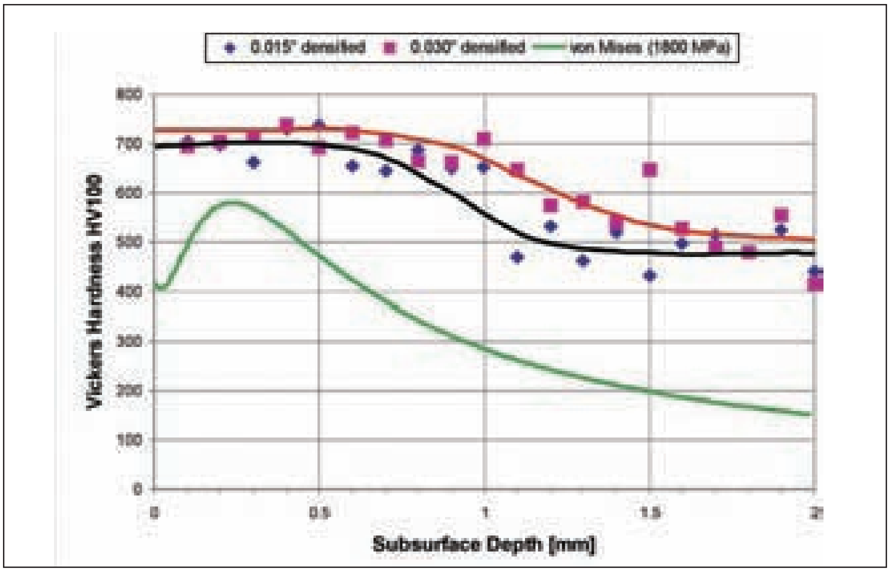


Figure 21—Microhardness and subsurface stress distribution.

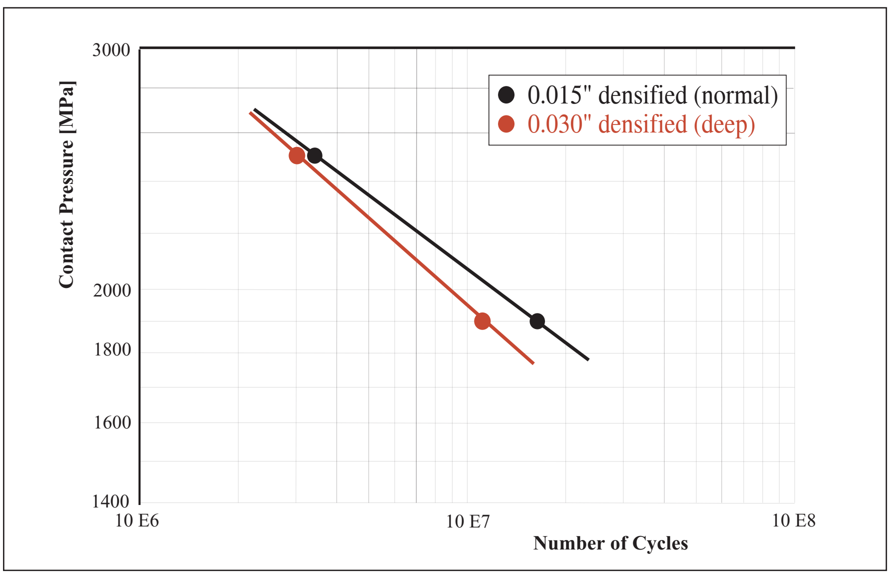
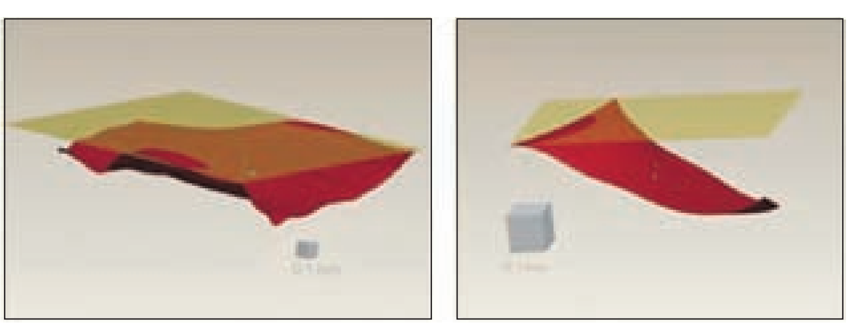


Figure 22—Effect of depth of densification on RCF strength of FLN2-4405.



a—0.015" Normal Densified

b—0.030" Deep Densified

Figure 23—3-D CAD maps of first cracks in FLN2-4405.

has to be adjusted to accommodate the subsurface stress profile like the case depth in case hardened steel. To prevent the second major gear failure—tooth root bending—a minimum densification depth of about 0.5 mm has to be maintained (Ref. 48). Therefore, even if the subsurface stress distribution would allow a shallower densified zone, it would not be beneficial for gear applications to reduce the densification beyond a certain depth.

2. There are few pores remaining at and near the surface that are isolated and not connected to other pores. Those pores can act as nucleation sites for cracks and, if open to the surface, as nucleation sites for surface cracks.

Test Results For Surface-Densified PM Steels

A systematic test program, sponsored by the National Science Foundation (Ref. 2), was designed to study the effect of materials and process parameters on RCF strength of surface-densified PM steels. In this program, the eddy current technology was used extensively. First cracks were used as failure mechanisms, crack growths were recorded, and the technique of sliced microstructures was used to visualize first cracks in 3-D maps produced by Pro-E CAD software. The results of this program were published (Refs. 3, 4).

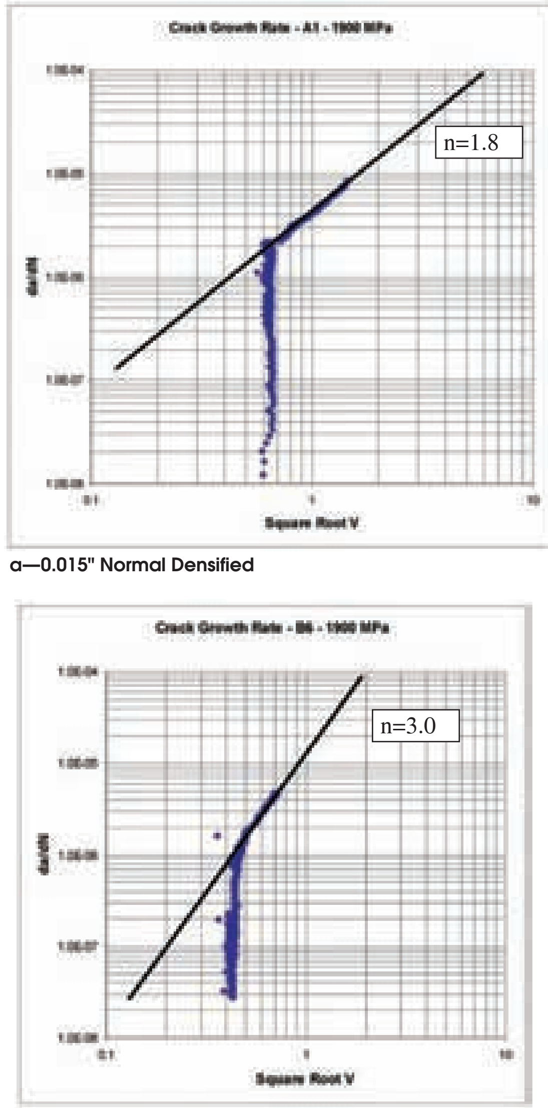
Effect of Densification Depth. To study the effect of the depth of the densification layer, a typical PM material (FLN2-4405) was densified to a normal depth of 0.015" (0.4 mm) and deep-densified to 0.030" (0.8 mm). Figure 21 shows the subsurface microhardness profile and the subsurface von Mises stress distribution of the test sample at 1,800 MPa. Both materials accommodate the stress profile very well.

The S-N curves of both materials (Fig. 22) indicate that deeper densification would have an unexpected, detrimental effect on RCF strength.

Comparing the first cracks, however, reveals that the failure mechanism in both materials is different. While the normal-densified steel shows subsurface crack initiation and growth, the deeper-densified material fails by surface-initiated cracks (Fig. 23).

The results emphasize the importance of crack analyses. By interpreting the S-N curve alone without taking the failure mechanism into consideration, the conclusions may be misleading. The full analysis of the failure will change the focus on the densification process. The reason for the change in failure mechanism still needs to be determined.

The crack propagation rate in both materials shows very little difference, and the Paris coefficient is within the range of wrought steels under both compression and tension (Fig 24).



a—0.015" Normal Densified

b—0.030" Deep Densified

Figure 24—Crack propagation rate in FLN2-4405 surface-densified PM steel.

Effect of Carburizing Cycle

The standard way of case-hardening steel by carburizing contains two cycles:

1. Increased carbon potential in the carburizing atmosphere for a certain period of time (boost cycle).

2. Reduced carbon potential in the atmosphere to allow carbon to diffuse into the material (diffusion cycle).

For case carburizing transmission gears, the automotive industry often uses special heat treatment cycles which contain multiple boost and diffusion cycles. Two different surface-densified PM steels were heat treated using the single- and the multiple-boost/diffusion carburizing cycles. Table 5 contains the process parameters of both carburizing heat treatments.

Table 5—Carburizing Cycles	
Process 1	Process 2
Normal vacuum carburizing	Special vacuum carburizing
T = 1700°F/927°C	T = 1700°F/927°C
Boost = 90 min Diffuse = 90 min	Boost = 30 min Diffuse = 30 min Repeat four times: Boost = 15 min Diffuse = 15 min
Rapid gas quenched	Rapid gas quenched
Tempered at 400°F / 205°C	Tempered at 400°F / 205°C

Figure 25 shows that the effect on surface-densified PM steel is marginal. Crack initiation analyses revealed that different failure modes occur in the different materials:

1. FLN2-4405-process 1: Subsurface cracks and dominant subsurface crack growth.

2. FLN2-4405–process 2: Mixed failure modes–surface and subsurface, dominant subsurface crack growth.

3. Ancorsteel 4300–both processes: Surface-initiated cracks which grow deep into the material, far below the maximum subsurface stress (see Fig. 26).

SEM pictures of both materials (Figs. 27 and 28) carburized with

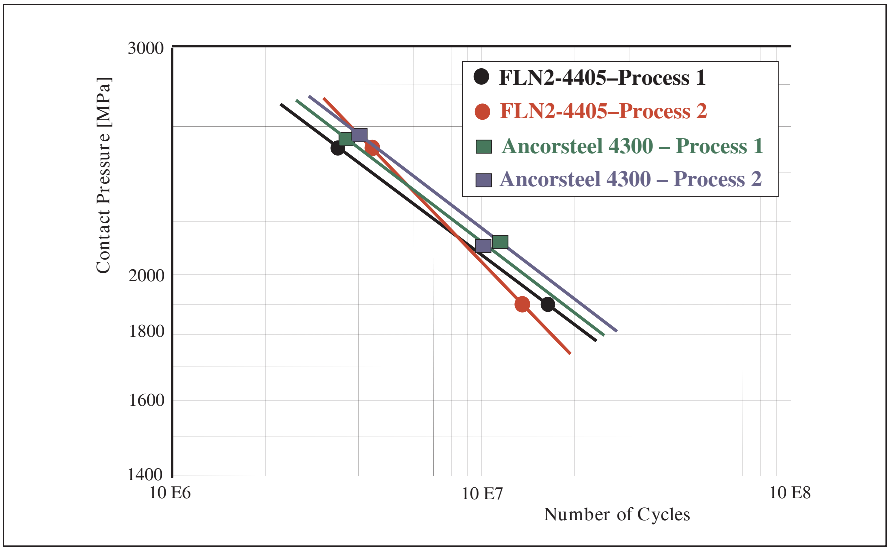


Figure 25—Effect of different carburizing cycles on RCF strength.FLN2-4405 and Ancorsteel 4300, both by Hoeganaes Corp. (Ref. 47).

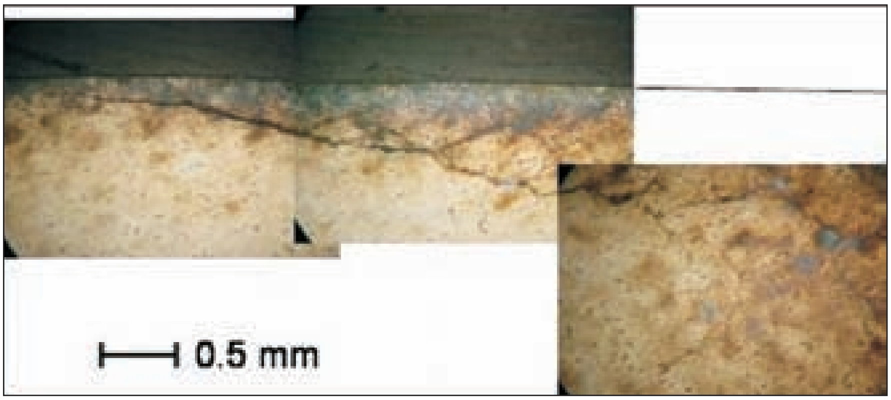
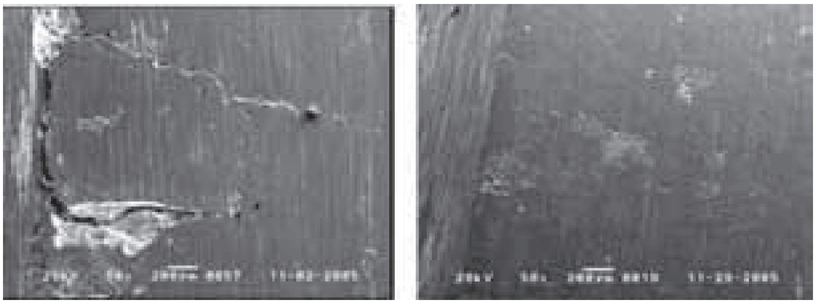


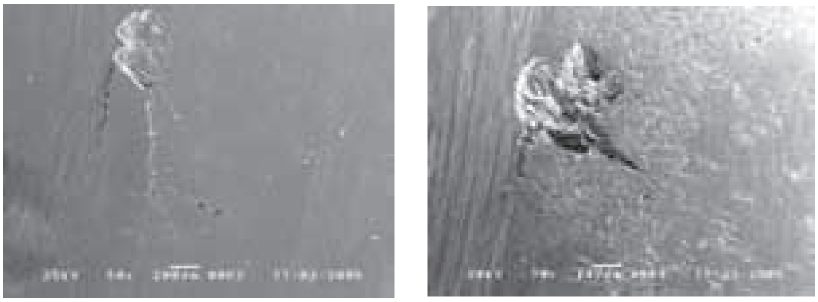
Figure 26—Crack path in Ancorsteel 4300.



a) Heat treatment process 1.

b) Heat treatment process 2.

Figure 27—SEM of FLN2-4405 after different carburizing processes.



a) Heat treatment process 1.

b) Heat treatment process 2.

Figure 28—SEM of Ancorsteel 4300 after different carburizing processes.

Process 2 show areas of micropitting, which is usually experienced in carburized steels and low-viscosity lubricants. Despite the fact that both conditions are fulfilled in the ZF-RCF test rig, it is the first time that micropitting was observed in model testing. It is not understood why the multiple-boost/diffuse cycle would increase the chance for micropitting, but the occurrence in two completely different steels may not be a coincidence.

Effect of Alloying Elements: Nickel versus Chromium

Copper, nickel and molybdenum are the most important alloying elements in iron powder metallurgy. The reason can be found in the low affinity toward oxygen, which prevents oxides from forming and existing oxides from being reduced at standard sintering atmospheres and temperatures (Ref. 36). With the exception of molybdenum, those alloying elements have limited effect on the hardenabilty of the steel. The PM industry tried for many years, with limited success, to use chromium and manganese as alloying elements because of their positive effect on hardenability, which becomes increasingly important due to the development of sinter-hardened PM steels and increased request for heat-treated and case-hardened products (Ref. 49). Recently developed chromium-containing iron powders show commercially promising properties and low oxygen content, even at standard sintering temperatures and atmospheres (Ref. 47, 50).

Two different chromium-containing materials produced by two different powder manufacturers were included in this program. Table 6 summarizes the chemical composition and major process parameters of both materials. Figure 29 shows the S-N curves of both materials.

At first glance, it seems as if Astaloy CrL is superior to Ancorsteel 4300 (Ref. 29). The 3-D maps of the first cracks (Fig. 30) reveal that Ancorsteel 4300 fails by surface-initiated cracks, while Astaloy CrL shows subsurface cracks. Therefore, the real

RCF strength of Ancorsteel 4300 may be higher if surface cracks could be avoided; the material simply is not utilized to its maximum strength due to premature failure by surface cracks.

Comparison: Wrought Steel Versus Surface-Densified PM Steels

Figure 31 summarizes the test results obtained with surface-densified PM steels in comparison to those obtained with traditional wrought steels. It is obvious that standard PM steels based upon FLN2-4405 (nickel-containing) are comparable to AISI 5120, and the newly developed Cr-containing steels reach the RCF strength of AISI 8620. The slope of the S-N curves of the PM steels is similar to the slope of the AISI 8620 curve, but not as steep as the AISI 5120. That means that PM steels and AISI 8620 are more sensitive for fewer but higher overloads than AISI 5120. It is not understood at this point in time if the effect is due to the surface-densification process or to the used alloying system.

It must be emphasized that surface-initiated failures are dominant in most materials, including the wrought steels. Therefore, reducing surface porosity and surface roughness would be beneficial to fully utilize the material strength. Whether special surface treatments can be developed which could be used economically in mass production has yet to be seen.

Procedure to Study the Effect of Individual Parameters

Based upon the information about failure mechanisms using eddy current, a procedure has been proposed which can be used to study the effect of material/process parameters systematically with only few test specimens in a short period of time. Assuming that the scattering of the data is not drastically affected by the variation of a single parameter, three tests should be enough to determine the relative effect on the RCF strength of the base material. The following test procedure is recommended:

1. Test—Determining the number of load cycles until the occurrence of the first cracks. Continue the test until

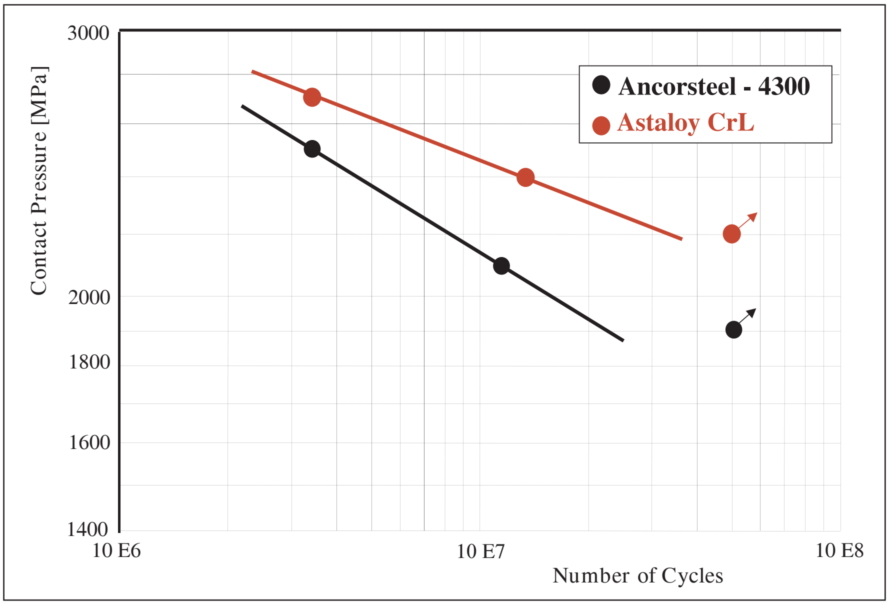
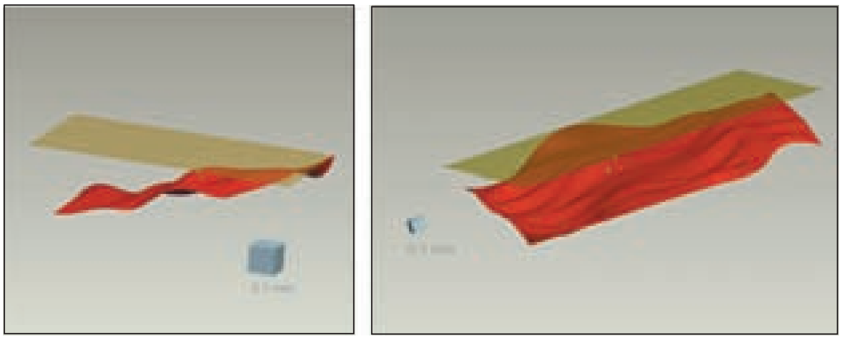


Figure 29—RCF strength of chromium-containing, surface-densified PM steels.



a) Ancorsteel 4300.

b) Astaloy CrL.

Figure 30—3-D CAD maps of first cracks in chromium-containing PM steels.

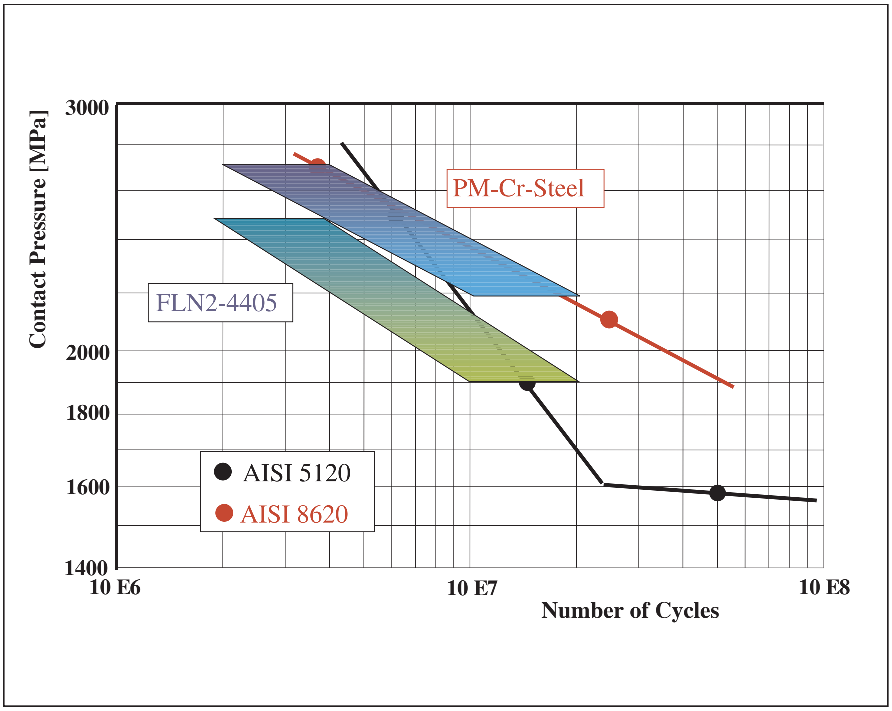


Figure 31—Comparison of surface-densified PM steels to wrought steels.

Table 6—Chemical Composition of Chromium Containing PM Steels

Material	Chemical Composition [wt %]				Core Density [g/cm³]	Case Depth [mn]
	Cr	Ni	Mo	Graphite		
Ancorsteel 4300 [47]	1.0	1.0	0.8	0.6	7.3	0.8
Astaloy CrL [50]	1.5	-	0.2	0.2	7.1	0.7

final pitting while monitoring crack propagation rate using the eddy current recording.

2. Test—Determining the number of load cycles until the occurrence of the first cracks. Continue with stepwise-reduced load levels and monitor crack growth to determine a threshold, if such a threshold exists.

3. Test—Determining the number of load cycles until the occurrence of the first cracks. Use the sliced microstructure technique and produce the 3-D CAD map of the crack to determine the failure mechanism.

This procedure allows study of material and process parameter effects such as:

1. Amount of retained austenite.
2. Residual stress and subsurface residual stress distribution.
3. Surface topography and roughness.
4. Effect of heterogeneous microstructures.
5. Depth of surface densification.
6. Heat treatment parameters.
7. Microstructural hardness depth profile.

After the optimum combination for a material/process has been developed, the final material shall be tested with a minimum of five test specimens at a minimum of two load levels for confirmation, and to characterize the S-N curve and the scattering of the data.

Summary and Outlook

The combination of RCF testing under full EHD lubrication and the eddy current technology opens a new field of study of material behavior under rolling contact fatigue loading. For the first time, it is possible to study the initiation of failures, monitor crack growth and path of propagation, and determine the threshold for crack growth. This new procedure of RCF testing allows for systematic studies of the effect of materials and/or process parameters within a significantly reduced period of time and number of test specimens.

There are still some improvements to be made to optimize this new procedure:

1. The correlation between eddy current signal and flaw size has to be established.

2. At the current setting, the eddy current detects flaws mainly when they reach the surface. It needs to be studied if by varying the sensor excitation frequency and the evaluation mode, subsurface cracks can be detected and monitored before they reach the surface. This would allow determining subsurface crack growth rate that could lead to a better understanding of what causes the subsurface crack to initiate and propagate.

Acknowledgment

The authors wish to thank the following companies for contributing test samples to the research program: General Motors Power Train Group, Harley-Davidson, Bombardier, Hoeganaes Corp., North American Hoeganaes, Inco Ltd., GKN SinterMetals, and Capstan-Atlantic. Part of the program was made possible by a National Science Foundation Grant (Award No. 0510141).

The authors would also like to recognize Marquette University for the use of their laboratory equipment, and the Rapid Prototyping Center of the Milwaukee School of Engineering for producing sliced microstructures and the 3-D CAD maps of the cracks.

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Asymmetric Teeth: Bending Stress Calculation

Giulio Di Francesco and Stefano Marini

Management Summary

This article includes a brief summary of the characteristics of involute asymmetric teeth and the problems connected with the related bending tests. The authors use an adaptation of the standard ISO C methodology to determine bending stress calculations for gears with asymmetric teeth. They compare their results with results obtained using modern finite element methods.

Introduction

In the design of transmission gears, it is often necessary to increase bending strength while maintaining load carrying capacity or increase the load carrying capacity while maintaining bending strength.

A method of achieving either of those goals is the design of gears with asymmetrical teeth. That is, the pressure angle on the drive side is different from the pressure angle on the coast side. It is possible to design teeth with the greater pressure angle on either the drive side or the coast side, and each method can have its advantages. For example, a greater pressure angle on the drive side results in gears with higher load-carrying capacity. A greater pressure angle on the coast side results in teeth with higher bending strength (Ref. 1).

Asymmetric teeth are well suited for cases where the torque is transmitted only, or mainly, in one direction. Because of the asymmetric teeth, designers are able to create gear drives capable of handling greater torque in the same amount of space, or they are able to reduce the amount of space required to handle the same amount of torque.

Since the dimensioning procedures, such as the widely used ISO C procedure, were developed and standardized for symmetric teeth, today we still need to study and fine-tune an ad hoc procedure for conducting bending tests on asymmetric teeth.

One possibility is to use the finite element method (FEM); for this purpose, the authors of this study have developed an ad hoc modeling system (Ref. 2) for making rapid and extremely accurate structural numerical analysis, the results of which have been proved through a number of experiments (Ref. 3). Using FEM analysis in dimensioning asymmetric teeth, however, may not be practical for all gear engineers. In particular, many engineers who are used to designing symmetric teeth do not regularly use finite element methods.

The objective of this work, therefore, is to study a calculation method which makes it possible to carry out the dimensioning of asymmetric teeth using a "modified" ISO C procedure, the same procedure that is widely used for symmetric teeth.

Form and Notch Factors for Asymmetric Teeth

According to the ISO C procedure, the maximum bending stress at the tooth root may be expressed through the following known relation:

$$\sigma_F = \frac{F_t}{b \cdot m} \cdot Y_{Fa} \cdot Y_{Sa} \cdot Y_{\varepsilon} \cdot Y_{\beta} \cdot \left(K_A \cdot K_v \cdot K_{F\beta} \cdot K_{F\alpha}\right) \quad (1)$$

The tooth asymmetry, if any, has no impact on either the overload factors K_A, K_V, $K_{F\beta}$, $K_{F\alpha}$, or the corrective factors Y_ε and Y_β ; hence, the bending stress in asymmetric teeth, on equal tangential force, face width and module, differs significantly from the bending stress in symmetric teeth, merely because of the different value given to form factor Y_{Fa} and to notch factor Y_{Sa}.

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In symmetric teeth, the factors' values are determined through the following relations:

$$Y_{Fa} = \frac{6 \cdot {h_{Fa}}/{m} \cdot \cos\alpha_a}{\left({s_{Fn}}/{m}\right)^2 \cdot \cos\alpha} \qquad Y_{Sa} = (1.2 + 0.13 \cdot L_a) \cdot q_s^{\frac{1}{1.21 + \frac{2.3}{L_a}}} \qquad (2)$$

where: $L_a = s_{Fn} / h_{Fa}$; $q_s = s_{Fn} / 2\rho_F$.

In order to use the ISO C procedure for asymmetric teeth, we need to create a calculation method that is capable of determining two factors, which we will here refer to as Ye_{Fa} and Ye_{Sa}, equivalent to the abovementioned factors Y_{Fa} and Y_{Sa} and applicable in Equation 1.

With reference to Figure 1, note the asymmetric tooth HCAK'I,' with the driving side on the left; note, also, the symmetric tooth HCDKI, both sides of which are identical to the driving side of the asymmetric tooth.

The methodology of this study is based on two hypotheses, the validity of which will be proven upon analysis of the results: the critical section HK' of the asymmetric tooth is assumed to be at the same distance from the center of the wheel as the critical section HK, determined on the symmetric tooth by the sixty-degree wedge; we define as axis of the asymmetric tooth the perpendicular to segment HK', passing through point L' of its center line.

The profile curvature radius, ρ_F , at the critical point H, is obviously identical for both symmetric and asymmetric teeth.

In conclusion, according to Equation 2, the form and notch factors of asymmetric teeth differ from those of symmetric teeth only inasmuch as the values of s_{Fn} differ, equal respectively to HK' and HK, and that of h_{Fa} , equal respectively to L'Y' and LY.

Considering that, for admissible $\Delta\alpha$ values (Ref. 4) of the tooth asymmetry, segment L'Y' is only slightly lower than the corresponding segment LY, we have deemed it opportune in this study to assume the value $h_{Fa} = LY$ also for asymmetric teeth, for the benefit of greater accuracy. (In fact, an approximated, rounded-up value is assumed for the arm, which is conventionally defined in procedure ISO C, of the bending component of the force of contact.)

Therefore, factors Ye_{Fa} and Ye_{Sa} for asymmetric teeth can be determined by replacing s_{Fn} in Equation 2, with the corresponding value s_{Fnas}, equal to the length of segment HK' of Figure 1.

Calculation Software

The first thing the user must do in order to use the calculation software, created using the *Matlab*® language, is to enter all the input data necessary for determining the characteristics of the toothing, namely, the number of teeth, the tool's geometric characteristics (module, pressure angle of the two sides, addendum, tip radius), and the addendum modification and addendum reduction coefficients. The user

Symbols

b	axial face width
h_{Fa}	distance between the critical section and the point of intersection between the tooth axis and the direction of the force of contact (arm of the bending component of the force of contact)
m	reference module
s_{Fn}	symmetric tooth thickness at the critical section
s_{Fnas}	asymmetric tooth thickness at the critical section
x	addendum modification coefficient
z	number of teeth
F_t	tangential component of the force of contact
K_A	application factor (depending on the type of driving and driven machine)
$K_{F\alpha}$	transversal load distribution factor (depending on the precision class and driving ratio)
$K_{F\beta}$	disalignment factor
K_V	dynamic factor (depending on the speed and precision class)
Ye_{Fa}	equivalent form factor for asymmetric teeth
Ye_{Sa}	equivalent notch factor for asymmetric teeth
Y_{Fa}	form factor
Y_{Sa}	notch factor
Y_β	corrective factor for helical teeth
Y_ε	corrective factor depending on driving ratio
α	pressure angle
α_a	angle between the direction of the force of con tact (applied at the outside radius) and the normal at the tooth axis
α_{01}	reference pressure angle of the drive side
α_{02}	reference pressure angle of the coast side
ρ_{a0}	tool's tip radius
ρ_F	profile curvature radius at the critical section
σ_F	maximum bending stress at the tooth root

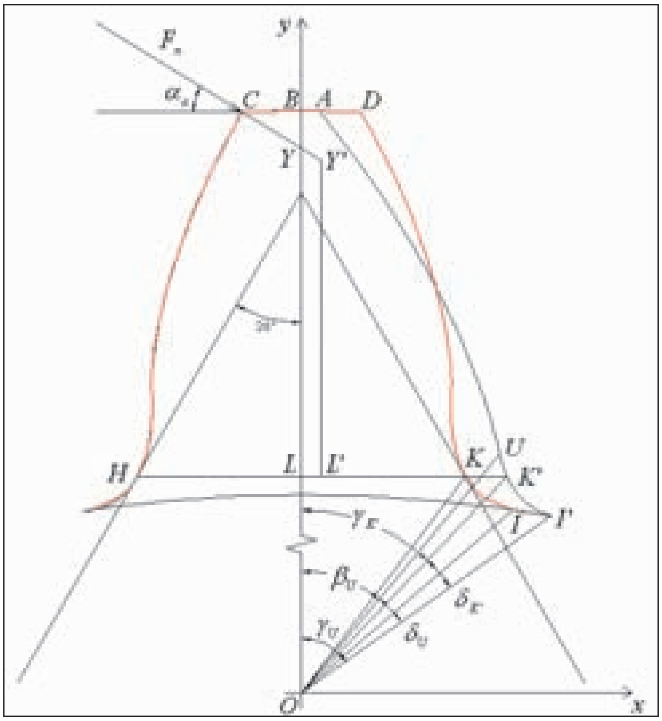

Figure 1—Comparison of symmetric (HCDKI) and asymmetric (HCAK'I') tooth forms.

Table 1—Stress values calculated with FEM and modified ISO C method.

Z	α_{01}	α_{02}	$\Delta\alpha$	$\Delta\sigma$ % ISO/FEM
20	20	20	0	10.55376
20	20	23	3	13.11262
20	20	26	6	12.58875
20	20	30	10	11.48727
20	20	32	12	10.41543
30	20	20	0	7.87013
30	20	23	3	9.699268
30	20	26	6	8.93965
30	20	30	10	7.161882
30	20	32	12	6.145928
50	20	20	0	6.190476
50	20	23	3	7.413509
50	20	26	6	6.276626
50	20	30	10	4.417433
50	20	32	12	3.26284
100	20	20	0	6.397039
100	20	23	3	6.906907
100	20	26	6	5.736783
100	20	30	10	3.71128
100	20	32	12	2.64881

must determine all the geometric parameters (characteristic radius, thickness, etc.) of both the asymmetric tooth being calculated and the symmetric tooth of reference, as described above. The coordinates of the intersection points between the involutes and the respective tooth fillet profiles are thus identified through the appropriate iterative cycles (for example, point U for the coast side of the asymmetric tooth in Figure 1); thus, the profiles of the two teeth, the symmetric and the asymmetric one, are fully defined.

Once the coordinates of point U are known, it is possible to calculate the amplitude of angles β_U , δ_U and γ_U shown in the figure (*I'* is the starting point of the trochoid on the inside circumference). Through the application of widely used procedures (Ref. 5), the coordinates of point H are determined, as well as the thickness s_{Fn} = HK of the critical section of the symmetric tooth. Through another iterative cycle, the coordinates of point K' are determined, from which we can obtain the value of angle δ_K'.

At this point, we determine the thickness of the critical section of the asymmetric tooth s_{Fnas} :

$$s_{Fnas} = HK' = HK/2 + OL \cdot tg\gamma_{K'} \quad (3)$$

where: OL = y-axis, previously calculated, of point H;
$\gamma_{K'} = \gamma_U - \delta_{K'}$.

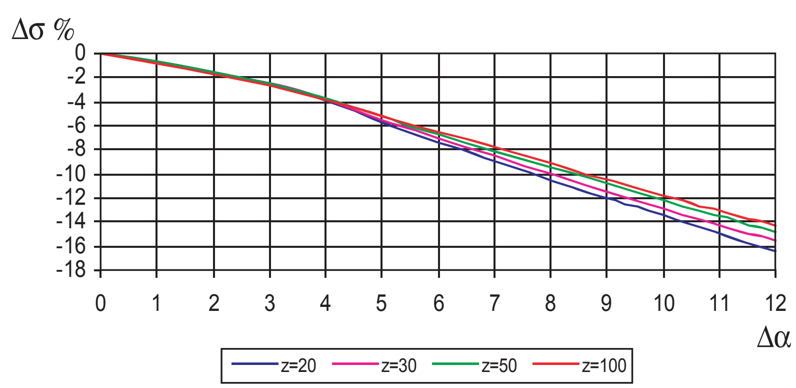

Figure 2—Percentage decrease of stress calculated using modified ISO C (x=0; ρ_{a0}=0.25).

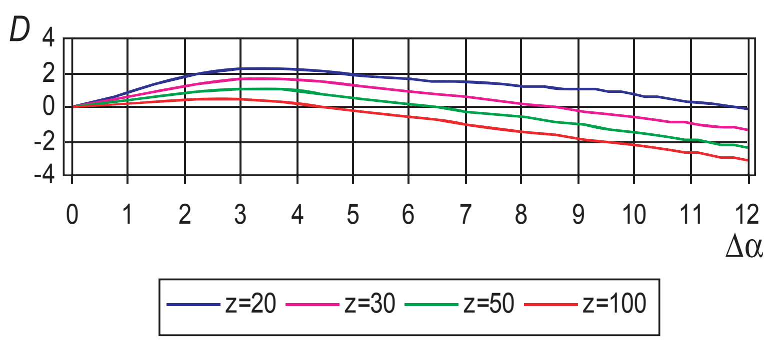

Figure 3—Difference D between the percentage stress reduction calculated using modified ISO C method and using FEM (x=0; ρ_{a0}=0.25).

Using the value of s_{Fnas} provided by Equation 3, we calculate the form and notch factors, Ye_{Fa} and Ye_{Sa}, for asymmetric teeth, through which we can finally determine the maximum bending stress, σ_F, at the root of tooth.

Results and Verification

As specified in the previous paragraphs, certain hypotheses and approximations were assumed in order to fine-tune the calculation methodology of this study. In order to assess the validity of such methodology, we have deemed it opportune to make a comparison—through numerous combinations of the tooth parameters—between the bending stress values calculated using FEM methodology and the values calculated using the modified ISO C procedure.

The test campaign highlights, in particular, how the stress values for both symmetric and asymmetric teeth calculated using the FEM methodology are, as already known for symmetric teeth, generally lower than the values calculated using the ISO C methodology. This depends mainly on the fact that the ideal stress calculated using the FEM methodology in the most highly stressed point of the tooth fillet of the driving side (traction area) takes also into account, with great accuracy, the compression resulting from the radial component of the force of contact between the teeth.

The most important point that we can make after having analyzed the results is the fact that the differences between the stress values calculated using the two methodologies are not directly dependent on the tooth's degree of asymmetry. It is possible to verify the above by the data in Table 1, which shows, for some of the case studies: the number of teeth z, the pressure angle of the driving side α_{01}, the pressure angle of the coast side α_{02}, the degree of asymmetry $\Delta\alpha = \alpha_{02} - \alpha_{01}$, the percentage difference $\Delta\sigma\%$ ISO / FEM between the stress calculated using the ISO methodology (modified in the case of asymmetric teeth) and the stress values calculated using the FEM methodology (the symmetric tooth case studies are highlighted in the table).

The values in Table 1, particularly those of $\Delta\sigma\%$ ISO / FEM, make it possible to propose the procedure referred to in this paper for determining the equivalent form and notch factors for asymmetric teeth and, consequently, the use of the ISO C methodology also for this type of teeth.

By using this methodology for a wide range of case studies, we were able to obtain a large number of calculation results. Figure 2 shows a graph—of the several obtained by varying z, x and ρ_{a0}—which indicates, in relation to the degree of asymmetry $\Delta\alpha$, the percentage of stress reduction $\Delta\sigma\%$ versus symmetric teeth (x = addendum modification coefficient; ρ_{a0} = tool tip radius).

Using graphs like the one shown in Figure 2, the designer of asymmetric teeth can obtain a direct estimate of the expected stress reduction, with respect to traditional symmetric teeth.

Finally, as further proof of the validity of the calculation method proposed in this paper (the "modified" procedure ISO C), we have evaluated, always in relation to the degree of asymmetry, the difference D between the above said stress reduction $\Delta\sigma\%$ and the corresponding stress reduction calculated using the FEM methodology. Also in this case, we have drawn numerous graphs (one example is shown in Figure 3), which show a very slight difference, in fact, lower than 2–3%.

In other words, for evaluating the stress reduction obtainable through the use of asymmetric teeth, the estimate provided by the proposed procedure does not differ greatly from the one provided by the FEM procedure.

Conclusions

The calculation method created in this study, used for the dimensioning of asymmetric teeth, allows the user to determine valid "equivalent" form, Ye_{Fa}, and notch, Ye_{Sa}, factors; the software created ad hoc simplifies this calculation.

Using the equivalent factors, we are able to estimate the maximum bending stress at the tooth root with an approximation, rounded up, which is very close to that commonly considered acceptable for symmetric teeth.

In brief, the results of this work clearly show that gear designers may conveniently use the widely used ISO C procedure for verifying the bending stress in the case of asymmetric teeth.

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Forest City

PUTS TEETH IN COMPETITIVE STRATEGY WITH SUNNEN'S BORE HONING MACHINE

Forest City Gear president Fred Young has a straightforward strategy for acquiring and retaining business—always give the customer a higher level of quality and performance than specified, but do it without adding much cost or time to the job.

"On bore-type gears," he says, "we have found that honing the bore is a good way to improve quality in the areas of size, roundness, straightness and finish, without adding a lot of extra cost. The customer notices the difference in a smoother, quieter, more efficient drive."

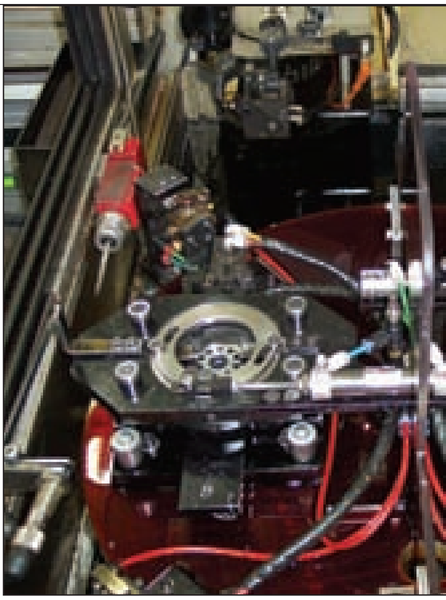
Depending on the production needs for a specific gear, Forest City Gear hones at various points in the manufacturing process using three different systems. One of those systems—a

fully automated vertical machine—uses Sunnen's patented Krossgrinding® tools, which the manufacturer says are capable of controlling bore size down to 0.00005" and finish to 16 µin or better.

Forest City produces fine- and medium-pitch custom gears, such as internal, helical and spur as well as worms, splines and sprockets at quality levels as high as AGMA 15 (DIN 2–3). Maximum O.D. on most parts is 20", except for worms (5") and worm wheels (16"). Forest City's gears are used in planes made by Boeing, Airbus, Cessna and Beechcraft, as well as for the space shuttle, the space station, Mars rover vehicles and the Abrams tank. Many motorcycles and race cars use Forest City gears, as does one of the few bait-casting reels made in the United States. About 30% of the company's work is aerospace-related, 5–10% medical, 5% military, and the remainder is industrial or instrument work. Part runs range from one to several hundred thousand. Typical materials include 12L14, 1215, 8620, 9310 and various stainless grades, as well as aluminum, bronze, brass, Inconel, Hastelloy, titanium, plastics, wood fiber and powdered metal.

One of Forest City Gear's core products is pump gears, which start as flat, washer-type blanks made on a screw machine. "These gears operate in a small housing, so any perpendicularity error in a shaft-mounted gear causes wobble, loss of efficiency, noise and increased friction," says Young. "An adage of gear making is that a gear can be no more accurate than the blank with which you start. On a bore-type gear, this means starting with parallel faces and a perpendicular, round bore with parallel walls, and no taper or belling. Our minimum standard is +/–0.0005" for parallelism and perpendicularity, and we'll work to tighter tolerances as

continued



circumstances require."

The pump gear blanks are double-disc-ground for face parallelism and width, then re-bored on an automated boring lathe to re-qualify the perpendicularity. "We leave some stock in the bore because it is much easier to control absolute size on a hone than it is on a lathe," Young adds. These blanks are stack-hobbed, and grouped on an arbor in quantities based on four times the diameter of the bore, divided by the face width of the part. "If you don't have good parallelism and perpendicularity, it can introduce lead error in cutting the gear, or it forces a reduction in the number of blanks on the arbor, eroding your production efficiency," he explains.

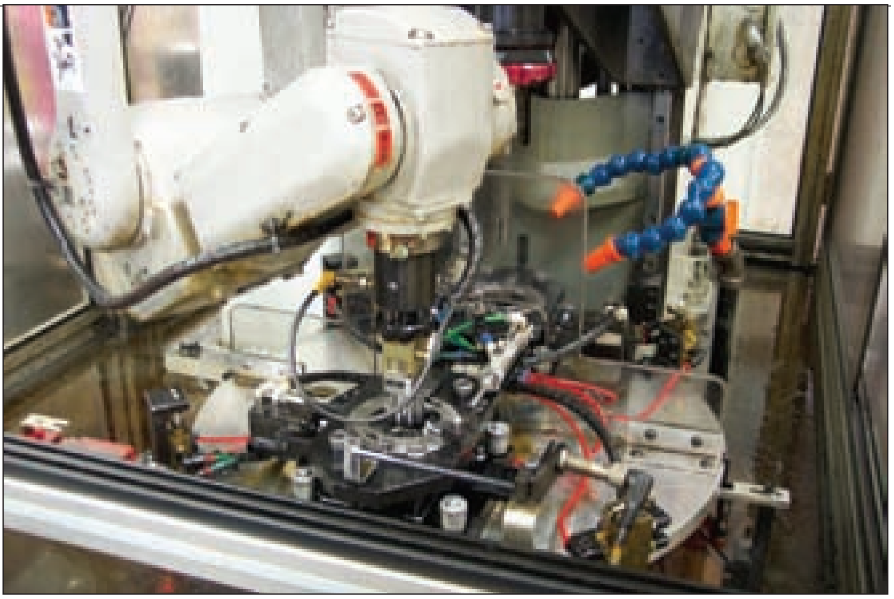
Pump gears often have a standard keyway or a blind-hole keyway added that must align with a tooth. "When we cut that keyway, it throws up a tiny burr, so honing for final size allows us to clean up that burr, too," says Young. "This is where the Sunnen machines really shine, allowing us to control final size automatically down to a few microns, a fraction of our allowed tolerance. Honing also leaves a crosshatch pattern on the bore surface, which helps maintain a film of lubrication for gears that rotate on a shaft."

Young explains that the five-tenths tolerance on the bore size shrinks to three-tenths or less when Six Sigma quality requirements are imposed. "Our real working tolerance is much smaller than the print spec, if we are shooting for a Cpk of 2 or better, which we often achieve," Young says. "In fact, we have run capability studies where we've hit double-digit Cpk levels when honing for bore size, and we consider it a less expensive and temperamental process than ID grinding."

Honing, in fact, is a less-costly process, with an automated single-spindle hone typically costing 50–75% less than an ID grinder, according to Rich Moellenberg, manager of Sunnen's custom products group.

"With automated honing, we can easily hit tolerances of 50 millionths to two tenths, so the gear is going to roll more smoothly, more quietly, with less vibration and probably last longer," Young stresses. "There will be a perceived improvement the customer can sense, even without sophisticated measuring equipment. This establishes high customer expectations that are difficult for competitors to meet."

Forest City Gear owns three Sunnen



hones: a fully automated vertical MHS system, predecessor to Sunnen's new SV line, and two EC-3500 machines, predecessors to the new ML-4000 power-stroked machine. The vertical MHS machine has a rotary table with two workholding positions fed by a robotic loading system, ensuring high "in cut" times. Krossgrinding tools combine the traditional expanding-mandrel design with a long-wearing, diamond-plated sleeve, so they operate much like a traditional honing tool with stones. "We get a tool life of about 250,000 parts, depending on the material, while typically removing 0.0020–0.0030" of stock at cycle times of 15 seconds," Young says. A new Sunnen SV-1005 vertical honing system will soon replace the workhorse MHS machine.

One of the two EC-3500 power-stroked hones has an auto loading system. These machines allow feed rate, stroke length and stroke speed to be set at the control. Sensing probes monitor bore size and automatically end the cycle when the bore hits the specified size. The control also has capability for automatic stone wear compensation and two-stage feed pressure, which allows cycle time reduction by removing most stock at a higher feed pressure, then finishing at lower pressure. "We use CBN and aluminum oxide tooling on these machines in several different configurations, depending on whether the bore is blind, keyed, etc.," Young explains.

Forest City Gear employs honing at various points in manufacturing. Parts are typically honed after hobbing, but on extremely critical gears, blanks might be honed before and after cutting. "If we have a very tight tolerance situation and want better sizing than we can get by boring on the lathe, we might hone before cutting, as well as after," Young says. "Fixturing on the hones also allows some degree of control and correction of perpendicularity, should we need to do that. If parts are heat-treated, they are honed afterward to correct for the slight shrinkage in bore size. And if there is a plating operation, we have found it is easier to remove plating from the bore using a hone than it is to mask the part for plating."

Forest City Gear devised a clever way to check the functional perpendicularity on bored gears that involves grinding almost all the taper out of a lathe mandrel, which then allows the gear to fit snuggly on it without tipping. With the mandrel mounted between centers and an indicator on the periphery of the gear, any perpendicularity error shows up when the gear is rotated. "This rotational check of perpendicularity is, we think, a better test of how the part will perform when sandwiched into the confines of a housing," Young explains.

No matter what the part print specifies, all customers want quieter drives, smoother operation and greater efficiency, Young stresses. "We strive to give customers a product that is noticeably better than what they would get from a competitor working to the same spec," he says. "Honing allows us to do that and to establish ourselves as a preferred supplier, while still making a profit."

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AT HANNOVER FAIR 2007, BIGGER IS BETTER

Hannover Fair 2007, the largest exhibition of industrial technology on the planet, is set to run April 16–20 in Hannover, Germany. Now approaching its 60th year, Hannover Fair is the ultimate industrial show for sellers and buyers of industrial automation for process, production and building automation; a full range of energy technologies; subcontracted components and systems for the production industries; industrial software and services; microsystems and nanotechnology; and research & development. Fair organizer Deutsche Messe anticipates nearly 6,000 exhibitors this year, comprising 2.15 million square feet of floor space.

Recognized through the years as a prime resource for stand-alone machinery and components, the venue is now widely attended for its display of fully integrated, latest-technology manufacturing solutions. Another benefit of Hannover Fair is its focus on expanded applications for existing technology.

SEW-EURODRIVE
Stefan Brill
Manager, Public Relations

"At Hanover Fair SEW-EURODRIVE will provide drive solutions for each customer, starting with components like geared motors or frequency inverters, de-centralized drive technology or a new series of industrial gears (gears beginning with 500,000 Nm), followed by systems for the drive automation technology based or focused on branches. Last, but not least, we will show a complete EMS system (Electric Monorail System). With this system, OEMs and end-users are able to optimize flexible transport and logistic processes.

"The Hanover Fair in general is one the important trade fairs for SEW. It's where we meet OEMs and end-users. Nevertheless, small and focused fairs are becoming—even in Germany—more interesting; like the SPS/IPC/DRIVES in Nuremberg, in November, or the FachPack."

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European Sales Manager

"Apart from its standard product range of Hansen P4 gearboxes, Hansen will present Hansen Services—a new department for servicing of gearboxes that was launched in the spring of 2006. Hansen Services will be part of the Hansen booth for industrial gearboxes in Hall 26. A second booth in Hall 13 will cover the Hansen business unit for wind energy, with gearboxes for wind turbines.

"Hannover Fair is an international event that is well-organized, and thus attracts interested visitors for each part of the show. It is a good opportunity to have a big number of customer contacts in a very short time frame. The Hannover show is bigger and more international than other shows."

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MOVENTAS OY
Kati Pesola
Communications Manager

"As we are exhibiting at Hannover for the first time as Moventas, our main interest is in exhibiting the new company name. Previously known as Valmet,

Metso and Santasalo, we changed our company name due to an ownership change in Spring 2005. One of the main goals at the show is to make Moventas known as a player in the mechanical power transmission industry.

"We will exhibit three gear units to demonstrate our product range in two of our main customer industries—wind energy, and minerals and mining.

"One wind gear unit will be a 1.5 MW, which will be delivered to our customer after the show. It is an example of the volume product at our Jyvaskyla (Finland) production plant, where the entire production capacity is in use for wind turbine gears. Today, around 50% of our net sales comes from the wind turbine gear production. The second exhibit is a planetary gear coal mill drive unit, which was custom-made at our Wuppertal (Germany) plant for a customer-specific need. The third gear unit will be a 'Duetto' gear unit, representing our modular gear series. The unit at the exhibition is modified according to the needs in mill drives for the minerals industry.

"What is completely new is our condition management system for wind turbine gears. Instead of just monitoring the condition and measuring the vibrations, Moventas' solution processes a wider range of information about a gear unit's condition. Thus we are able to carry out the needed maintenance operations before any damage occurs.

"At Hannover, we can contact all the players in the field of mechanical power transmission; not only the ones that operate in the same customer segments as we do—in wind, mining and minerals, and pulp and paper—but the entire audience. Honestly, we cannot afford to stay away. All the main players will be there, but it is a remarkable investment and every time we wonder whether the investment pays back.

"This is more of a general show. We do meet a lot of our existing customers at Hannover. But instead of reaching potential customers or co-operation partners like in industry-specific shows (e.g., Husam Wind, PulPaper and A BTCP), at Hannover we reach the public interested in mechanical power transmission in general—suppliers, press, students and competitors.

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March 15–17—AGMA/ABMA Annual Meeting. Marco Island Marriott Resort, Marco Island, FL. Discussions include Dr. Mike Bradley's Report on the Economy, American Politics: Looking Toward 2008 & Beyond; The Worker of the Future: Why the Profit Future of American Business is Tied to the Quality of America's Future Workforce; and ExtraPreneurship: Re-inventing Industrial Work to Compete in a Flat World. $895 for the first registrant from an AGMA/ABMA member company, $795 for additional registrants from an AGMA member company. For more information, contact the American Gear Manufacturers' Association by telephone at (703) 684-0211 or on the Internet at *www.agma.org*.

March 21–22—KISSsoft Software Training. MicroTek Orlando facility, Orlando, FL. Dr. Stefan Beermann, KISSsoft founder and vice president, will be conducting the course. Class size is limited to 15. $1,250 includes course instruction, lunches, snacks and a cocktail reception. For more information, contact KISSsoft USA by telephone at (815) 363-8823 or by e-mail at *dan.kondritz@kisssoft.com*.

April 1–3—2007 Plastic Parts Innovation Conference and New Product Design Competition. Peabody Hotel, Memphis, TN. The SPI Alliance of Plastics Processors (APP) is accepting abstracts or proposals for technical presentations, panels, or workshops. The APP seeks papers on topics that include the latest uses of materials; case studies; emerging business issues; new market developments; low-pressure structural foam; creative design/tooling; innovative new process technologies; time- or cost-reducing product development methods; and production innovations to advance attendees' knowledge of the plastics processing arena. $625–$725, depending on membership status. For more information, contact the Society of the Plastics Industry by telephone at (202) 974-5247 or on the Internet at *www.plasticparts.com*.

April 16–20—Hannover Messe World Trade Fair for Industrial Technology. Hannover Fairgrounds, Hannover, Germany. See coverage on page 60. Full event tickets are 48 euros in advance, 57 euros on site. Day tickets are 21 euros in advance and 26 euros on site. For more information, visit *www.hannovermesse.de*.

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Siemens Flender

WINS METSO MINERALS ORDER

Siemens Flender received an order from Metso Minerals UK Ltd., a minerals processing equipment specialist that is constructing a number of rail car dumper and train marshalling systems for coal export facilities in China.

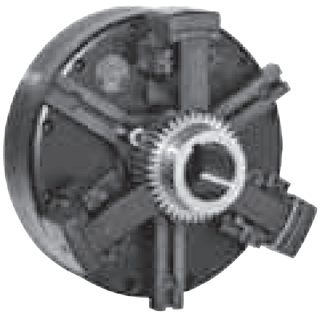
According to Flender's press release, the latest order is for the Port of Jingtange, where 24 planetary drive units have been supplied for two positioners, which marshall full coal wagons into the dumper area. Loaded trains can be 200 wagons long. Flender has already supplied the drive unit assemblies for the coal dumpers, which empty coal from rail wagons.

Each position drive unit comprises a Siemens 90 kW, 1,500 rpm motor, Neupex/Autogard torque limiting coupling, Sime Stromag electromagnetic brake and Planurex P2NA10 planetary gear unit with an extended output shaft fitted with a 15-tooth pinion.

Chris Weeks, Metso project manager, says "We first used Flender gear units on a project in China back in 1983, and since that time, Flender has remained our preferred supplier in China. We are very happy with the performance and reliability of Flender units."

The project is slated for completion by August 2007.

N.A. Woodworth
Workholding Worldwide
"Quick-Pitch" Diaphragm



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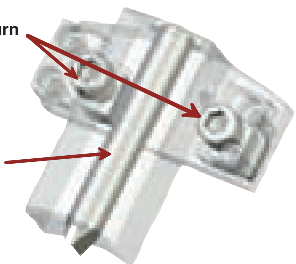
- Standard "pull-back" action
- Centrifugal force compensation for higher speeds
- Minimal maintenance, no sliding parts
- Lightweight assembly
- Ideal for hard turning and grinding applications



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Industri Kapital

ACQUIRES MAJORITY STAKE IN MOVENTAS

Industri Kapital signed an agreement with CapMan Funds to acquire a majority stake in Moventas, a Finland-based manufacturer of industrial and wind turbine gears and provider of gear maintenance and service.

CapMan acquired Moventas and Metso Drives in 2005. CapMan and Varma will remain minority shareholders in Moventas. Upon completion of the transaction, Industri Kapital will own 58% of Moventas. The remaining ownership of the company is divided between Varma (4%), CapMan Funds (16%) and company management (22%).

Moventas reported sales of 207 million euros for 2006.

Michael Rosenlew, a partner at Industri Kapital, says, "We are delighted to be acquiring Moventas, which benefits from a leading position as an independent major wind gear manufacturer with a strong position in selected industrial market segments. We are looking forward to working with the management team and CapMan to bring the company to its next stage of development. We will continue organic expansion by leveraging Moventas' unique position, focusing on supporting the company in enhancing operational excellence and in particular in improving customer service. We will also pursue acquisition-led growth."

OC Oerlikon AG

PURCHASES FAIRFIELD PARENT COMPANY, SAURER AG

Fairfield Manufacturing Company, Inc. headquartered in Lafayette, IN announced that Saurer AG of Switzerland, parent company of Fairfield, has been acquired by the OC Oerlikon Corp. AG, Pfäffikon, Switzerland.

OC Oerlikon finalized the stock purchase and acquisition of Saurer AG on January 1 and is currently implementing the steps for integration of the Saurer Group into the Oerlikon corporate structure.

"The acquisition of Saurer forms a platform which allows us to fully exploit potential synergies within the Oerlikon Group and makes perfect sense for a technology-driven company like Oerlikon," says CEO Thomas Limberger.

Oerlikon's core business technology segments are coatings, vacuum, precision, textile and drive systems. Key industries served by these segments include automotive, space, energy, consumer electronics, IT, life sciences and machinery and tool manufacturing.

Fairfield Manufacturing will become part of the drive technology segment of the Oerlikon Group and will be branded as Oerlikon Fairfield Drive Systems in the U.S.

According to Gary Lehman, president and CEO of Fairfield, "This integration of Saurer AG into OC Oerlikon adds a new and greater dimension to Fairfield's global expansion plan through utilization of Oerlikon's high-technology focus and vast global footprint. We are very excited about this latest development within our ownership structure."

Fairfield Manufacturing Company, Inc. provides engineered gear and drive solutions for mobile and industrial machinery, including the Torque-Hub® brand planetary final drives. The company's facilities include a 600,000-square-foot facility in Lafayette, IN as well as the Fairfield Atlas, Ltd. facility in Belgaum, India. Fairfield also has locations in China and Europe devoted to providing gear and drive solutions to a broad range of markets.

Gary Kimmet

APPOINTED PRESIDENT OF GEAR RESEARCH INSTITUTE

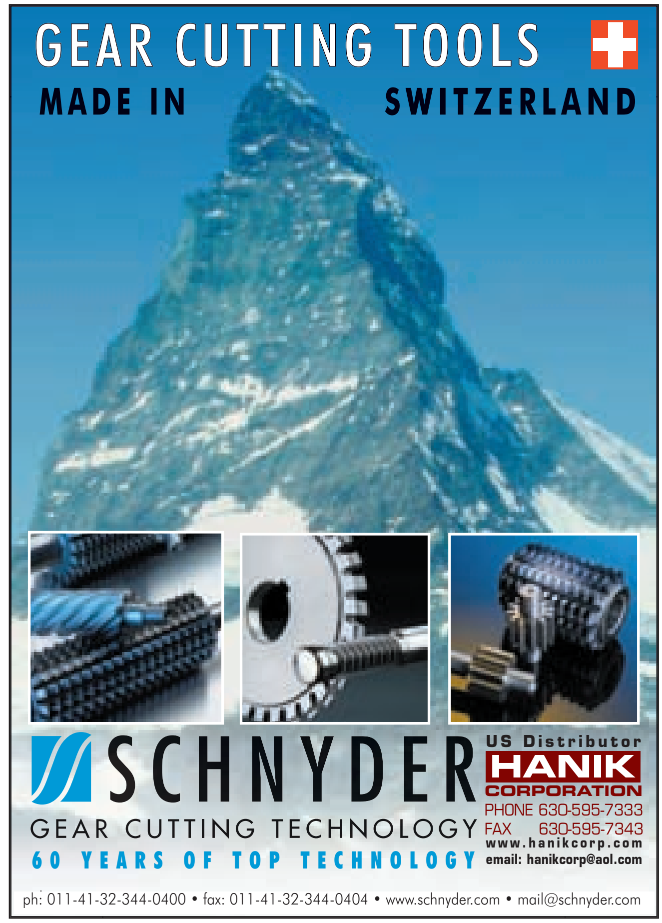

Gary Kimmet

Gary Kimmet, vice president of worldwide sales and marketing at Gleason Corp., was appointed president of the Gear Research Institute.

The institute, affiliated with the ASME and AGMA, conducts research and development, consulting, analysis and testing in areas such as gear materials, heat treating, noise characteristics and durability.

Kimmet has been with Gleason since 1968 in a variety of positions, including vice president of engineering. He holds several patents related to gear manufacturing and processes. Kimmet is a past member of the Board of Directors at AGMA and has been a member of the Board of Trustees of the Gear Research Institute for 10 years. He is also a member of the Board of Directors of the Gleason Foundation.

Suren Rao, senior supervisor at the institute, says, "In my humble opinion, Mr. Gary Kimmet brings a vast wealth of experience in the gear industry to assist the Gear Research Institute in expanding its value to its sponsors. He has been on the board of the institute for the last ten years and knows it well. The institute, which is in its 25th year, will need an individual with considerable gear industry experience, vision and knowledge of the institute to lead it on its next 25 years. I believe Gary is that individual."



Bodine

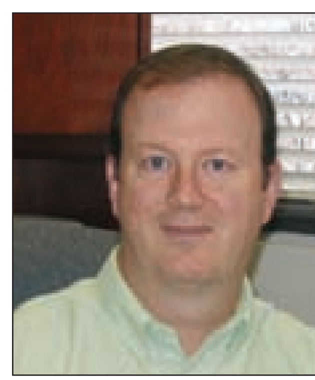
ANNOUNCES MANAGEMENT PROMOTIONS

Bodine Electric Co. has promoted Michael Gschwind to vice president of sales and marketing.

Gschwind, who has been with the company for nearly 30 years, has worked in all aspects of product research, development and sales at Bodine. He began his career at Bodine as a sales engineer, directly serving accounts in the Midwest and western U.S. In the mid-1980s, Gschwind transferred to Bodine's research and development group, where he developed electronic products for stepper and brushless DC motors. In 1999, he became engineering manager for Bodine's AC, brushless DC and e-TORQ product lines. In 2002, Gschwind was named director of sales, where he managed the company's corporate sales force.

"Mike's experience in product design, his extensive knowledge of motor system applications, and strong understanding of sales make him a welcome addition to our executive team," says John Bodine, president and CEO of Bodine Electric Co.

Additionally, Edmund Glueck has been promoted to marketing and product development manager, and Terry Auchstetter has been promoted to business development manager for custom products.


Michael Gschwind

Both Glueck and Auchstetter have extensive experience in marketing and applications for the Bodine product line. Since joining the company in 1993, Glueck has been responsible for market development and sales of all of Bodine's AC and Brushless DC products. In his new role, Glueck will oversee all Bodine marketing activities. Auchstetter, who has been with Bodine for 21 years and most recently has supervised all DC and control products, will assume responsibility for managing opportunities for custom (built-to-order) products.

"I'm confident these changes will allow us to focus our efforts in a consistent, customer-driven manner," stated Gschwind. "The end result will be enhanced growth in markets that demand the highly reliable, value added products and services offered by Bodine."

Ikona Gear

NAMES NEW VICE PRESIDENT

Joe Vosburgh

Joe Vosburgh was named executive vice president of Ikona Gear.

Vosburgh will assume the overall responsibility for strategic planning, building strategic alliances and general operations at Ikona. Laith Nosh, company president and CEO, says Vosburgh has served on the board of directors for a year and a half, and will now be involved on a daily basis.

Vosburgh has 12 years' experience in the development, marketing and commercialization of breakthrough technologies. Vosburgh held senior marketing and product strategy positions with Creo Products, and most recently Ballard Power Systems. While at Ballard Power, Vosburgh was the architect of a $22 million fuel cell contract targeting the materials handling equipment market. Through his product strategy, which included design, pricing and contract negotiating, Ballard signed the single largest fuel cell order in industry history.

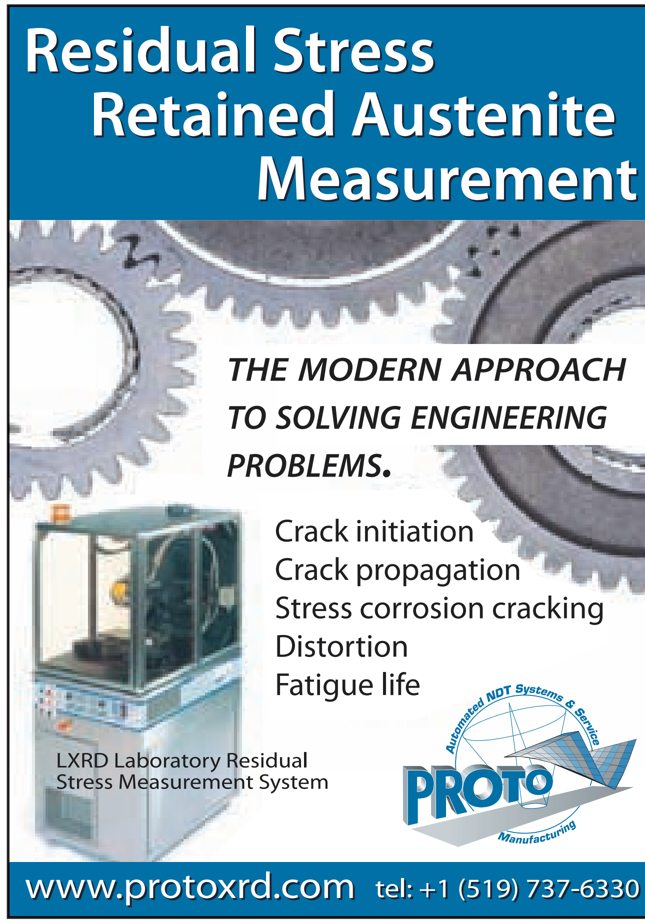
"I look forward to executing our business model, and will work to leverage Ikona's innovative technology in the successful penetration of target markets while maintaining a focus on disciplined growth and fiscal responsibility," says Vosburgh.

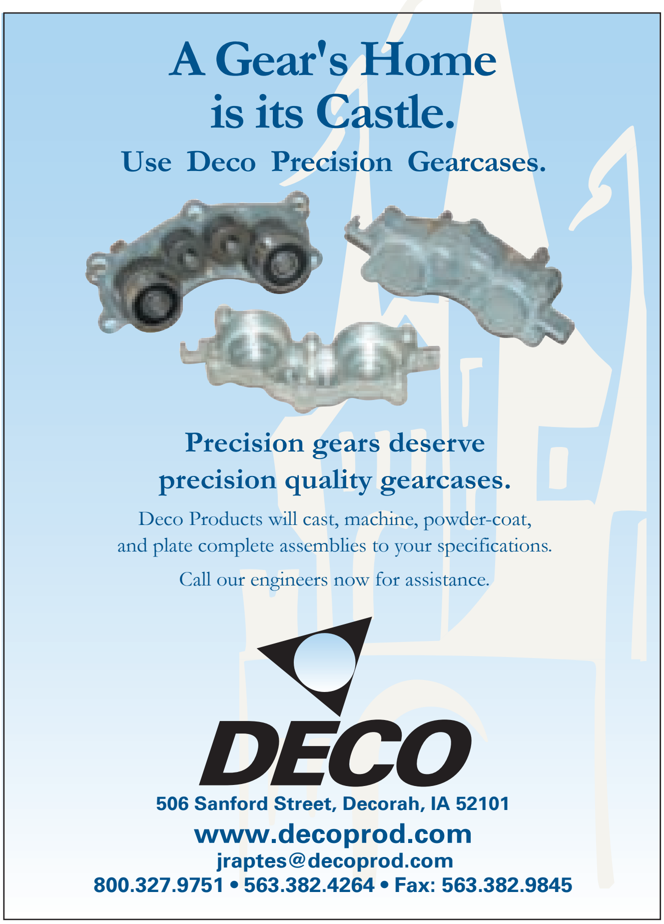
Applied Process

COMMISSIONS HEAT TREATING FACILITY IN CHINA

Applied Process CEO John Keough recently commissioned AP Suzhou as the newest member of the Applied Process family of companies.

The AP Group held the grand opening of its newest facility in conjunction with the 4th China Conference on ADI. AP Suzhou will offer its customers austempering services.





According to the company's press release, AP Suzhou will have the support of Applied Process' R&D and technical marketing departments to aid its Chinese customers with the implementation of austempering processes that make their components stronger, tougher, lighter, and more wear-resistant.

Tim McLaughlin

JOINS WHEELABRATOR AS SALES MANAGER

Wheelabrator Plus announced that Tim McLaughlin has joined the company as territory account manager and will have account responsibility for Ohio, Kentucky and West Virginia.

According to the com-pany's press release, McLaughlin has more than 31 years of experience in abrasive blast cleaning equipment, peening applications and abrasives. He retired as CEO of McLaughlin, Inc., in Middletown, Ohio, in 2004. He most recently served as the sales manager for Ervin Industries in Ann Arbor, MI., covering seven states.

"I'm thrilled at the prospect of coming to work for Wheelabrator Group, and I've been made to feel extremely welcomed by everyone connected with the enterprise," McLaughlin said. "I look forward to bringing my know-how and the re-sources of the Wheelabrator Group to my new territory."

Tim McLaughlin

mG miniGears Sales Figures

SOAR PAST 70 MILLION EURO MARK

Worldwide sales of mG miniGears rose by 7.6% to 73.9 million euros, surpassing the 70 million euro mark for the first time.

According to the company's press release, with an increase of 16.2%, the growth in sales of loose gears made of cut metal and powder metal, primarily for the hand power tool and automotive markets, was particularly strong. Sales for the gardening segment improved by 3.7%, whereas the fork lift market segment matched last year's level.

Europe remained the strongest region, contributing 59% to sales, followed by North America with 28%, the Far East region with 11% and Latin America with 2%.

"Demand in all segments for the next months is above the level of the same period last year," states Alexander Bossard, miniGears' CEO, "and I expect miniGears to reach the 80 million euro mark this year."

Houghton and Eaton

COLLABORATE ON CHEMICAL MANAGEMENT PROGRAM

Houghton Fluidcare, a division of Houghton International, signed a three-year agreement with Eaton Corp., Cleveland, OH, to provide a comprehensive chemical management program to reduce industrial fluids usage and associated costs.

The agreement is an extension of the original contract, which was signed in November 2000.

Houghton Fluidcare will provide chemicals and fluids procurement and management services for selected Eaton plants in the U.S., U.K., Spain, Poland, Mexico, Italy, Germany, China and Canada. In addition, Houghton's specialists will provide daily technical services at many of Eaton's larger facilities.

1,473 American Axle Employees

PARTICIPATED IN SPECIAL ATTRITION PROGRAM

American Axle & Manufacturing Holdings, Inc. announced that 1,473 UAW-represented employees agreed to participate in AAM's special attrition program.

10th International MFN Shot Peening Workshop & Trade Show in Florida, USA

Date: 15th - 17th May 2007

Register online at www.mfn.li/workshops

- 21 Different Topics
- Trade Show with 22 Booths
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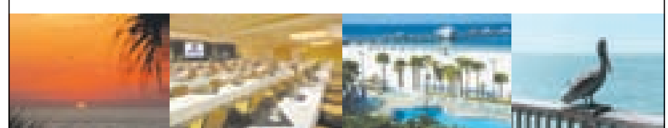

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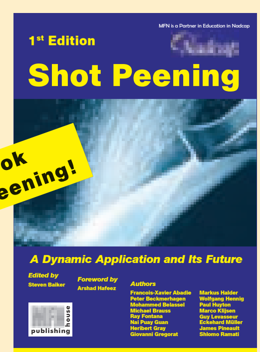

New Book On Shot Peening!

"Each chapter in this book is written by an acknowledged expert in the field of shot peening. I would highly recommend it for anyone interested in using this application to improve the performance of structural components, particularly those that are expected to experience subsequent fatigue loading."

Prof. Lothar Wagner, Acting Director, Institute of Materials Science and Engineering, Clausthal University of Technology, Germany

Topics:
introduction to peening and theory, peening intensity, effect of peening, Almen saturation curves, peening coverage, exposure time, trouble shooting, process documentation, masking solutions, workpiece fixtures, shape & size inspection of peening media, cut wire, cast steel shot, ceramic media, specifications, shaded strips, audits by third parties, peening equipment components, air & wheel peening, machinery types and application examples, hole peening, flap peening, peen forming, optimization of shot peening for fatigue critical applications, residual stress, XRD measurement, quantative characterization of the shot peening process, etc.

Price: $155 plus shipment - Order online at www.mfn.li/books or E-mail to info@mfn.li

The program was offered to UAW-represented employees at AAM's facilities located in Detroit, MI; Three Rivers, MI; Buffalo, NY; Tonawanda, NY; and Cheektowaga, NY.

Under this special attrition program, AAM offered a range of early retirement incentives, buy-outs and educational opportunities to its associates. Approximately 265 retirement-eligible associates participated in this program, while an additional 1,208 associates elected one of the buyout options at these facilities. More than 1,300 of these associates left the company before year-end 2006.

"The special attrition program accelerates our ability to realign our hourly workforce with actual and projected production and market conditions," said AAM co-founder, chairman, and CEO Richard E. Dauch. "The structural cost benefit to AAM resulting from the special attrition program and other related restructuring actions should exceed $100 million annually. This will enhance our ability to invest in the continuing expansion of AAM's product portfolio, served markets, customer base and global manufacturing footprint."

In addition, AAM also announced that it plans to idle a portion of its U.S. production capacity dedicated to the mid-size light truck product range. As a result of these plans and other capacity rationalization initiatives, AAM expects to incur asset impairment charges of as much as $200 million in the fourth quarter of 2006.

Conicity Technologies

NAMED ALLIANCE PARTNER FOR DEPARTMENT OF DEFENSE

Conicity Technologies was named an alliance partner of the National Center for Defense Manufacturing and Machining (NCDMM).

According to NCDMM's alliance partner charter, "The objective of NCDMM is to support the Department of Defense's transformation to more cost-effective, sustainable and maintainable use of high-performance materials through a focused initiative for the development of advanced machining and manufacturing techniques."

Alliance partners may participate in NCDMM-sponsored technical and research programs, perform research that NCDMM cannot or chooses not to perform, provide technological support to NCDMM, and help promote technology.

As an alliance partner, Conicity Technologies will participate in NCDMM initiatives to develop more efficient and cost-effective means of machining advanced workpiece materials; increase industry, cutting tool suppliers, machine tool builders and end-user participation in federally-funded research and development programs; and foster greater cooperation and coordination among manufacturing technology providers and their customers.

KBE+

PROVIDES CONSULTING SERVICE TO CHINESE AUTOMOTIVE MANUFACTURER

KBE+ Inc. recently was awarded a contract with Nanjing Automobile (Group) Corp., located in Nanjing, China.

According to the company's press release, Nanjing Automobile is a state-owned automaker that produces 200,000 vehicles annually, including the Rover, MG, Austin, Morris, and Soyat car brands.

As part of a SAE-ARI (Automotive Resources Institute) initiative, KBE+ will assess the product-testing capabilities of the Nanjing factory and provide recommendations for improving equipment and production processes, with the aim of achieving a 100% increase in fiscal performance by the close of 2007. In addition, KBE+ consultants will develop a cross-training program for all test facility employees and laboratory personnel to foster efficiency and cooperation throughout the workforce.

Based in Camillus, NY, KBE+ is an engineering consulting firm that specializes in mechanical power transmission, gear design and analysis, and powertrain design and application. The company also provides professional development seminars targeted toward the automotive industry's design, production, and marketing employees.

AGMA

SEEKS STAFF ENGINEER

The American Gear Manufacturers Association is seeking a staff engineer responsible for coordinating technical committees in the development of domestic and international standards.

The staff engineer acts as the AGMA liaison to various

Correction

In the January/February 2007 issue of *Gear Technology*, an article titled "AGMA Delegates Meet Chinese Counterparts" quoted Brian Slone from Process Equipment Co. The comments attributed to Slone should have been attributed to Otis Edwards, an international markets coordinator in Hong Kong who represented Process Equipment at the show.

We apologize for any confusion this may have caused.

The Editors
Gear Technology magazine

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AGMA technical committees; edits standards from the working draft through final acceptance stage; prepares and submits AGMA and ANSI reports; organizes and administers AGMA's technical education seminars; prepares and submits advertising copy for industry trade journals; updates and maintains the technical division content on the association's website; creates drawings using AutoCAD Lt for standards and other uses; and provides technical guidance for internal staff.

The ideal candidate should have a BS in engineering with gear industry experience, and working knowledge of Word, Excel, Powerpoint, AutoCAD and publishing software.

For more information, visit the AGMA website at *www.agma.org*.

Altra Holdings

ACQUIRES TB WOOD'S

Altra Holdings, Inc. and TB Wood's Corp. announced that they have entered into a definitive agreement specifying that Altra will acquire TB Wood's for $24.80 per share. According to an announcement on Altra Motion's website, the boards of directors of both companies have unanimously approved the transaction.

Michael L. Hurt, Chairman and CEO of Altra, says, "The acquisition of TB Wood's broadens our growing coupling product line and adds engineered belted drive systems as well as adjustable speed electronic drives and systems to our product portfolio."

The acquisition of TB Wood's is expected to be immediately accretive to Altra's earnings in 2007 and approximately 15–20 cents per share accretive to fully-diluted earnings per share in years 2008–2009. TB Wood's complementary product lines will expand Altra's breadth of products and provide access to new markets. TB Wood's offering of elastomeric couplings will expand engineered coupling revenues by over 50%, according to the release.

The company says Altra revenues generated through distribution will increase by approximately 37% and will enable the combined company to serve this channel more efficiently, offering a broader portfolio of products and services.

In addition to five U.S. manufacturing locations, TB Wood's will expand Altra's global footprint by adding facilities and resources in Mexico, Italy, and India.

Ipsen International and VFS

CONSOLIDATE INTO NEW ENTITY

Ipsen International and VFS combined into a new entity called Ipsen Inc.

John Schmitt, president and CEO, says, "Together, our new company will offer furnace customers better technical expertise, a broader product base, and the most extensive customer service network in North America. As part of this process, staffing, manufacturing and sales have been retooled to provide the most efficient, robust and responsive furnace manufacturing firm in the U.S. Our Illinois and Pennsylvania plants will deliver the best manufacturing efficiency, quality and product available in the area."

Ipsen and VFS furnace brands will continue to be maintained, sold and serviced as they have been. Ipsen will continue to provide aftermarket support of any furnace type and brand.

Each brand maintains its own web site, with a full offering of products and services while the consolidated website is under development.

Donald Brownrigg

PROMOTED TO CEO AT SM-CYCLO

Donald J. Brownrigg was promoted to CEO/president for SM-Cyclo of Canada.

Brownrigg has worked in the power transmission industry for the past 35 years, including 15 years at SM-Cyclo in various sales, marketing and operations positions. Brownrigg began at the company in 1991 as Canadian general sales manager when the company was a subsidiary of Sumitomo Machinery Corp. In 1996, he was promoted to international operations manager and worked out of the SMA headquarters in Chesapeake, VA. He returned to Canada in 2001 to accept the position of COO/president of SM-Cyclo.

"We are pleased that we have an executive of Don's caliber to take this important position and continue SM-Cyclo's forward momentum," says Nobuhiko Kawamura, general manager of international sales and marketing for Sumitomo Drive Technologies' PTC Group. "Don has been in the power transmission industry for more than three decades. His combination of managerial skills and technical knowledge will be vital to SM-Cyclo's continued success."

A Microhardness System Can Test Samples without Mounting or Fine Polishing?

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It's true. The MT90 Microhardness Test System can. And it performs the tests much more quickly and without operator influence.

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If hardness testing is important to your company then knowledge about Newage hardness testers is critical. Take the time to see what Newage can do for you.

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Test large parts and awkward shapes without sectioning. Test in dirty environments. Test at high speeds or easily automate.

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Upgrade your existing micro test system to increase speed and eliminate operator influence.

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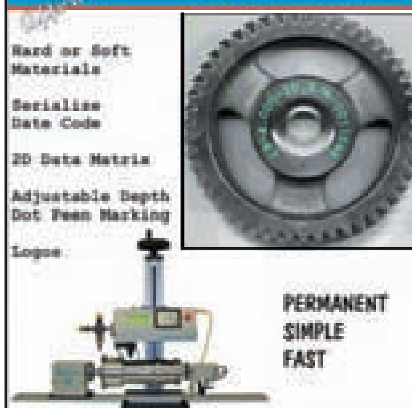

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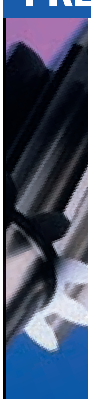

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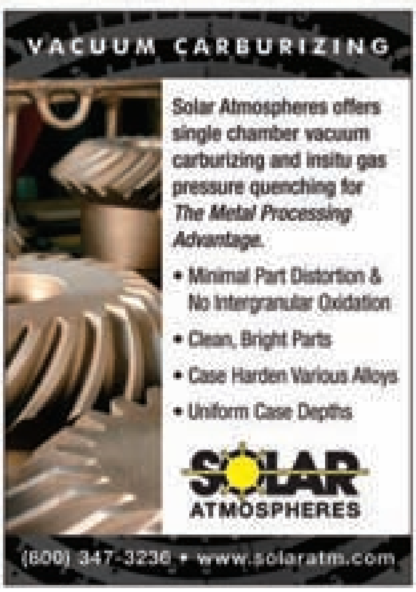

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INTRODUCING

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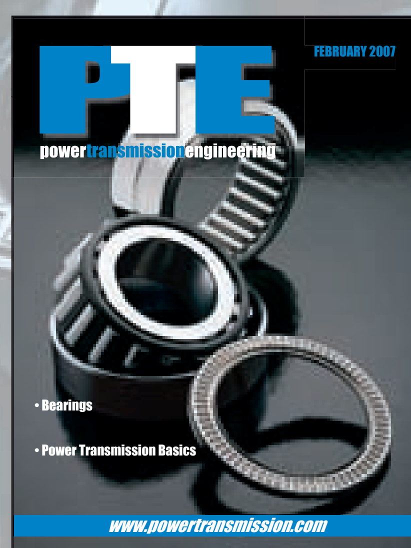
We'll be taking the same editorial approach with *Power Transmission Engineering* that we take with *Gear Technology*. That is, we'll provide the best technical articles and latest industry and product news—information that's practical and useful for design engineers, plant maintenance and engineering professionals, purchasing agents and others involved with power transmission products.



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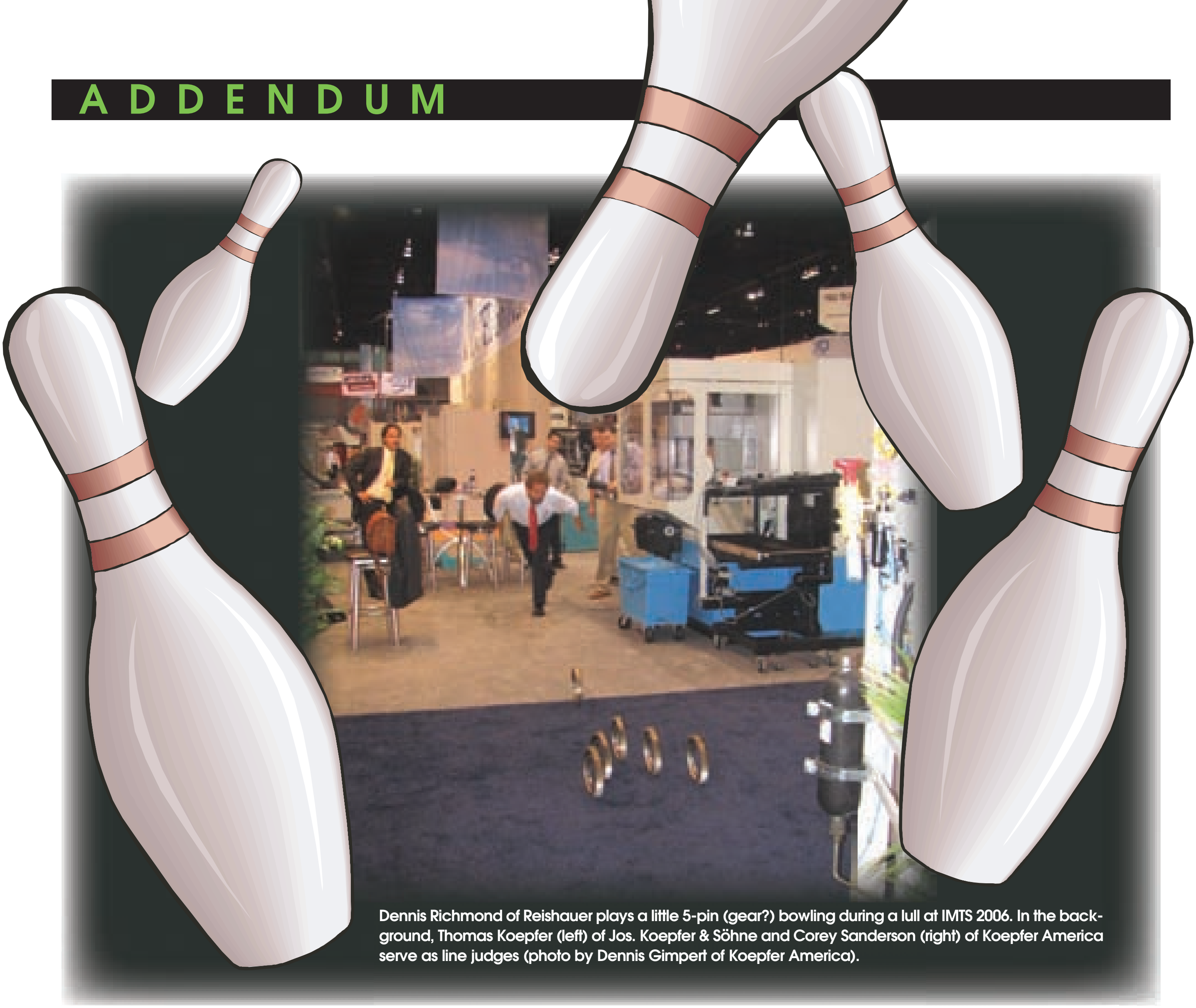

Dennis Richmond of Reishauer plays a little 5-pin (gear?) bowling during a lull at IMTS 2006. In the background, Thomas Koepfer (left) of Jos. Koepfer & Söhne and Corey Sanderson (right) of Koepfer America serve as line judges (photo by Dennis Gimpert of Koepfer America).

HERE'S WHAT DENNIS WAS THINKING…

ANNOUNCER 1 (whispering)
Dennis Richmond's closing in on his first perfect game as a professional. One more strike and he'll have it. His face is a stony mask of concentration as he takes the ball.

ANNOUNCER 2 (whispering)
All eyes are on Richmond now. You can just feel the tension in the crowd. They all want to see that perfect game.

ANNOUNCER 1 (whispering)
He steps onto the lane and hefts his ball into position.

ANNOUNCER 2 (whispering)
Look at him just staring down the pins.

ANNOUNCER 1 (whispering)
He begins his approach, very smooth, very deliberate…and the release.

The crowd buzzes with chatter as the ball rolls down the lane.

ANNOUNCER 2
It looks good! I think he's got it! I think he's got it!

The crowd erupts in a frenzy of excitement.

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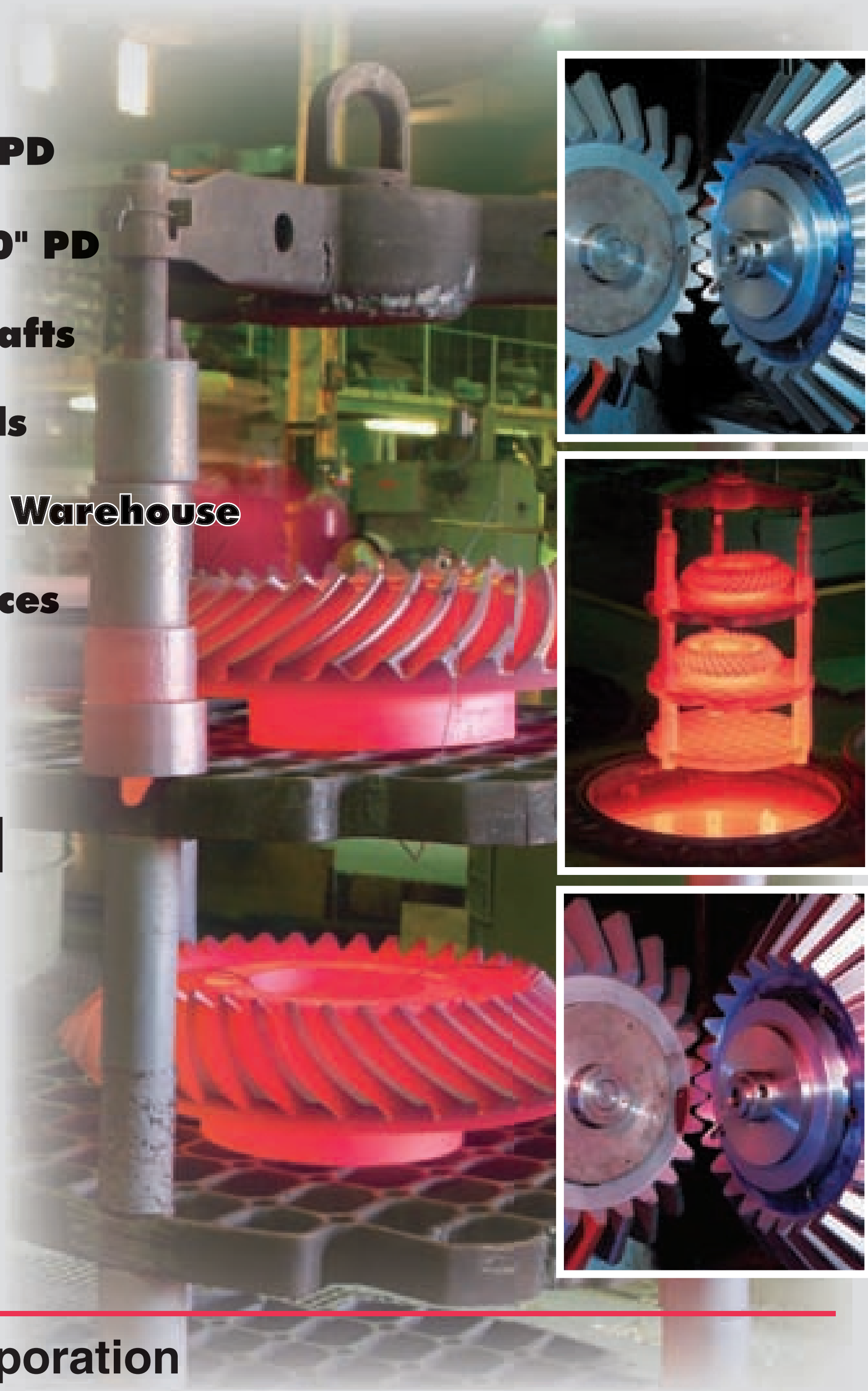

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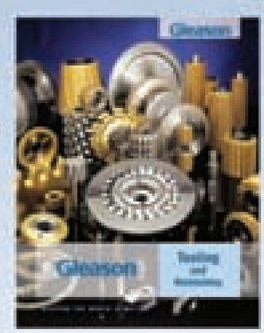

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