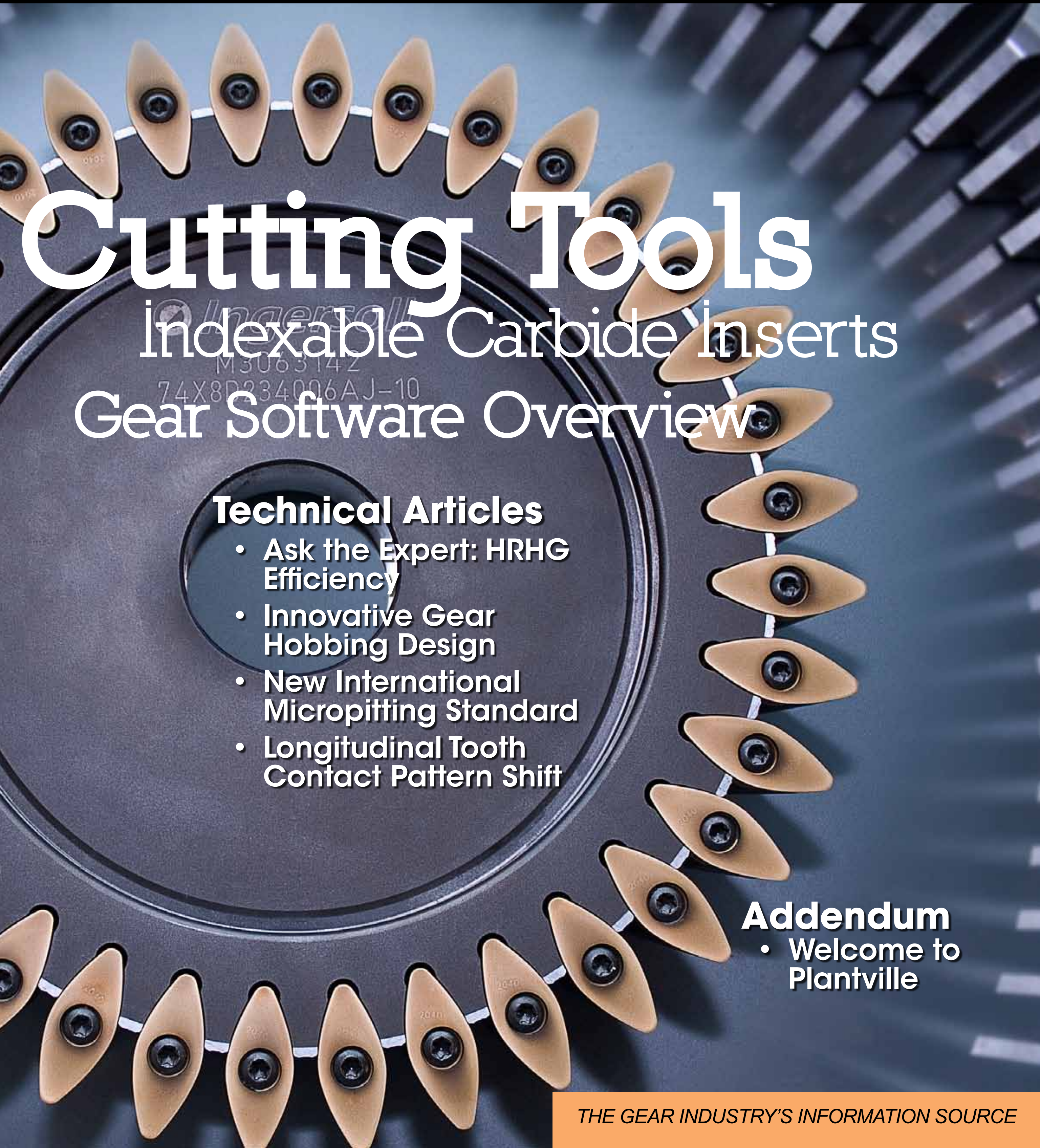
May 2012

GEAR TECHNOLOGY®

www.geartechnology.com

The Journal of Gear Manufacturing



Cutting Tools

Indexable Carbide Inserts

Gear Software Overview

Technical Articles

- Ask the Expert: HRHG Efficiency
- Innovative Gear Hobbing Design
- New International Micropitting Standard
- Longitudinal Tooth Contact Pattern Shift

Addendum

- Welcome to Plantville

THE GEAR INDUSTRY'S INFORMATION SOURCE


PTG-1


GS 400

Affordable hob sharpening and in-house tool maintenance

Star's PTG-1 sharpens both straight and spiral gash hob designs up to 8" OD x 10" OAL. Additionally, it sharpens disk, shank and helical type shaper cutters and a wide range of round tools, making it a versatile tool room machine.

Shaving cutter and master gear grinding

Designed to grind shaving cutters and master gears, the GS 400 sets new standards for precision, reliability and ease of use. An integrated measuring unit automatically checks the quality of the first tooth ground without unclamping the workpiece.

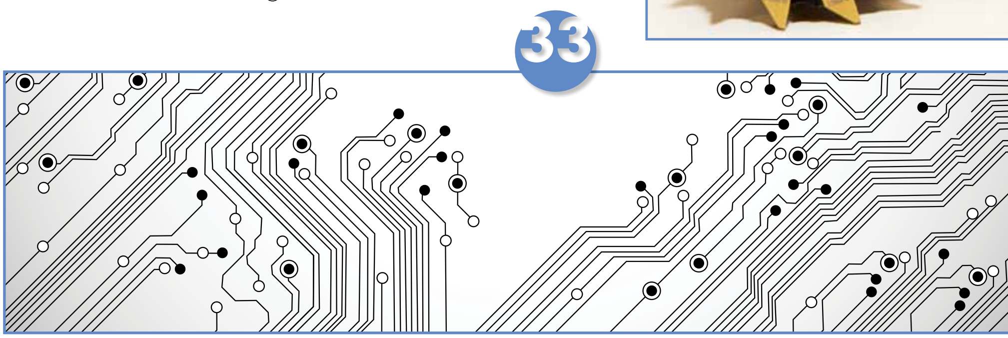
MAG FEDERAL BROACH & MACHINE COMPANY SICMAT

Plan to see us at IMTS!

http://info.star-su.com/plan-to-attend-imts-2012

CONTENTS

FEATURES



TECHNICAL ARTICLES

Vol. 29, No. 3 GEAR TECHNOLOGY, The Journal of Gear Manufacturing (ISSN 0743-6858) is published monthly, except in February, April, July and December by Randall Publications LLC, 1840 Jarvis Avenue, 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 Publications 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, 1840 Jarvis Avenue, Elk Grove Village, IL, 60007.

GEAR TECHNOLOGY

May 2012 CONTENTS

DEPARTMENTS

ONLINE

GEAR TECHNOLOGY
www.geartechnology.com

- **E-MAIL NEWSLETTER**
  Sign up for our NEW monthly e-mail newsletter with exclusive gear-related articles and content at *www.geartechnology.com/newsletter*

PTE powertransmissionengineering
www.powertransmission.com

twitter facebook LinkedIn

- **Power Transmission Engineering**
  Sign up for a free subscription.
- **NEWS**
  The latest products, industry news and calendar items.
- **BUYERS GUIDE**
  Search for power transmission products and services and communicate with the industry's leading suppliers

GEAR TECHNOLOGY

VOL. 29, NO. 3

RANDALL PUBLICATIONS LLC
1840 JARVIS AVENUE
ELK GROVE VILLAGE, IL 60007

847-437-6604
FAX: (847) 437-6618

EDITORIAL

Publisher & Editor-in-Chief	Michael Goldstein *publisher@geartechnology.com*
Managing Editor	William R. Stott *wrs@geartechnology.com*
Senior Editor	Jack McGuinn *jmcguinn@geartechnology.com*
Associate Editor	Matthew Jaster *mjaster@geartechnology.com*
Editorial Consultant	Paul R. Goldstein
Technical Editors	William (Bill) Bradley Robert Errichello Octave Labath, P.E. Joseph Mihelick Charles D. Schultz, P.E. Robert E. Smith Dan Thurman

DESIGN

Art Director	David Ropinski *dropinski@geartechnology.com*

ADVERTISING

Advertising Sales Manager	Dave Friedman *dave@geartechnology.com*
Materials Coordinator	Dorothy Fiandaca *dee@randallpublications.com*

CIRCULATION

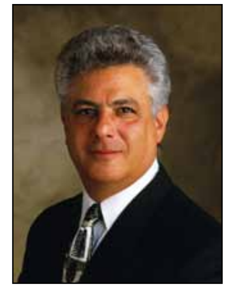
Circulation Manager	Carol Tratar *subscribe@geartechnology.com*

RANDALL STAFF

President	Michael Goldstein
Accounting	Luann Harrold

Photo courtesy of Ingersoll

BPA WORLDWIDE



THE CALL OF CUBA

I've had the great fortune to visit many countries and experience their cultures, and I often tell stories based on those experiences. But when I begin to tell people about my most recent trip—to Cuba—their eyes light up, their attention sharpens and they lean forward with great interest and curiosity.

Most Americans' feelings about Cuba are closely tied to our very intense memories about one of the most nerve-wracking periods in U.S. history. With a Communist dictator on our doorstep, the Cold War in full swing, and the recent defeat at the Bay of Pigs, Cuba was central to our nation's collective fear. Most people of a certain age remember exactly where they were on October 22, 1962, when President Kennedy went on national television to tell us that U.S. spy planes had detected and photographed missile sites on Cuba and that a flotilla of Russian ships was on its way to supply those sites. He explained that he had ordered our Navy to encircle Cuba and to not permit the Russian ships to deliver their goods, even if it meant war. The world collectively held its breath until the Russians blinked, by turning their ships around and promising to dismantle the missile facilities.

But the fascination with Cuba is as much about forbidden fruit as it is about fear. Since 1960, when the United States began its embargo, we've been denied access to Cuba's world-famous cigars, its tropical beaches and its vibrant culture. The former playground of the world's rich and famous was renowned for drinking, dancing and gambling—and decades later Cuba still calls to us, tantalizing our imagination.

I was lucky enough to have the opportunity to visit Cuba for eight days in March. My wife and I went as part of a cultural exchange mission sponsored by an art group we belong to.

In Havana, you could easily see the grandeur of what once was, but only if you looked past the dirt and disrepair. We saw beautiful buildings, both commercial and private, whose architecture was unlike anything we're used to in America. Many of the homes were very grand, patterned off European styles. Scattered throughout the Hotel Nacional were photos of the famous politicians, movie stars and sports heroes who had stayed there before. But the elevators worked sporadically, the windows hadn't been washed in years, and the carpeting was threadbare. Everything appeared to have at least 10 coats of paint. But through all that you can still see the glory and beauty of the past.

Traveling around Havana was like being on a movie set from the 1940s or 50s. The vibrant colors of the vintage Cadillacs, Buicks, Chevrolets, Chryslers, Plymouths—and yes, even DeSotos—made me feel like I was in the pages of a Dick Tracy comic book. Old American-made automobiles were everywhere to be found. Because many of the cars are used as taxis, their owners keep them in pristine condition. Even in Cuba, private enterprise seems to have an effect.

Although much of Cuba is run-down and shabby, its people are decidedly energetic, vibrant, warm and welcoming. Being on a cultural mission, we visited musicians, dancers, actors and artists at their studios, homes, schools and universities. We spent a lot of time with young people—typically eight to 25 years old—as well as established artists. These people are held in the highest regard in Cuban society. Although wages are very low for most everyone—mostly under $50 a month—those in the arts can often do quite well financially. They are the only ones who can trade with non-Cubans using foreign currencies. Some artists sell their work worldwide for as much as $50,000 per piece. When sold through an official government gallery, the government takes a cut, but artists are also allowed to sell directly to collectors and museums around the world. In that case, they get to keep the entire sales price. Those in the arts also have far greater opportunities to travel and experience other cultures. Despite the disparity in lifestyles, there doesn't seem to be any envy in their society, only respect. Everyone is given the same free opportunity to develop their skills, with free schooling through the university, free healthcare from cradle to grave and almost free housing for everyone.

All in all, this trip has given me a new perspective on Cuba. Seeing the sights has shown me the splendor of what used to be. Meeting the people has given me hope that Cuba's future might one day again be grand. Although I'm not quite ready for a return trip yet, it might be interesting to go back in five years to see what changes have taken place.

Michael Goldstein,

Publisher & Editor-in-Chief

P.S. To see photos of those old cars in Havana, visit *http://www.geartechnology.com/cuba*

New Technologies for Challenging Workpieces

EMAG OFFERS TURNING, MILLING AND GRINDING SOLUTIONS

The ever-increasing demand made on precision components as well as the decrease in price is pushing traditional manufacturing processes to their limits. In recent years, EMAG LLC has been working on new production technologies that will complement or replace traditional processes such as turning, milling and grinding. These new technologies will be featured at IMTS (September 10–15) in Chicago later this year.

PECM FOR NICKEL- AND TITANIUM-BASED ALLOYS

With its PECM (Precision Electro-Chemical Machining) technology, EMAG presents a production process that opens up entirely new fields of application. PECM is a process for the machining of high-alloyed materials, such as nickel- and titanium-based alloys. The disadvantages of traditional metal cutting—tool wear, mechanical stresses, micro-fissuring caused by heat, oxidization layering and the need for subsequent deburring operations—are eliminated, as this process is a non-contact one without heat input. All electro-chemical machining processes are characterized by stress-free material removal, smooth transition points and surfaces without ridge formations.

"Many of our PECM customers are eliminating the traditional steps in the machining process, such as milling, turning, drilling, etc. and replacing them with one technology using PECM," says Peter Loetzner, CEO of EMAG. "In situations where customers are doing near-net shaping, the customers changed from forging parts to using the PECM process to machine the shape and finish (polish) the workpieces in one step. If they don't have near-net shaping, we are doing roughing with ECM. When they are finished, the workpieces have a very fine surface and geometry."

EMAG has been involved with the use of solid-state lasers in the welding of powertrain components from an early stage.

The advantages that the PECM process provides for a number of different branches of the industry are best shown on the example of a turbocharger for the automotive industry. The electro-chemical process is one that can be used effectively in the machining of many high-alloy components, especially those in the high-temperature sector of the turbocharger. It also offers a much shorter and very efficient process chain. The kind of downstream clean-up operations necessary when traditional machining processes are used—such as deburring after milling—are no longer necessary. PECM machining operations are burr-free. And there is hardly any tool wear. The result: downtimes are minimal, when compared to milling (which requires regular tool changes). The process as a whole is sturdier and less prone to errors. And another important factor that our example of the turbocharger shows: the superb surface finish of the PECM process, where Rz values of 0.3 micron can be achieved."

"Since the process started, we have learned a lot about different types of

continued

Production laser welding has led to a significant reduction in the cost to customers as well as the reduction in capital investment in the manufacturing process of gear wheels.

materials," Loetzner says. "For example, there is a big influence in what direction an alloy is forged or produced. We also learned about how to protect a workpiece and how to get the best result through pre-cleaning and after cleaning. It is sometimes very tricky to polish a specific material these workpieces are made out of, and with ECM and PECM we are able to achieve better accuracy and durability using different fluids. For example, some with higher amps or more connectivity. We learned a lot about the final details which end up influencing the entire process."

One of the industries that EMAG believes would definitely benefit from ECM and PECM is the aircraft/aerospace industry. "In this industry they are machining a lot of parts out of Inconel, titanium alloys and nickel-based alloys," Loetzner says. "The big benefits come with these alloys because they are difficult to machine with traditional technologies, there are huge costs and a lot of tool wear. With ECM and PECM technology there is no wear—so no tool wear and so no tool cost. I think that this technology will break through in the aircraft industry in the next 2 or 3 years due to the major benefits the technology brings."

Precision Electro-Chemical Machining (PECM) is eliminating traditional steps in the machining process such as turning, milling and drilling (all photos courtesy of EMAG).

REDUCING OPERATING COSTS BY 50 PERCENT

Production laser welding is already a highly productive process in the manufacturing of gear wheels. The use of diode-pumped solid-state lasers—such as disc or fiber lasers—reduces operating costs by up to 50 percent. "Production laser welding has led to a significant reduction in the cost to customers as well as the reduction in capital investment in the manufacturing process of gear wheels," Loetzner says. EMAG has been involved with the use of solid-state lasers in the welding of powertrain components from an early stage and is considered a pioneer in the technology. EMAG again

has fulfilled a promise to their users of offering them the lowest possible cost-per-piece, by coming up with an innovative technology that brings true cost benefits.

For many applications, solid-state lasers allow welding without shielding gas. This not only reduces operating costs, it also avoids having to follow the annoying logistics imposed by the use of shielding and laser operating gases. In many cases, the welding process can also be sped up considerably. This increases productivity and—through a reduction in energy input per unit length—reduces welding distortion, resulting in better component quality.

SINGLE PIECE CAMSHAFTS?

Another highlight is EMAG's heat-shrink assembly technology, a process that scores particularly well in camshaft production. The high degree of precision achieved with the joining process drastically reduces the number of cam profile grinding operations or—with the use of precision cams—avoids them altogether. Another benefit of the process is the ability to combine different materials in the construction of the shaft, such as forged cams (e.g. in 100Cr6) and sintered cams, which do not require regrinding. Accessory components, such as plugs and end pieces, can—like the shaft itself—also be made of better materials. This allows for the camshaft to be adapted to the requirements of the engine and to be optimized in load bearing capacity and manufacturing costs.

For more information:
EMAG LLC
38800 Grand River Avenue
Farmington Hills, MI 48335
Phone: (248) 477-7440
www.emag.com

Ticona

OFFERS INTEGRATIVE SIMULATION TECHNOLOGY

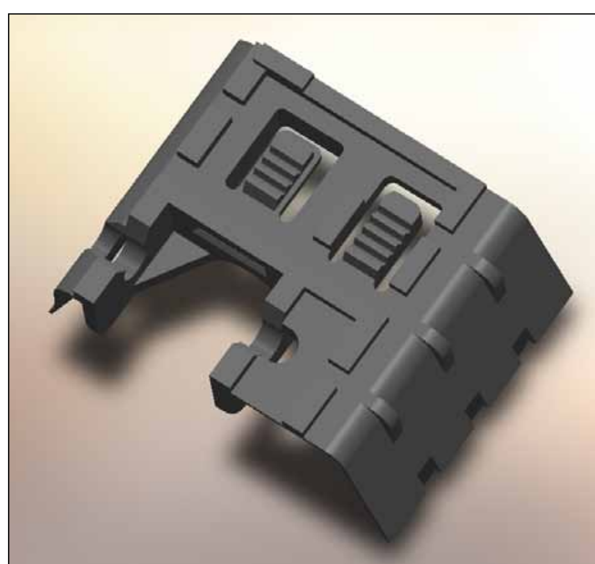
Ticona Engineering Polymers has announced the global availability of "integrative simulation" technology that can help customers design cost-effective complex glass fiber reinforced parts. "As a solution provider, Ticona recognizes that successful new components rely on the speed and quality of computer-aided engineering (CAE) predictions," said Ulrich Mohr-Matuschek, Ticona global part design/CAE leader. "Customers today expect working solutions based on detailed structural response predictions and optimized mold design."

Since 2009, Mohr-Matuschek and his team have worked with e-Xstream engineering Digimat material and structure modeling tools to link Autodesk *Moldflow* plastic injection molding simulation tools with Ansys Inc. structural analysis to improve the accuracy of computing fiber reinforced components under load. Labeled integrative simulation, because it integrates processing simulation data in the computation of the component, this technology can be used in designing complex parts that use both short- and long-fiber reinforced thermoplastics.

"By systematically comparing simulation and experimental results, we have shown this procedure can move simulation forecasts a lot closer to the actual experimental gradients," Mohr-Matuschek said. "Thus, the non-linear and anisotropic simulation of a sunroof mount made with a glass fiber reinforced Celanex thermoplastic polyester (PBT) matches the experimental values a lot better than the results of other computation models."

FIBER FLOW ORIENTATION KEY TO SUCCESS

The field of application for fiber reinforced thermoplastic polymers is constantly increasing, especially in parts exposed to high loads. Cost and time factors are issues that have played a significant role in increasing the relevance of CAE in part design. Standard procedures, based on the finite element (FE) method, are frequently used. Numeric methods provide information on the component's behavior under load assuming uniform mechanical properties of the molded material. However, mechanical properties of fiber reinforced thermoplastics vary depending upon the orientation of the fibers. During the mold filling phase of the injection molding process, the fibers typically are oriented in different directions within the part as a function of the melt flow. The influence of this local fiber orientation is substantial



Ticona used "integrative simulation" technology to help Inteva Products - Roof Systems Germany GmbH in analyzing the design of a sunroof mount molded from glass fiber reinforced Celanex thermoplastic polyester (PBT).

and not taken into account in the common numerical methods, a factor which plays a significant role for components subject to high or extreme loads.

Unlike standard FE calculation methods, integrative simulation takes into account the influence of the local fiber orientation in the component as well as the elastic-plastic behavior of the matrix materials. Non-linear anisotropic material models are used for this method. Models are based on stress/strain curves that are determined on specimens of the specified material in the main orientation direction of the glass fibers, at a 45-degree angle and perpendicular to the main direction. The results for the fiber directions are transferred after the mold filling simulation via so-called "mapping" to the structural analysis.

Very Good Approximation of Gradient

Ticona applied the integrative simulation for the design of a glass fiber reinforced sunroof mount made of Celanex 2300 GV1/30 PBT and examined the results in terms of accuracy in comparison to experimentally determined values. "This is a great example of an effective joint project with one of our customers, Roland Peter, manager simulation & analysis, Roof Systems, Inteva Products in Germany," Mohr-Matuschek added.

The systematic comparison of this non-linear anisotropic simulation displays a considerably improved compliance with experimentally determined values. The resulting simulation for the sunroof mount illustrates that the integrative simulation provides more accurate results than common linear isotropic calculation methods. "Our integrative simulation is an effective technology for the optimal design of a fiber reinforced component and offers major advantages in material savings and cost in complex parts," said Mohr-Matuschek. "Integrative simulation demonstrates the tools Ticona can deliver in helping customers to design components and underscores its position as a solutions provider in the field of material, component design and processing."

For more information:
Ticona
8040 Dixie Highway
Florence, KY 41042
Phone: (800) 833-4882
www.ticona.com

Drake

SHIPS THREAD GRINDERS TO CHINA

Drake Manufacturing Services Co. has recently shipped two linear motor 4-axis CNC thread grinders to a Chinese petroleum company manufacturing drilling rigs, pumping units and other oil field equipment. The first machine, a Drake GS:TI-LM 650 High Accuracy Internal Thread Grinder, will grind threads on ring gages for checking API threads. The second machine, a Drake GS:TE-LM 650 High Accuracy External Thread Grinder, will grind threads for API plug gages. Drake fitted the machines with CNC contour dressers for creating complex wheel forms including all API, full radius and gothic arch, acme with crest and root radii or chamfers, as well as a 60-degree buttress and other thread forms. Both machines were programmed on the customer's parts and proved out at the Drake factory in Warren, Ohio, prior to shipment. Changeovers can be accomplished in as little as 15 minutes by simply entering new part parameters into the Drake *PartSmart* menus in the Fanuc CNC. The machines will be installed by Drake service engineers, and ongoing service will be handled by local trained field service technicians.

For more information:

Drake Manufacturing Services, Inc.
4371 N. Leavitt Road
Warren, OH 44485
Phone: (330) 847-7291
Fax: (330) 847-6323
www.drakemfg.com

Gleason

BUILDS GENESIS SERIES IN INDIA

Gleason Corporation recently announced that they have started building their highly popular Genesis series of gear hobbing machines at their Gleason Works (India) facility in Bangalore. The Genesis models 130H and 210H hobbers are being built for the fast-growing Indian market using the same high-precision components as with Genesis machines built in other locations. The 210H machine accommodates gears up to 210 mm in diameter, including those with shaft lengths up to 350 mm. Features include Siemens 840D controls, integrated chamfering and deburring, and a high speed loading system to reduce load/unload cycles to a minimum. Gleason already builds the Genesis series of gear hobbing machines at facilities in the U.S., Germany and China.

The Genesis 260H and 400H, which was introduced at the EMO in September 2011, will also be built in India at a future date. Supporting the entire Genesis line of gear hobbers in India is an array of cutting tools, including high speed steel and carbide hobs, as well as an existing tool sharpening service. Gleason already has a presence in Bangalore for sales, service and cutting tool manufacturing, as well as sales and service offices in Mumbai, Pune, Chennai and Coimbatore.

Said John J. Perrotti, Gleason's president and CEO, "Building Genesis gear hobbing machines in India for

the Indian market is a logical extension of the strategy we embarked upon several years ago. We have for many years been rebuilding gear production machines at our Bangalore facility and have developed a competent staff and the necessary skills to smoothly transition to successfully building our leading line of gear hobbers. Global auto and truck companies, both domestic and foreign-based, are expanding their operations in India, and are eager for us to expand our local manufacturing footprint in this growing region."

For more information:

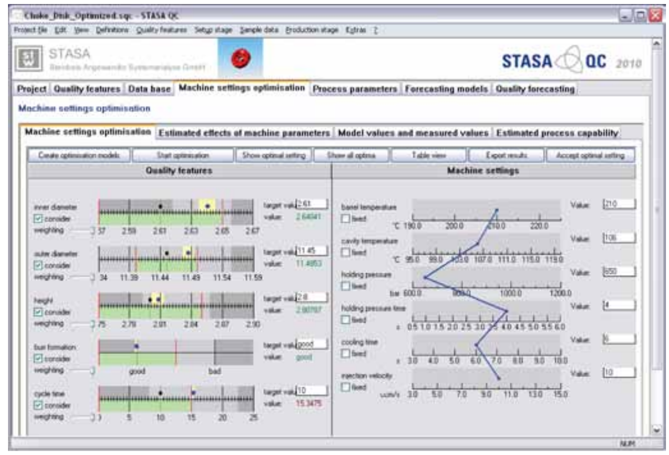
Gleason Corporation
1000 University Avenue
Rochester, NY 14692
Phone: (585) 473-1000
www.gleason.com

Kistler

INTRODUCES INJECTION MOLDING SOFTWARE

Kistler North America, a worldwide supplier of precision sensors, systems and instrumentation for the dynamic measurement of pressure, force, torque and acceleration, has announced the global market introduction of its industry exclusive *STASA QC* plastics injection molding process optimization software. *STASA QC* is expressly designed to optimize the machinery parameters, including process stabilization, shortened cycle times, and production efficiencies, most critical to zero-defect medical, automotive, electrical component, optical, and LSR plastics injection molding operations.

Traditional injection molding machinery optimization involves time-consuming, manual "trial-and-error" adjustments of relevant parameters until all quality targets are met. During this phase, user experience with similar parts, materials and injection molding machinery is critical. Online process optimization (i.e., during active production) is even more complex, as each parameter change can mean new machinery setting modifications, cycle time data recording and molded parts measurements. Due to post-production shrinkage or water absorption, parts can take several days to be ready for use, often first requiring time-consuming readjustment of machinery operating points, creating costly downtime.



STASA QC is based on a repeatable systematic design of experiments (DOE) method for determining best machinery setting operating points, as well as online processes. With user-selectable parameters, such as holding pressure levels, injection speed and others, *STASA QC* recommends a number of experiments, allowing for a setter to change or enhance a selection as needed. The DOE methodology allows for machinery behavior simulation and visualization, preventing unnecessary experiments. All parts created from these experiments and their associated geometries are analyzed to determine best machinery settings. All mathematical calculations occur in the background, with a minimum number of tests required to run at various parameter settings.

During a typical *STASA QC* simulated injection molding process, experiments are carried out on a PC, with parameters that can be changed interactively by the clicking and dragging of a mouse. The effects of these changes on each quality feature can be tracked on-screen, without doing so on the injection molding machine. This is of benefit, particularly for the online optimization of active production processes. *STASA QC* has an integrated report feature for protocols that provides an end-to-end documentation of the setting procedure and all optimization results. Resultant measurements from these experiments are imported into *STASA QC* for proper system storage of required dimensions and variations, as well as attributive part features for each machinery setting. It also verifies potential processing capability of a defined setting. By using this data and applying innovative data-based modeling methods, *STASA QC* identifies a precise correlation between machinery setting and part quality. With the help of this correlation, the software determines the ideal point and setting at which the machine meets set quality requirements, taking into account statistical fluctuations of part dimensions. The best machinery operating point is one that is producing the fewest defective parts. At the same time, *STASA QC* automatically determines the effects of machinery settings on individual part quality features.

New Kistler *STASA QC* software offers lower overall production costs, with shorter cycle times, fewer defective parts and greater ability to accurately forecast parts processes; faster production start-up; fewer required experiments; safer injection molding processes; more stable and continuous zero-defect parts production; fewer required readjustments during large-scale production processes; and more readily available, accurate process information, with fully reproducible and recordable results.

For more information:

Kistler Instrument Corp.
75 John Glenn Drive
Amherst, NY 14228-2171
Phone: (716) 691-5100
sales.us@kistler.com
www.kistler.com

Allison Transmission

PURCHASES GRINDING CELL FROM C&B MACHINERY

Allison Transmission, which manufactures commercial-duty automatic transmissions and hybrid propulsion systems for truck and off-road vehicle manufacturers, has ordered another new grinding cell from C&B Machinery. After multiple machine orders for a plant in Chennai, India, they are bringing this same technology to the United States. C&B Machinery develops and builds grinding systems for manufacturers around the world; in this case, it will build a "flexible" double-disc grinding cell for Allison Transmission in Indianapolis.

The new cell is designed to grind the faces of transmission pinion gears for Allison's 3000 series transmissions. This machine will be set up to grind three different pinion configurations, flexible for future expansion and any future part program changes. The grinding cycle time for a finished part will be 15 seconds.

Double disc grinders remove an equal amount of material from both faces, simultaneously. The new machine performs a "rotary plunge" grinding cycle, which means the pinions are introduced to the grinding wheels via a rotary carrier, one at a

time, while the grinding wheels plunge grind simultaneously through axis interpolation. There are several advantages for grinding in this manner, the most important of which is the grinding wheels are adjusted perfectly parallel and concentric to each other. Most often, conventional double-disc grinding requires compound head settings. Keeping the wheels parallel results in a more uniform wheel wear and it reduces the frequency of dress cycles required. The cost per piece is reduced and the return on investment is faster.

This grinding cycle was developed by C&B Machinery engineers. In addition to the operating and investment cost savings it allows 100 percent gauge feedback on every component ground. Size control is tightened, resulting in higher statistical capability.

For example, the grinding cells previously shipped by C&B far exceeded 2.0 ppk in overall height (±0.030 mm) and parallelism (0.026 mm).

For more information:

C&B Machinery
12001 Globe Street
Livonia, Michigan 48150
Phone: (734) 462-0600
www.cbmachinery.com

Star SU

TOOLS OFFER ADVANCED COATINGS

Balinite Alcrona Pro, the second generation of AlCr-based coatings, is now available on new and re-sharpened tools from Star SU. Developed by Oerlikon Balzers, Alcrona Pro can be used in a wider range of applications than other aluminum-based coatings because it provides better heat resistance for high temperatures and better wear resistance for tough cutting applications. Lower thermal conductivity allows Alcrona Pro-coated tools to work well in low temperature applications and allows faster hobbing speeds; 200 m/min is the new base speed. The cost savings include 30 percent lower tool costs, 50 percent longer tool life, 20 percent faster cutting parameters and 100 percent dry cutting. These tools will be on display at IMTS 2012 (September 10–15).

For more information:

Star SU LLC.
5200 Prairie Stone Parkway,
Suite 100
Hoffman Estates, IL 60192
Phone: (847) 649-1450
www.star-su.com

Mazak Integrex

COMBINES VERSATILITY AND HIGH ACCURACY

The Mazak Integrex i-200ST Multi-Tasking machine efficiently processes mid-size complex components. It offers versatility and high accuracy in a compact design as well as features twin spindles, a lower turret and milling spindle for unbeatable Done-In-One productivity. As a Level 4 machine in Mazak's Five Levels of Multi-Tasking, the Integrex i-200ST turns, drills, taps and mills, while offering off-centerline and full simultaneous 5-axis contouring. Mazak developed its Five Levels of Multi-Tasking as an effective way for manufacturers to determine the best multi-tasking technology for meeting their specific application and process needs.

Both turning spindles on the Integrex i-200ST provide equal high performance with spindle speeds of 5,000 rpm and C-axis turning control. And both have a bore capacity measuring 3" (76 mm) in diameter. For C-axis contouring versatility at either turning spindle, the i-200ST vertically mounted milling spindle provides 30 hp (22 kW), 12,000 rpm and a rotating B-axis range of –30 to +240 degrees. Mazak's unique roller cam drive for the B-axis ensures higher accuracy and rigidity, while providing zero backlash. A 36-tool (72-tool optional) magazine allows for fast tool changes and provides ample tooling for continuous part processing.

The lower turret on the Integrex i-200ST model comes standard for nine turning tools. The lower turret working in combination with the machine's milling spindle that can be applied to either side of the machine headstock reduces machining cycle times. Mazak incorporates its MX Hybrid Roller Guide System into the Integrex i-200ST for durability and reliability that result in long-term accuracy. The MX Hybrid Roller Guide System dampens vibration to extend tool life, handles higher load capacities, accelerates and decelerates quicker to shorten cycle times, consumes less oil for "greener" operations, and lasts longer with less required maintenance.

For a compact multi-tasking center, the Integrex i-200ST provides an ample Y-axis travel of 9.8" (249 mm) and vertical X-axis of 24.2" (615 mm), with 4.92" (125 mm) below centerline. The machine accommodates parts up to 25.9" (657.8 mm) in diameter. And because its tool magazine is located at the front, machine operators can do programming and tool setup with minimal required movement. Additionally, all machine lubrication points and gages are gathered into a single panel for ease of viewing and maintenance.

For more information:

Mazak Corporation Headquarters
8025 Production Drive
Florence, KY 41042
Phone: (859) 342-1700
www.mazakusa.com

FULL SPEED AHEAD

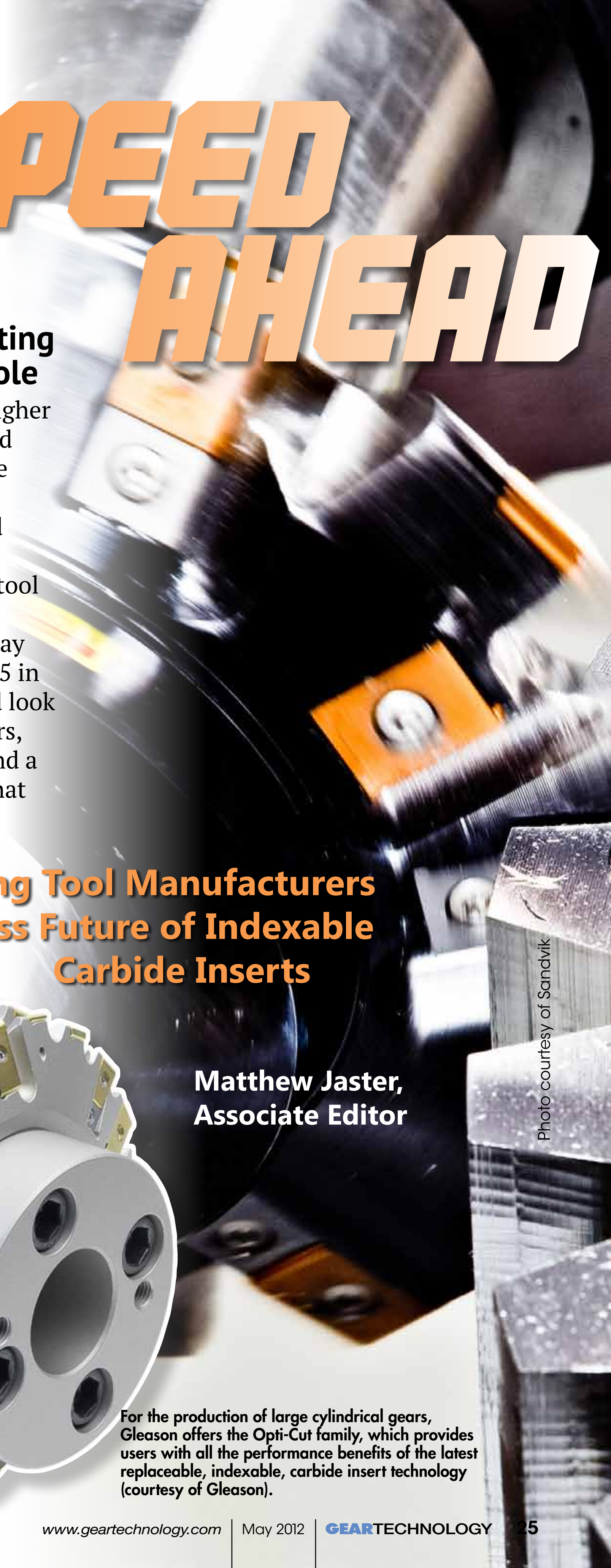


Photo courtesy of Sandvik

Indexable carbide insert (ICI) cutting tools continue to play a pivotal role in gear manufacturing. By offering higher cutting speeds, reduced cycle times, enhanced coatings, custom configurations and a diverse range of sizes and capabilities, ICI tools have proven invaluable for finishing and pre-grind applications. They continue to expand their unique capabilities and worth in the cutting tool market.

Many of these technologies will be on display at the 29th edition of IMTS (September 10–15 in Chicago) where attendees will get a firsthand look at tooling advancements in machining centers, productivity gains utilizing two-start hobs and a wide variety of new coatings and materials that will lower manufacturing costs.

Cutting Tool Manufacturers Discuss Future of Indexable Carbide Inserts

Matthew Jaster, Associate Editor

For the production of large cylindrical gears, Gleason offers the Opti-Cut family, which provides users with all the performance benefits of the latest replaceable, indexable, carbide insert technology (courtesy of Gleason).

Gear Technology is getting a head start on IMTS by speaking with representatives from Ingersoll, Gleason, Sandvik, Seco Tools and Banyan Global Technologies on the future of indexable carbide inserts—a future that promises to keep high-speed steel (HSS) tools in check as reducing cycle times and cutting speeds remain a manufacturing priority.

Expanding Operations

While the normal range of indexable tools is from module 5–25 for quoting purposes, many cutting tool manufacturers are expanding to both larger and smaller sizes. Increasing the cutting tool production range is necessary in today's manufacturing environment, thanks in part to the volatile market segments. Areas like energy, mining and heavy industry, for example, are in constant flux. Manufacturers are learning that in order to provide tooling/workholding systems to these markets, flexibility is a premium.

"We typically produce ICI hobs and gashers from module 6 on up," says Frank Berardi, gear machining product manager at Ingersoll. "We can go smaller depending on the diameter of the gear and the cutting tool. There is almost no limit on the high end. We have built gashers, for example, up to 100 module for pinions used in offshore oil rigs."

"Seco offers milling cutter roughing from module 1–30, milling cutter finishing from module 6–24 and gear hobbing from module 6–24," says Alessandro Manta, international application expert, power transmission at Seco Tools AB, Sweden.

"While we have no set limits, we are constrained by the physical limitations to carbide insert and machine tool technology. For practical limits we can operate from module 1 to 50," says Darryl Witte, vice president, sales at Banyan Global Technologies.

The Sandvik Coromant program for gear cutting has a full range of tools from module 4 to 40. "Within that range are three different programs," says Kenneth Accavallo, industry and applications specialist at Sandvik Coromant. "Module 4–8, covered by our CoroMill 176 full profile hob; module 8–18, covered by our CoroMill 177 hob; module 8–40 covered by our disc cutters."

"If the range is smaller or larger than module 5 to 25, then more investigation is required for the quote and design of the indexable tool," says Michael Tennutti, senior project manager at Gleason Cutting Tools.

Small Module Gears. Ingersoll is currently developing a line of ICI hobs in the 4–6 module range with plans to go down to module 3. "We feel this is an important segment to address because of the large number of gears in this size range," Berardi says. "Because of the small tooth profiles, the challenge is to produce a robust design that remains user-friendly. We have had good results with our initial prototype testing and expect to have products on the market in the near future."

While indexable insert tooling is limited around module 3, Ingersoll offers other solutions for smaller sizes. "We have our ChipSurfer line of cutters with replaceable carbide heads that are ground to the finish spline involute size," Berardi says. "These have been very successful for machining small splines down to 16/32 NDP and smaller."

"Sandvik Coromant is planning on releasing module 3, module 9 and module 10 over the next year," Accavallo says. "The full program will be between module 3–10. Also, with the innovation of the Invomilling method, which uses a five-axis machine to produce the gear form with standard tools, we will be able to offer a wider range of opportunities. It's hard to get indexable tooling small enough to machine gears much smaller than 2.5 module or approximately 10 diametral pitch. Sandvik Coromant is working on a program that will be able to mill splines and racks smaller, but the current hob program is limited."

Banyan is engaged in constant discussions relating to fine-pitch cutting.

"We have a solid solution for single- and multi-tooth spline milling, and are developing a revolutionary approach for fine-pitch indexable hobbing," Witte says. "To date we have only provided tools for spline milling, and have not addressed indexable spline hobbing. In the coming years most every tooling provider will have some solution for gears 1 module and finer. The discussion is centered on tolerance and accuracy as finer gears have finer tolerances and indexable tools have the same repeatability and pocket tolerance limits regardless of tooth form."

There have not been many requests for the smaller range of modules at Gleason. "The current size range for the

inserts for the smaller modules is limited by the size of the insert and the hole required to lock and position the insert. Many requests have gone from an indexable request to a solid design tool," Tennutti says. "There are smaller tools available in the marketplace today which can take insert carbide forms which screw into a body adaptor that can be used for thread milling and producing involute splines."

"Small module (less than 6) normally needs direct finishing with a high quality that is difficult to obtain using indexable tools," Manta says. "We'll always have an open question regarding quality, but it's really hard to do better than solid tools and due to small dimensions they are cost effective."

Large Module Gears. "Large gears have always been a major focus in the development of our indexable gear tooling lines," Berardi says. "Primarily because large gear tools more readily lend themselves to the application of indexable tooling. For large gears, solid carbide, if feasible, is usually cost prohibitive, leaving indexable carbide as the obvious solution. The productivity gains can be very dramatic when applying indexable carbide tooling over HSS on large gears."

In one case study on a very large diameter Module 20 gear with 181 teeth, the customer was finishing with a HSS hob in 2 passes, which required 70 hours to machine, according to Berardi. "The Ingersoll ICI Finish Hob completed the 2-pass finish operation in just six hours… a whopping 64 hour time savings, and AGMA 10 quality which was as good as or better than HSS." Ingersoll continues to see strong growth in mining and heavy construction, shipping, rail, and oil & gas. "We have a long history in providing tools for the wind industry, and although growth has slowed in recent years, it continues to be a very important customer segment," Berardi adds.

"It is no secret that production tax credits from state and federal programs push the wind energy market in and out of growth modes. Mining, agriculture and other energy producing sectors have played an important part in our business growth, and continue to be a focus for us in 2012 and 2013," Witte at Banyan adds.

Coating/Materials Technology

In addition to the developing size range, cutting tool technology is advancing in new coatings and materials—which in turn is reducing manufacturing production and costs. Sandvik is developing optimized grades for gear milling applications. "The objective is to find substrates and coatings that allow higher cutting speed and/or longer tool life, which will in the end bring benefits to the end-user in terms of reducing manufacturing costs," Accavallo says.

Tennutti at Gleason agrees, "The coatings used on these inserts yield more pieces per index. The better these coatings are able to endure the heat when operating at higher speeds, the better the life the inserts will have. Currently, the more advanced coatings, i.e. AlCroNite, are being used. Future coatings will enhance the performance of these inserts."

"For Seco Tools, coating is one of the main investments, and Duratomic coating is one of our best achievements. Duratomic is already changing the market, and its development will go even further," Manta adds.

"Coating technology is a constant evolution and does not look to cease evolving for many decades, if ever. The most interesting technology looks to be improved coating adhesion via new PVD machine technology," Witte says.

"With oxide coatings by the PVD process, we are applying coatings that have similar resistance to abrasive wear, heat, and chemical attack that have so far only been possible through the higher temperature CVD processes," Berardi at Ingersoll says. "By using the lower temperature PVD pro-


Photo courtesy of Sanvik

cess, the end result is an insert that has a higher toughness *and* higher wear resistance. Additionally, surface treatments for both before and after coatings are showing significant improvements in tool performance. Whether by improving the adhesion of the coating, reducing crack initiation sites, lowering frictional forces, or smoothing the finish left on the work piece, the advantages of the various surface treatments contribute to productivity gains."

Custom Insert Configurations

While standard cutting tools provide capable results, many companies come up with innovative custom tooling solutions that outshine their counterparts. "Custom insert configuration has always been the hallmark of Ingersoll engineering," Berardi at Ingersoll says. "Over the course of our long history we have produced many insert design innovations including the tangential mounted insert that made indexable carbide insert gear tooling possible in the first place. We continue to place as much emphasis on geometries as we do with grade development. We feel they are equally important in the performance of the insert and the entire tool in terms of part quality and tool life."

"The profile on the inserts can be compared to any form that is being used on the current solid hobs or milling centers. The features such as protuberance, full tip radius, semi-topping, or curved profile can be achieved using inserts," Tennutti says. "There appears to be no limit on the current applications compared to the current HSS cutting tools. This being the case, the biggest advantage when using carbide inserts is the higher speeds that can be achieved, which will reduce the cutting cycle time."

"Modern insert manufacturing technology and the tool manufacturing process allows Sandvik to be able to manufacture and measure gear tooling to a close tolerance. This allows higher cutting speed and feed rates while maintaining gear wheel quality. This also allows closer tolerances to allow less grind stock to increase productivity while reducing overall production cost," Sandvik's Accavallo says.

"Custom machines and tooling have always dominated the calculation for process improvements," says Banyan's Witte. "Many tooling manufacturers are pressing to enter the stable gear market while the balance of manufacturing is in flux, there are a select few that have the gear background to understand the gear tooth knowhow to best design an optimal solution. These intelligent gear solutions center around custom components, and while some customers use a custom solution from 10 years ago, others are using the newer methods and improved solutions to dramatically reduce costs and increase efficiency and accuracy."

Touting the Technology

IMTS will likely shed some light on the future of indexable carbide insert cutting tools. Tooling/workholding systems will once again play a large role in the Chicago exhibition and all participants in this article plan on bringing their latest products/equipment to the show floor.

"The future of indexable tools may go from a single form indexable insert to a multiple form insert. These inserts may have several forms on the inserts and have the capability of one index. This would be an advantage when producing finer module rack type milling and finer pitch module hobs," Tennutti at Gleason says.

"Due to the large interest in the large module gears with a high number of teeth being hobbed, multiple thread hobs have their advantage. Multiple thread indexable hobs have a place in this industry today. We expect to see more interest in these hobs and will have a two-start hob on display at IMTS for review and discussion," he adds.

Invomillling and uP-Gear Technology will take gear production to new levels as these methods offer manufacturers savings in both time and money, according to Sandvik. "With uP-Gear Technology the machine cost is no higher than a traditional five-axis machine and the tool cost is considerably lower than by using dedicated bevel gear tools. On top of this, the machining time is very short compared to an end mill process. Similarly, the Invomilling method offers high machining flexibility at high productivity levels and at low costs, using standard or standard-like tooling. These methods offer alternatives to existing solutions, so it will be interesting to see how this will influence the future of indexable cutting tools," Accavallo says.

"At IMTS, Sandvik will showcase a new product, CoroMill 172 for machining of gears and splines in multitask machines, machining centers and turning centers," Accavallo adds. "In the Sandvik Coromant Smart Hub at IMTS it will be possible to see the full line of products for hobbing machines, for example hobs, roughing disc cutters, semi-finishing disc cutters and finishing disc cutters."

"We are currently developing our indexable hob line. Early concepts are planned for IMTS release," Witte says. "The Banyan Indexable hob will be like no other and developed by gear engineers for production gear applications. We are also seeing great push for ganged tool assemblies (duplex and triplex) and will show our latest technology for those medium-pitch components as well."

"We will be exhibiting our expanded line of hobs, gashers and shapers and to be sure there will be some interesting new concepts on display," Berardi at Ingersoll says.

Seco will also be showing its first two-start hob at IMTS, according to Manta. IMTS will also give the company a chance to highlight its entire range of new and established cutting tool solutions. "Indexable carbide solutions continue to gain ground in this market. In the future, we'll have more requests in the highly specialized cutting tool industry, allowing our customers to be more competitive."

For more information:

Banyan Global Technologies
20836 Hall Rd. Suite, Suite 156
Clinton Township, MI 48038
Phone: (815) 786-5986
www.banyangt.com

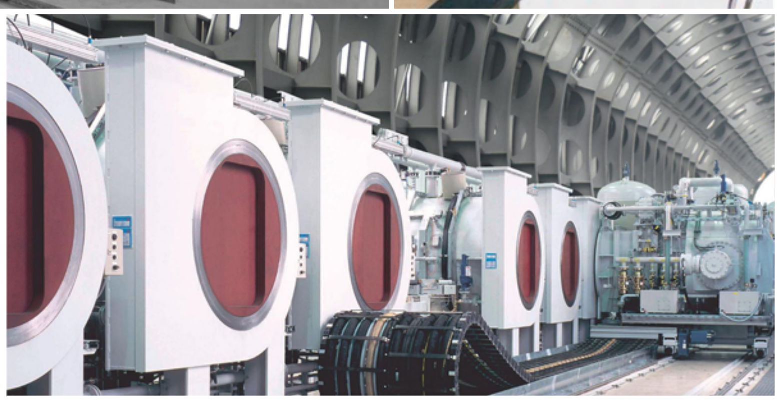
Gleason Cutting Tools Corporation
1351 Windsor Road
Loves Park, IL 61111
Phone: (815) 877-8900
sales@gleason.com
www.gleason.com

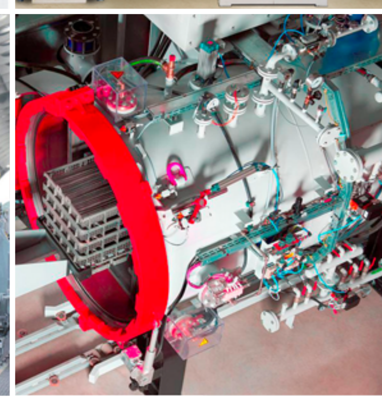
Ingersoll Cutting Tools
845 S. Lyford Road
Rockford, IL 661108
Phone: (815) 387-6600
www.ingersoll-imc.com

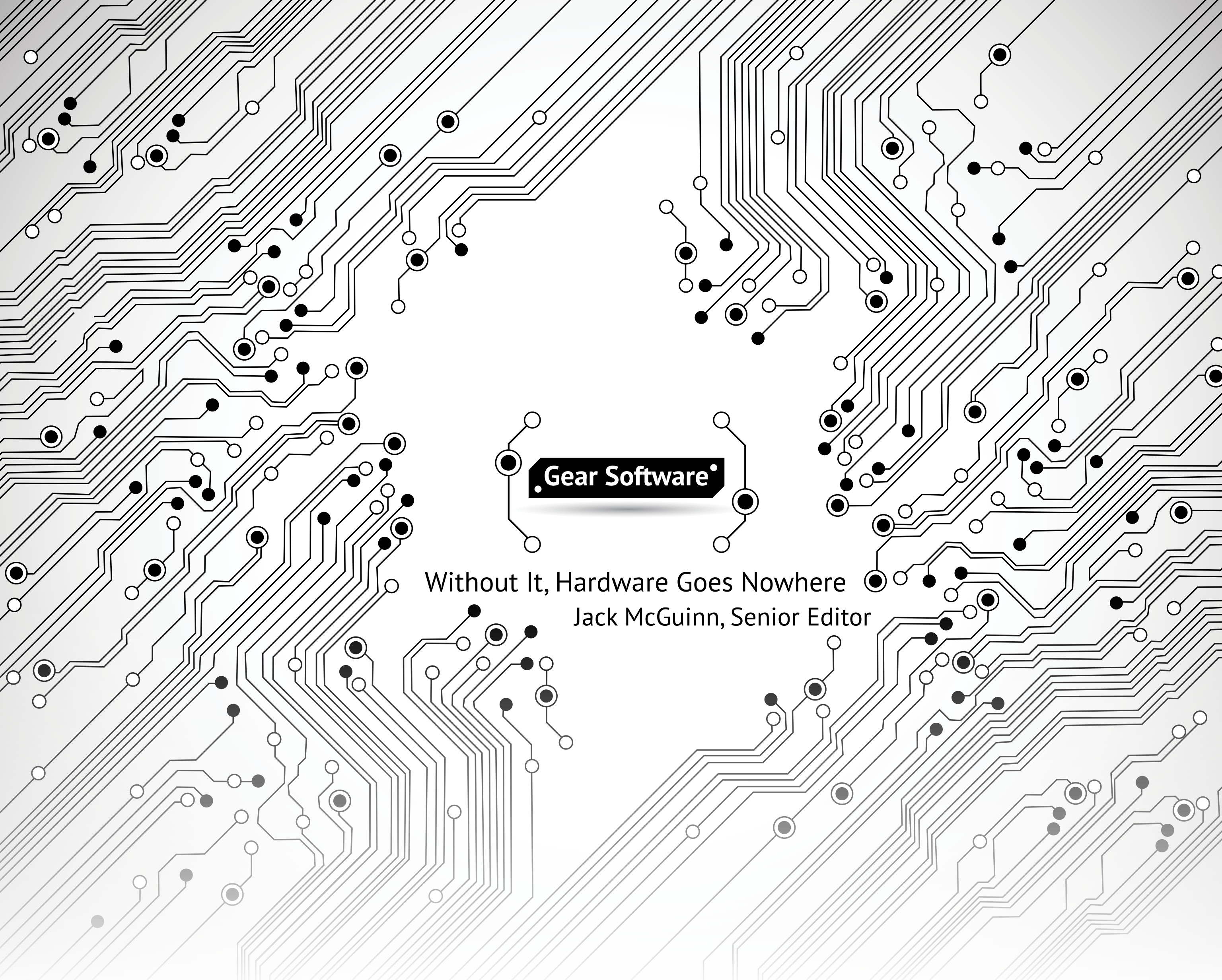
Sandvik Coromant
1702 Nevins Road
Fair Lawn, NJ 07410
Phone: (800) SANDVIK
www.sandvik.coromant.com/us

Seco Tools Inc.
2805 Bellingham Drive
Troy, MI 48085
Phone: (248) 528-5200
www.secotools.com


Photo by David Ropinski







Gear Software

Without It, Hardware Goes Nowhere

Jack McGuinn, Senior Editor

It's a brave, new hardware-software world out there.
Players in the worldwide gear industry who don't have plenty of both run the risk of becoming irrelevant—sooner than later.

Gear industry-related software—both design- and manufacture-oriented—is essential to any number of steps inherent in gear design, inspection, metrology and manufacture. Those include: prototyping, preliminary design and calculation; standards compliance; geometry factors; measurement; enabling closed-loop gear manufacture; time- and downtime-savings; tooth contact analysis; gage certification; mesh; reverse engineering; material and hardness analysis and so on. Many of these elements serve to determine the optimal machine settings for, say, cutting machines, a modern means of practicing the tried-but-true practice of "measure twice, cut once."

Bottom line, all of the above serve to make according-to-spec gears that customers demand. Absent software today—no NASA, no moonwalks, no CGI (Holy Holigraphs Batman!)—no MRIs and certainly no high-ratio hypoid gears (*which you can read about in this issue's Ask the Expert column on page 43*),

How to Choose Right Software Vendor/Package

"An engineer looking to purchase software has to consider a number of important factors," says Robert Forrest, SMT (Smart Manufacturing Technology) product support and marketing manager, "some of which include knowing whether the software is reliable and gives accurate results to the latest standards; (whether) the vendor provides timely technical support; whether the software meets their current and future needs: and if there is a clear vision for future software development."

For Excel Gear Inc. president N.K. "Chinn" Chinnusamy, "This is highly variable; some do an Internet search and look for a familiar name and/or read the ads. A recommendation from the machinery supplier carries a lot of weight. A consultant's recommendation can sometimes be decisive."

"Different software packages are applicable in different situations," says Mike Fish, co-founder of Dontyne Systems Limited. "In each case, a cost/time/function evaluation must be performed—preferably on several options in the market. There is no one package applicable to every situation; some companies are of the opinion that due to budget restrictions they must opt to develop existing, in-house methods themselves. I think that if engineers, though in many cases technically capable, considered the time to develop and maintain a calculation tool with continued support, documentation and transferability, it would not be cost-effective."

And from S. M. "Jack" Marathe of UTS (Universal Technical Systems, Inc.), "The key criteria by priority are capability of the software as it pertains to the needs of the user; ease of use; ease of learning; credibility; i.e., who else is using it, how long has the product been on the market and how long has the software developer been in business; quality of support available; and price."

"The most important aspect is that the software vendor has a proven history of validated usage across a range of industries across the globe," says Dr. Jamie Pears, product manager, Romax Technology. "You also need to choose a software vendor that has a highly qualified and knowledgeable team covering software development, mechanical engineering and commercial activities. A vendor who actively invests in R&D shows that they are in it for the long haul and will continue to support customers in the future."

Once you've chosen a vendor the next task is identifying the best software package or packages for your business.

Forrest says that "Two important features that differentiate software packages from one another are ease of use and expandability, and a clear vision for the future. The highly modular nature of *MASTA* means that engineers can select the functionality that is important to them in the knowledge that additional functionality can be easily added to meet their changing needs."

Why Not Just Use the Machinery Vendor's Software?

Not surprisingly, "A machinery vendor has a major advantage," says Chinn. "Someone buying a machine is likely to try the vendor's software if he has it. A reason not to use a vendor's software is if it works only with the vendor's machine and the buyer has different machines. Using one software program instead of many is a major advantage."

"I don't think this would be common practice unless the software was specific to the function of that particular machine, which may be the case in high volume production and patented gear manufacturing methods," says Fish. "Conversely, we have several machine manufacturers as customers who have opted to utilize certain sections of our code integrated to their machines. This is particularly the case when a manufacturer wants to offer solutions for specialist applications without the cost of reinventing it themselves."

"It depends on the type of software being considered," says Marathe. "Typically a machinery vendor does not provide gear design and analysis software. Their main business is to sell machinery and not software. In some cases if the software is very closely aligned to the use of the machinery, then it may be practical for the machinery vendor to provide such software and for the customer to consider buying it from the machinery vendor.

"For example, if it is a gear checking/inspection machine, then it may be logical to get certain software that does further analysis of the results of the gear inspection from the machine vendor. Also it may be appropriate to buy the change gear software or CNC part programming software from the machinery vendor."

"We are seeing that customers normally require a solution that is seen as independent from the machinery vendor," says Pears**.** "This means that they can avoid being tied to one particular vendor and enable the same software to be used across a range of machinery; it 'future-proofs' them to a certain extent.

"However, sometimes the machinery vendor has unique knowledge and understanding of the manufacturing machine, especially for bevel and hypoid gears. In these cases, we see that customers want to use the specialized machinery vendor software, but often want to combine this with an independent system level gearbox analysis tool. This was one of the drivers for the successful partnership between Romax Technology and Klingelnberg GmbH, where we have linked *RomaxDesigner* with *KIMOS*. This enables customers to use the sophisticated *RomaxDesigner* gearbox system level analysis to predict the misalignment of the bevel or hypoid gears, and then use *KIMOS* to perform a detailed loaded gear contact analysis, considering the predicted mesh misalignment and the manufactured gear profile."

What Drives Gear Software Development Today?

"Good software follows machine technology to the extent that the software should not allow something to be designed that cannot be made," says Forrest. "However, good software should allow the user to push the boundaries of the machine technology to get the best design possible."

"Gear software usually follows technology," says Chinn. "However, a major step forward in technology may require simultaneous release of software in order for the technology to be used properly."

Pears adds that "The driver for new software is mainly a requirement to design and analyze gears in a process that is quicker and easier to use; we are seeing that users of our *RomaxDesigner* software have less gear-specific experience and are required to be multi-skilled across a range of engineering areas."

What About Price?

"As modules are priced individually and can be added at any stage, the user retains the flexibility of seamlessly adding more functionality at a later date to meet their requirements," says Forrest. "The price for software from different companies varies considerably but the old saying, 'You get what you pay for,' applies here; and sometimes what you pay for is not what you want."

"There are differing packages available which have differing prices," says Fish. "It is important for a company looking to buy software not to look purely at the outlay, but to consider the benefit to the improved production. Once it is established that there is a technical benefit, it can be more easily justified financially. Says Marathe, "It all depends on the capability and the underlying complexity of the software and the type of investment that is required to develop such software." There is a huge difference between being able to make drawings that show gear tooth profiles versus making the gear calculations that are the heart of a good gear design."

Expertise Required

"A range of disciplines are required when creating and developing gear system design and analysis," says Forrest. "These include gear design engineers; bearing engineers; gearbox system designers; analysts for NVH and dynamics; software specialists; and manufacturing engineers. SMT employs engineers in all these disciplines who collectively have decades of practical experience in gear and transmission design and between them have delivered numerous successful transmission designs for the automotive, wind turbine, industrial machinery, aerospace and marine sectors."

"Good 'user-friendly' gear software requires gear design knowledge and experience," says Chinn. "Programmers do not require much industry experience if an experienced design/manufacturing engineer leads them. The best program results from a team headed by an experienced engineer, some good programmers and some feedback from a few users."

"The experience is crucial," Fish believes. "A trained software engineer can rapidly develop an interface and even implement standards from documentation to produce a calculation procedure, but would have no feel for the accuracy or application of this tool. We have also experienced many gear engineers who developed their own calculations on various platforms. These are fine for internal use but generally only reflect one approach to design."

"Knowledge of the gear industry (where and how the gears are to be used and real-life problems being addressed) is very important," says Marathe. "Equally important is the knowledge of the gear mathematics and expertise in developing and maintaining the software. Gear design engineers may or may not have such breadth of background that is crucial."

Pears believes that "Gear industry experience is definitely required to ensure that the technical details are correct and the work processes are properly captured in the software; another important aspect is that the software is user-friendly and intuitive."

Customized Solutions

"All users want a solution that fits their specific application needs and good software should accommodate this as far as possible," says Forrest. "For example, in *MASTA*, as well as industry-standard materials and a comprehensive catalogue of commercially available bearings, the designer can define (and store) customer-specified materials, bearings and gear tooling parameters."

"This used to be common," says Chinn. "Software was written in-house or by a consultant. It probably is still done for high-value or high-volume work. Since no one knows everything, some special applications require special, specific-type programs that become too complex for common use."

"Some customers may have specific requirements," says Fish, "but all such systems should at least have the capability to work to a recognized standard system for a traceable reference."

"It is common if the software we are talking about is very closely aligned with the operation of the machine," says Marathe. "Also, customer-specific software may be the most practical way to get software developed that meets the targeted needs of a customer for whom the software that meets the needs of a broader customer base may not be as beneficial."

"Romax often performs customer-specific developments, says Pears. "On *RomaxDesigner*, for example, a customer may have their own gear contact analysis algorithm that has been proven over the years in their particular application. (At some point) they may come to (us to) integrate their code into *RomaxDesigner*, which we then supply back to them on an exclusive basis; we handle the time-consuming and risky maintenance and updates of the software to Romax."

"First and foremost, it must be fit for purpose," says Fish. "Apart from the list of available functions appropriate to their production, the speed to perform a specific task should be considered. Customers may also have a preference in the layout of the GUI, technical support and response to dealing with any issues or questions that arise."

And from Pears: "A technical lead in software can only be established by actually doing the same work as your clients. Romax has done more than 65 NVH projects in the last 10 years, designed automotive transmissions that are made in volumes of over 1 million-

per-annum and has completed dozens of wind turbine gearbox designs—up to 5 MW."

It's Not *ALL* about the Software

"Software is a tool," says Forrest. "And like any tool it can be misused by inexperienced people. Design engineers need to understand the application (i.e., where and how the gearbox will be used) in order to design both for robustness and functionality.

"In addition, the designer needs to have knowledge of how the product will be manufactured. All designs are a compromise; the use of good software tools allows the impact of decisions made to facilitate manufacture to be explored before metal is cut."

"Almost any software can be misunderstood/misused," says Chinn "An experienced engineer should always review critical applications. This is especially true of design and analysis software. Inspection software is less likely to be misused."

Fish contends that "There is an increasing element in the inquiries that ask for some kind of solver or optimizer to present a solution based on the input data; it is important to resist this. In our experience good software simply facilitates the ease with which a competent gear engineer completes their task, providing observations and suggesting areas in the design, manufacturing or measurement to which it relates could be improved. It will never replace the role of a competent engineer."

"Younger engineers have a tendency to feel that 'If the results came (from) software, then it must be the perfect answer,'" says Marathe. "However, they do not understand that good engineering judgment is a must. That comes from real-life experiences of having to live with what you have designed. Otherwise, it is a case of 'garbage in–garbage out.'"

Hot Industries for Software

"In general, gear products that have demanding requirements in terms of power density and safety, such as aerospace or high-value products such as wind turbines, large marine or industrial transmissions, benefit more from utilizing gear system analysis software tools like *MASTA*," Forrest says. "This is because many different design scenarios can be explored before finalizing the design direction. The automotive sector is increasingly using these system tools to predict potential NVH issues in vehicle drivelines."

"Support is a huge issue to all sectors," says Fish. "Quite often now, gear production is a global operation with the design in one country, manufacture in another, and sales in another. All sectors will require—and should expect to have—timely access to customer support (in line with) their operations."

"In all sectors that involve reliability and need to have optimized designs (in terms of performance, minimum size and weight, minimum cost, reliability, etc.) having good software to work with is a *must*, says Marathe. "Aerospace and wind turbines are certainly the kinds of applications that do need good software but frankly speaking as do most applications these days."

Keeping it Lean

"MASTA was developed to enable a designer to build a 3-D model of the gearbox, run the model through a virtual development program before creating the CAD models for production," says Forrest. "The *MASTA* models can be exported to CAD for packaging studies and adjustments made, again before creating the final CAD models. This can significantly reduce product design and development time. The biggest hurdle to 'leaning out' the product development cycle is that most companies follow the traditional route of laying out the gearbox, analyzing, adjusting the design, re-analyzing, building prototypes, testing, adjusting the design, etc."

"Machine manufacturers will perform a degree of performance evaluation trials for testing and marketing," says Fish. "Statistical evaluation methods will be employed by the manufacturers. This is certainly present in some inspection equipment; the data can be used to improve production accuracy and efficiency, as well as change the performance characteristics of products."

"Lean manufacturing requires integrated software that links all aspects of a business," says Marathe. "But in addition to lean manufacturing (i.e., optimum), design is also a need of the hour."

(*Author's Note: When reporting on gearing software, one could write a suite's worth of stories on the subject—each one on a different code capability and application. With that said, we'd love to hear from you regarding the finer points and capabilities of manufacture and design software. Inspection, cutting—whatever—if you have something you think your fellow readers should know about, please send your suggestions, technical papers, white papers at jmcguinn@geartechnology.com.*)

For more information:

Dontyne Systems
Software Development Center
Rotterdam House
116 Quayside
Newcastle Upon Tyne
England NE1 3DY
Phone: +44 191 206 4021
Fax: +44 191 206 4001
uk@dontynesystems.co.uk

Excel Gear Inc.
11865 Main St
Roscoe, IL 61073
Phone: (815) 623-3414
Fax: (815) 623-3314
quotations@excelgear.com

Romax Technology (USA)
1050 Wilshire Drive, Suite 280
Troy, Michigan 48084
Phone: (248) 250-7691
Fax: (248) 250-7698
sales_us@romaxtech.com

Smart Manufacturing Technology Limited (SMT)
Chartwell House
67-69 Hounds Gate
Nottingham NG1 6BB
Phone: +44 (0)115 941 9839
Fax: +44 (0)115 958 1583
robert.forrest@smartmt.com
www.smartmt.com

Universal Technical Systems Inc. (UTS)
202 West State Street, Suite 700
Rockford, IL 61101
Phone: (815) 963-2220
Fax: (815) 963-8884
support@uts.com


GHO-200
S&T
CNC GEAR
HOBBING MACHINE
WET/DRY COMBINATION
S&T Dynamics

Got a Gear Question?

Ask the Expert!

Welcome to *Gear Technology's* latest installment of Ask the Expert, a regular feature intended to help designers, specifiers, quality assurance and inspection personnel in addressing some of the more complex, troublesome gearing challenges that never cease to materialize—whether on the drafting table or the shop floor.

Here's how it works: Have a standards question? Design query? How about a backlash or tooth profile problem that needs fixing? Or maybe you need a material recommendation or are wrestling with a tricky contact ratio. And just which lubricant is best for those open-gearing applications?

Look no further. *Gear Technology* will call upon its deep reserve of industry experts from around the world to help solve your dilemma and get you back on track.

So stop fretting (no pun intended) about that nagging gear conundrum. Simply e-mail your question—along with your name, job title and company name (if you wish to remain anonymous, no problem)—to: Jack McGuinn, senior editor, *jmcguinn@geartechnology.com.*

High Ratio Hypoid Gear Efficiency

Our question this issue deals with high-ratio hypoid gears, and it should be noted here that this is a tricky area of gearing with a dearth of literature on the topic. That being the case, finding "experts" willing to stick their necks out and take on the subject was not a given.

Nevertheless, we have indeed for your edification responses from no less than four intrepid men in the industry—names probably familiar to most of you. Two of our guest experts—Dr. Hermann Stadtfeld and Robert Wasilewski—appeared in the March/April Ask the Expert. Also taking on the question are George Lian of Amarillo Gear; Ted Krenzer of Gleason Corp. and *Gear Technology* technical editor Bill Bradley.

THE QUESTION

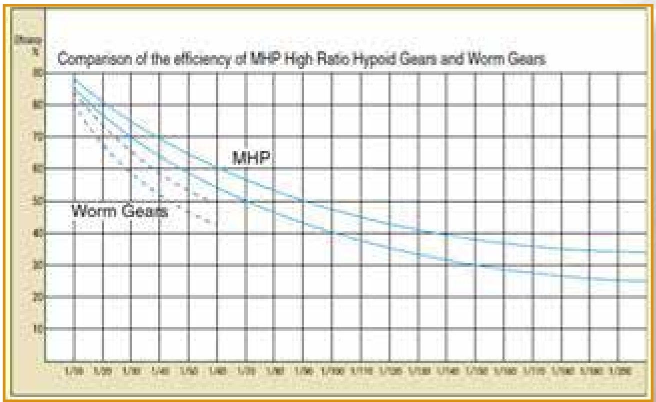
We are studying a gearmotor with high-ratio hypoid gears (HRHGs) and I would like to ask you if you know who manufactures this kind of gear.

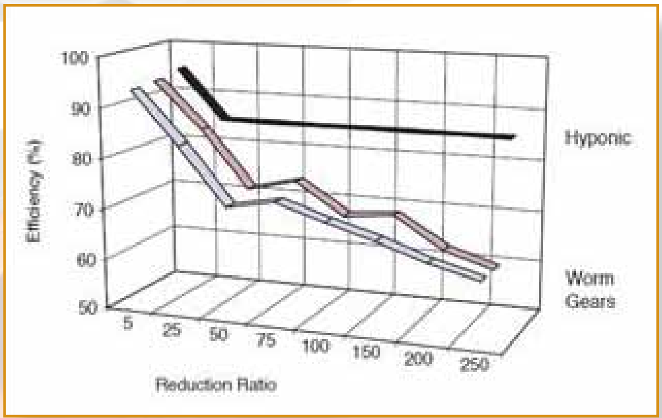
I found that there is some confusion about their efficiency: some say that the efficiency is near 90%—even for high-ratio; others say that the efficiency decreases with the ratio, i.e.—the higher the ratio, the lower the efficiency (see two graphics below).

Could you help me with this question? Are there high-ratio hypoid gears with high efficiency—even at the highest ratio?

Thank you.

Walmir Fernandes Navarro, mechanical engineer and R&D manager,
WEG-Cestari Redutores e Motorredutores, Brazil





continued

The Answer is Yes—and No

Mr. Navarro,

There are (only) a few companies that manufacture high-ratio hypoid gears (HRHGs) and gearmotors:

Kohara Gear (KHK) manufactures HRHGs, which consist of bevel wheels and conical mating pinions. The company makes catalog HRHGs for ratios in the 15:1 to 200:1 range.

ITW Heartland manufactures spiroid gears (similar to KHK HRHG) and helicon gears, which consist of bevel wheels and cylindrical mating pinions. Spiroid and helicon gears can have a gear ratio up to 400:1.

Sumitomo Drive Technologies manufactures gearmotors under the brand name Hyponic. The gear drives use HRHGs for the input stage.

You asked a very good question about the discrepancy in the efficiency of HRHGs reported by various sources. One reported the efficiency of HRHGs decreases as the gear ratio increases, while another indicated that the efficiency of HRHG gears remains the same—at about 90%—over the full range of ratios.

Can both be correct?

The answer is Yes, both can be correct! The following attempts to explain why the HRHG efficiency could be constant in one case and variable—according to gear ratio—in another.

Hypoid gear mesh efficiency is affected by the amount of tooth lengthwise sliding; i.e., the higher the tooth sliding, the higher the resultant friction loss, in turn lowering mesh efficiency. The lengthwise sliding is a function of hypoid offset. Larger offset will cause higher lengthwise sliding.

The lengthwise mesh efficiency can be calculated with the following equation (*ISO/TR 22849 Technical Report, "Design Recommendations for Bevel Gears," April 2011*).

$$\eta_{\mathrm{ffl}} = \frac{T_{\mathrm{o2}}}{T_{\mathrm{i2}}} = \frac{1+\mu_{\mathrm{m}}\dfrac{\tan\beta_{\mathrm{m2}}}{\cos\alpha_{\mathrm{n}}}}{1+\mu_{\mathrm{m}}\dfrac{\tan\beta_{\mathrm{m1}}}{\cos\alpha_{\mathrm{n}}}}$$

where:

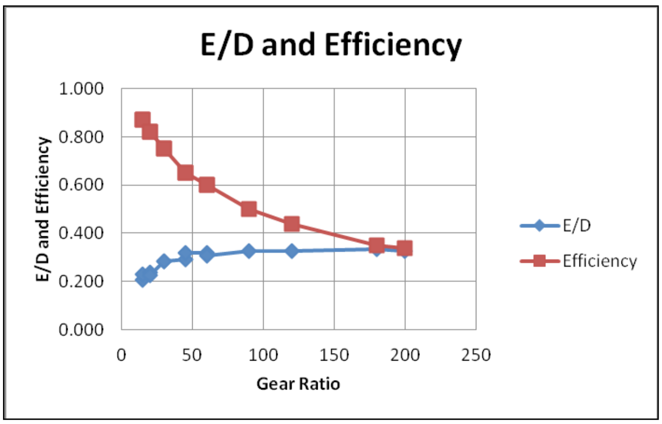
η_{ffl} = Lengthwise sliding (mesh) efficiency
T_{o2}, T_{i2} = Gear output and input torque, respectively
μ_{m} = Coefficient of friction
β_{m1}, β_{m2} = Mean spiral angle, pinion and gear, respectively
α_{n} = Normal pressure angle

For efficiency comparison of similar gears, we can consider them to have the same coefficient of friction, μ_{m}, and normal pressure angle, α_{n}.

For HRHGs, the difference between wheel and pinion spiral angles, β_{m1} and β_{m2}, is loosely related to the ratio of offset E to wheel pitch diameter D. As the $\frac{E}{D}$ increases the difference between β_{m1} and β_{m2} becomes greater. Since $\tan\beta_{\mathrm{m1}}$ is in the denominator and $\tan\beta_{m2}$ in the numerator of the mesh efficiency equation, the calculated mesh efficiency, η_{ffl}, will decrease when $\frac{E}{D}$ increases, and η_{ffl} will increase when $\frac{E}{D}$ decreases.

The first graph included in your question—Comparison of the Efficiency of MHP High-Ratio Hypoid Gears and Worm Gears—showed the efficiency of HRHGs decreases as the gear ratio increases. The graph data was apparently from KHK. In the figure below, the efficiency of KHK HRHGs (in red) and $\frac{E}{D}$ ratio of HRHGs (in blue) were plotted against the gear ratio. It is seen that as $\frac{E}{D}$ increases, the KHK/HRHG efficiency reported by the KHK figure decreases.

Based on the mesh efficiency equation presented above, increasing $\frac{E}{D}$ will cause mesh efficiency to decrease. Therefore, it is true that the HRHG efficiency can vary over the full range of ratios.



Your second figure showed efficiency of hypoid gears (some in HRHG-ratio range) to remain constant for all gear ratios. The source of the figure was apparently from a paper by Stefanie Burns (*Stefanie Burns; "Hypoid vs.Worm Gear Efficiencies;"whitepaper, Sumitomo Drive Technologies, November 2009*).

(It appears that) the efficiency calculation for the paper could be based on a series of Sumitomo HRHG gearmotors. For the same series of gearmotors, the offset and the wheel pitch diameter would be the same due to gear housing constraints. Consequently all the HRHGs compared by Ms. Burns could have the same $\frac{E}{D}$ ratio. As discussed earlier, gears with common $\frac{E}{D}$ would have the same mesh efficiency. This explains the case where all HRHGs had the same efficiency.

Summing up the above discussions, we can say that HRHGs could have identical gear efficiency over the range of ratios, and also could have decreasing efficiency as gear ratio increases.

Finally, you asked if there (are) 'high-efficiency' HRHGs—even at extremely high ratio.

The answer would depend on your definition of high-efficiency. If you consider 90% efficiency being high, then the answer would be in the affirmative. One HRHG example mentioned in this letter showed 90% efficiency for HRHGs, even at high gear ratio. Efficiency higher than 90% could be possible, but difficult to attain, because HRHGs always have some tooth sliding that reduces efficiency.

Hope the above helps.

George Lian, *engineering supervisor, Amarillo Gear Company LLC and member of the AGMA Bevel Gearing Committee.*
and **Ted Krenzer,** *Gleason Corp. and member of the AGMA Bevel Gearing Committee.*

Super Reduction Hypoids

High-ratio angular drives can be realized with worm-shaped pinions that mesh with Formate ring gears. The Gleason Corp. HRH system (high-reduction hypoids) has existed in the field for many decades. HRH teeth are face-milled and have parallel depth. The whole depth of HRH is limited to about 5 mm.

"But there is now a more modern system—Gleason Corp. SRH—or *super-reduction* hypoids. The whole depth of SRH is now only limited by the tool and machine capacity. SRH allows the application of universal motions and an "artificial" pinion diameter reduction. Both can be used as tools in order to maximize efficiency; all high-efficiency HRH and SRH gear sets are ground.

"If the number of pinion teeth is above 5, the efficiency of hypoid gears depends on the offset. If the number of pinion teeth is below 4, the number of teeth and offset have relatively equal influences on efficiency."

(*Following are some graphics in support of Dr. Stadtfeld's response, with additional comments.*):

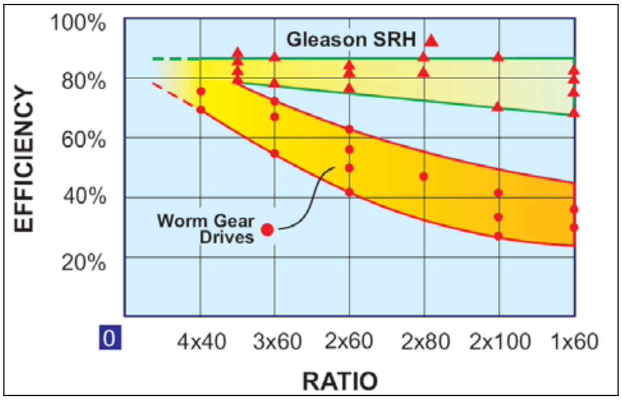


Figure 1—Efficiency comparison between worm gear drives and SRH drives.

"Figure 1 shows an efficiency comparison between worm gear drives and SRH drives. The diagram shows that average optimized SRH gear sets have efficiencies between 80% and 65%. Highly optimized SRH gear sets can almost be constant at the 83% to 87% level—even for ratios of 1x60. However, the reduced number of teeth and the higher ratio deliver the lower efficiency. A better sense of the dependencies between the parameters ratio and number of teeth is provided in Figure 2.

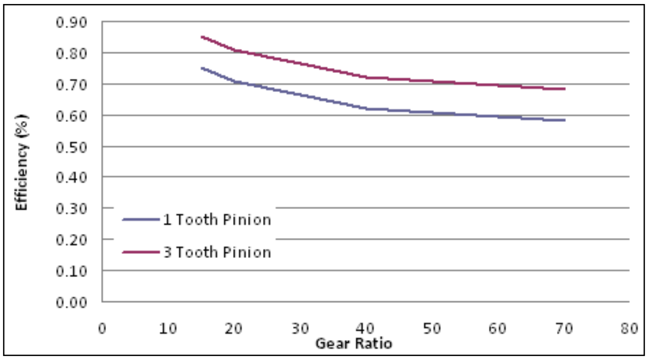


Figure 2—Dependency between number of teeth, ratio and efficiency.

"The graph in Figure 2 shows two qualitative diagrams, which imply that a lower number of teeth results in lower efficiency (red graph vs. blue graph). Both graphs show that as the ratio increases a drop in efficiency is noticed. Ninety-percent efficiency can be achieved with three pinion teeth if the ratio is below 10.

"The belief that with ratios greater than 25 the hypoid efficiency is constant at about 83% is incorrect. A reduction ratio of 250 will most likely be realized with one pinion tooth and 250 ring gear teeth. Such a transmission will show an efficiency of 45–53%. But don't be mistaken: a worm gear reduction is still 5–10% below that.

"Manufacturing of HRH and SRH gearsets is offered by Sumitomo, Nissei, Ningbo and by the Specialized Gear Services Department of The Gleason Works."

Figure 3—HRH gearset; HRH gearset with wormgear drive (courtesy Gleason Corp.).

Dr. Hermann J. Stadtfeld, *vice-president/bevel gear technology/R&D, Gleason Corp.*

Efficiency is Determined Case by Case

Traditionally, high-ratio hypoids needed to be cut on hypoid generators that have special modifications to adjust for the very low numbers of teeth and the amount of movements necessary to cut the extreme spiral length. (While) CNC generators (require) software to overcome these deficiencies, not every hypoid manufacturer has this equipment. Tooth contact development is (also problematic).

But whether your hypoid requires special machinery or not really depends on the specifics of your design.

The subject of efficiency is not as simple as saying 'All hypoids are 90% or better.' Technically, spiral bevel gears are hypoids and their efficiency is much higher. We have seen typical (i.e., not high-ratio) hypoids below 90%.

The key here is that a hypoid gear is normally considered to have an offset between the pinion and the mating gear. As this offset is increased, the pinion gets larger in diameter and the spiral angle can get bigger too. As you increase the ratio you typically need to reduce the number of teeth on the pinion, and the pinion spiral angle approaches the thread-like appearance of a worm gear. The result is a larger percentage of lengthwise sliding, similar to a worm gear set—and greater losses. You can adjust some of the geometry to reduce losses, but as the number of teeth and offset approach those of the equivalent worm, so does the efficiency.

Without a specific set of parameters it is difficult to say what efficiency you will have. There are calculations that can be done both in manufacturing software and industry standards that give efficiency predictions. ISO TR 22849 (proposed for AGMA adaptation) has a calculation procedure for hypoids that also takes into account windage and churning. These are calculations and you need to actually verify your efficiency in your application.

So in short, it would be best to compare a specific hypoid to a specific worm to see how different they really are.

Robert F. Wasilewski, *design engineering manager, Arrow Gear Company*

Typically, There Are No High-Ratio Hypoid Gears with High Efficiency—But Read On

Gearbox efficiency is a very complex topic as there are many sources for the loss of power into heat. When thermal losses of a gearmotor are considered, the major sources are the motor; bearings; gear mesh; shaft seals; windage; and churning.

In the past (the days of cheap energy), the efficiency of a gearmotor or a gear mesh was not a big concern, as industrial energy consumption was not a big concern. When it in fact became one (and continues today), there was confusion when efficiency was quoted, as the methods for its determination were not the same. Also, it is very difficult and expensive to accurately measure differences in efficiency of a gearmotor. In the world of international gear standards the calculation of losses has taken the form of standardized methods for the determination of thermal rating of a gearbox.

Specifically, for right-angled gearing, (bevel, hypoid and worm) the mesh friction losses are an important consideration. The designer can theoretically evaluate friction losses based on relative sliding between the teeth in mesh—in both profile and lengthwise direction. Generally, for similar size and ratio, bevel gears will have the best efficiency and wormgears the worst—with hypoid in the middle. This is because the relative sliding tends to increase, going from bevel-to-hypoid-to-worm.

In general, with these gears the relative sliding increases as the ratio increases. Therefore, relatively speaking, there are no high-ratio hypoid gears with high efficiency. The efficiencies can vary considerably with right-angle gearmotors—generally between 95% – 75%, depending on design and lubrication.

If you want more detail, a reference standard is AGMA ISO 14179: Gear Reducers—Thermal Capacity Based on ISO/TR 14179–1:

"This information sheet utilizes an analytical heat balance model to provide a means of calculating the thermal transmittable power for a single- or multi-stage gear drive lubricated with mineral oil. The calculation is based on standard conditions of 25C maximum ambient temperature and 95C maximum oil-sump temperature in a large indoor space, but provides modifiers for other conditions. Differences from ISO/TR 14179–1 are: a) errors were identified and corrected; b) text was added to clarify the calculation methods; and c) an illustrative example was added to assist the reader."

A reference technical paper of interest is AGMA 05FTM06: "A Model to Predict Friction Losses of Hypoid Gears," by H. Xu, A. Kahraman and D.R. Houser. Quoting here, "In it a model to predict friction-related mechanical efficiency losses of hypoid gear pairs is proposed, which combines a commercially available finite element-based gear contact analysis model and a friction coefficient model with a mechanical-efficiency formulation. The contact analysis model is used to provide contact pressures and other contact parameters required by the friction coefficient model. The instantaneous friction coefficient is computed by using a validated formula that is developed based on a thermal elastohydrodynamic lubrication (EHL) model. Computed friction coefficient distributions are then used to calculate the friction forces and the resultant, instantaneous mechanical efficiency losses of the hypoid gear pair at a given mesh angle. The model is applied to study the influence of speed, load, surface roughness and lubricant temperature as well as assembly errors on the mechanical efficiency of a (sample) face-hobbed, hypoid gear pair."

Bill Bradley, longtime AGMA gearing expert, Bevel Gear Committee member and *Gear Technology* technical editor

An Innovative Way of Designing Gear Hobbing Processes

F. Klocke, C. Gorgels, R. Schalaster and A. Stuckenberg

Management Survey

In today's manufacturing environment, shorter and more efficient product development has become the norm. It is therefore important to consider every detail of the development process, with a particular emphasis on design. For green machining of gears, the most productive and important process is hobbing. In order to analyze process design for this paper, a manufacturing simulation was developed capable of calculating chip geometries and process forces based on different models. As an important tool for manufacturing technology engineers, an economic feasibility analysis is implemented as well. The aim of this paper is to show how an efficient process design—as well as an efficient process—can be designed.

(First presented at the VDI International Conference on Gears, October 2010, Technical University of Munich)

Introduction and Objective

In order to shorten production time, it is wise to use simulation tools at every step of product development. Simulation tools can help avoid iterative steps based on trials and minimize development time—as well as costs. Along with existing WZL software packages (Refs. 1–2), a software simulation tool for gear hobbing has been in development for several years—i.e., *PARTApro.* Gear hobbing is one of the major manufacturing processes in the industry; indeed, nearly every soft-machined gear made is hobbed.

It therefore makes sense that—especially for a manufacturing technology with such high importance—a manufacturing simulation is needed for the reasons mentioned above, and due to the complexity of the process design. The complexity results from numerous, mostly non-linear, interacting factors. The tool costs-per-piece are also determined by the geometrical tool design. The parameters for a given machining operation require a specific design in order to meet operational requirements (machining time and costs). What's more, a manufacturing simulation is needed to enable easy and fast process design. The approach includes a penetration calculation in order to identify the chip geometries. But knowing only the chip geometry is insufficient for manufacturing simulations; of equal importance are characteristics and/or other values with a technological or economic background relative to a specific process.

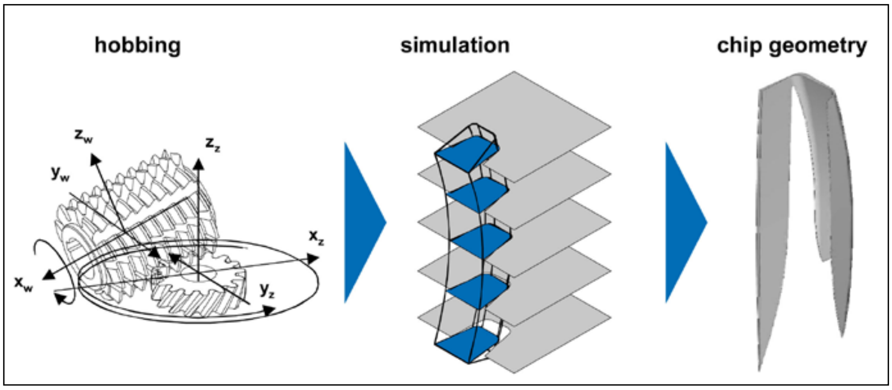


Figure 1—General approach for Penetration Calculation I.

Basics of a Manufacturing Simulation

Manufacturing simulations make the characteristics of complex processes more visible. The complexity of the hobbing process, for example, is demonstrated by the existence of the various chips created for every generating position caused by the complex kinematics. In gear hobbing, hob and workpiece move in a linked revolution ratio. The most common kinematic approach in hobbing is to start machining below the workpiece with the correct in-feed to reach the tooth height and feed the tool along the axis of the workpiece until the entire width of the workpiece is machined. Additional opportunities exist concerning the kinematics.

The kinematics are represented in the software. By a mathematical, geometric calculation the penetration between tool and workpiece over the complete manufacturing process is calculated

(Fig. 1). The resolution is limited by the number of layers along the workpiece width (199), the number of angle steps for a single chip (200) and the medium dot distance on the workpiece and tool profile. This distance has a relative limitation of 0.05 times module.

With the input data hob, workpiece and process kinematics, the chip geometries can be evaluated by modeling and creating non-deformed chips. Figure 2 (right) shows an exemplary chip geometry; the chip width is displayed on both the axis unrolled cutting edge and the cutting length on the axis cutting direction. The chip thickness is displayed vertically to the picture and distinguished by different colors; the dark areas have a low chip thickness, the light areas at the top have a high chip thickness.

Tool Design with Manufacturing Software

Along with technological investigation requiring concrete chip geometries, determination of economic value is of equal importance to the process designer. Therefore, examples of how manufacturing software assists in that determination are shown. To be determined in this case is which cutting material and tool design fit best for an existing, exemplary process. In determining which cutting material is preferable, one must consider not only productivity and tool life, but tool costs as well. Generally, the tool costs for PM-HSS hobs are lower than for carbide tools; tool costs consist of three parts:

1. Purchase cost—especially for hobbing tools
2. Re-coating cost
3. Re-sharpening cost

The costs for re-coating typical, various cutting materials are quite similar, but the purchase and re-sharpening costs are higher for the more robust carbide tools. That is why in analyzing which is the best tool, determining total cost of ownership is crucial. For machining a 16MnCr5N steel, for example, a profitability analysis is shown (Fig. 3). Starting with investigated parameters in an analogy process for gear hobbing, the process is opti-

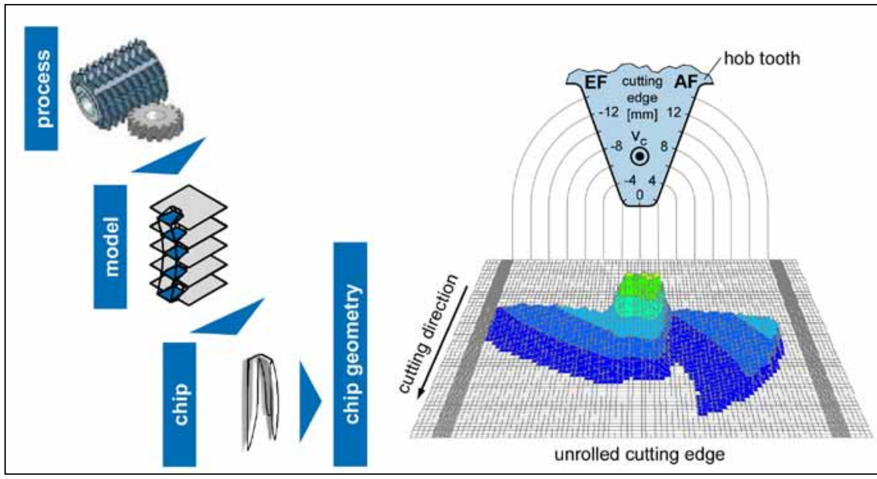


Figure 2—General approach for Penetration Calculation II.

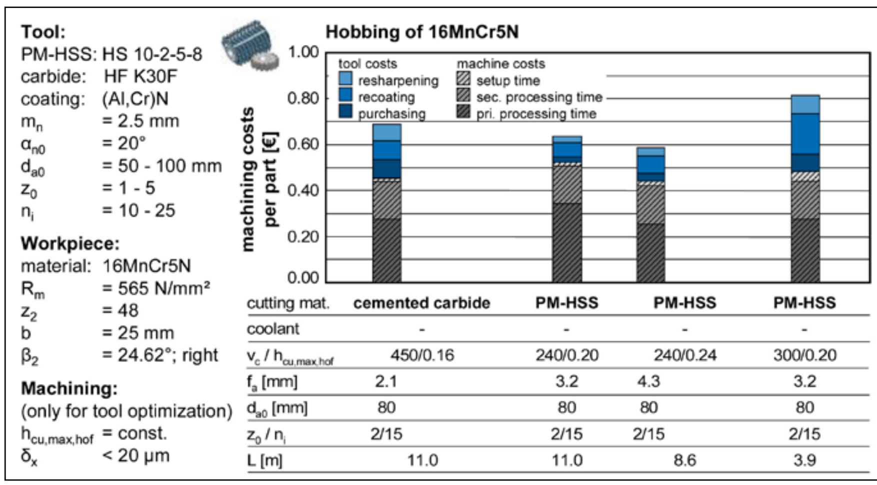


Figure 3—Process design of existing process for 16MnCr5N.

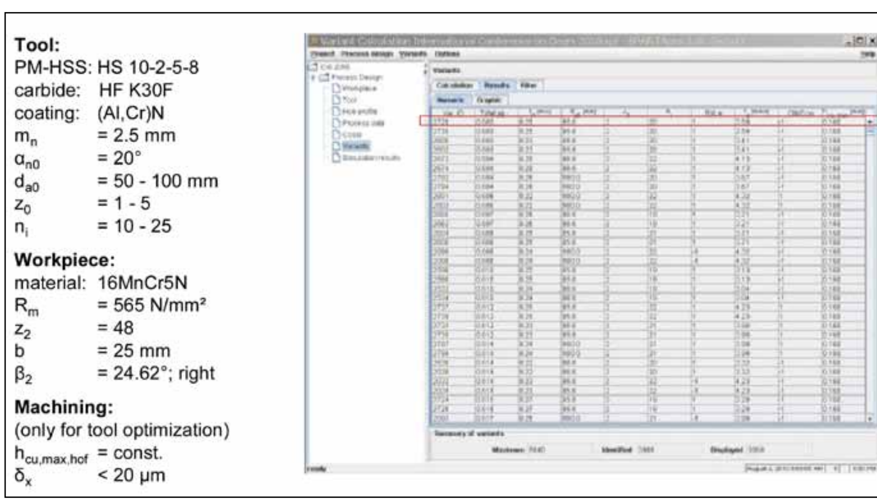


Figure 4—Variant calculation to optimize tool and process design.

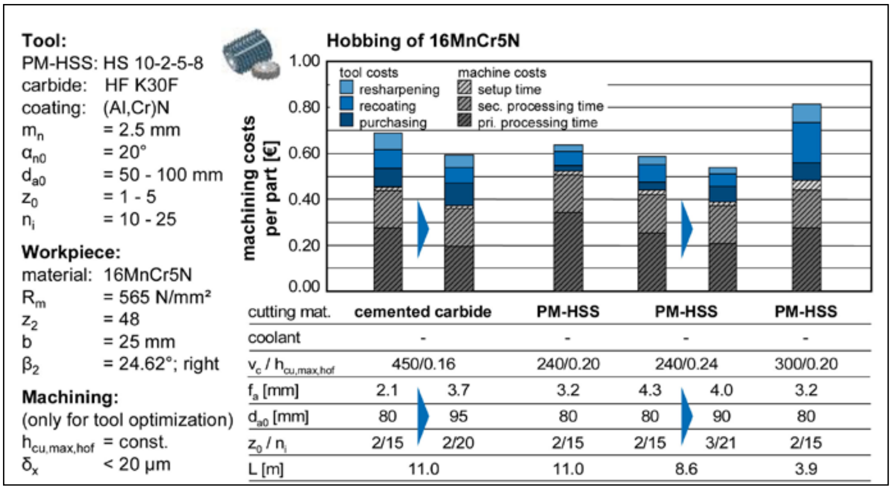


Figure 5—Profitability analysis of machining case-hardening steel 16MnCr5N.

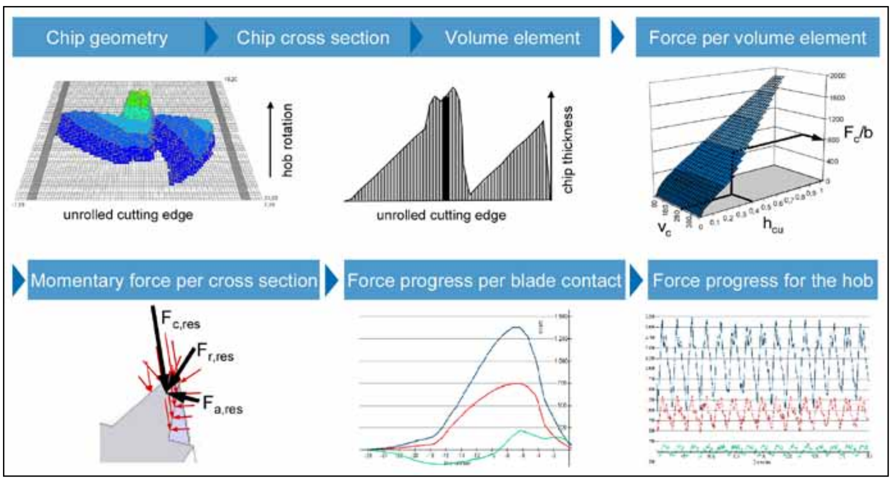


Figure 6—Approach for calculation of cutting forces in gear hobbing (Gutmann, Ref. 3).

mized with software. Based on trial parameters, the first determination of cost-per-part is made.

Initially, the cost-per-part for PM-HSS at medium cutting speed (Fig. 3) is lower than for machining with carbide. Only the PM-HSS process with very high cutting speeds is not competitive. With the results for the tool life based on trials, a calculation of different tool and process variants is made with the target of an axial feed with feed marks of δ_x<20 µm and a constant maximum chip thickness for each set of cutting parameters. The tool outside diameter and number of starts and gashes are varied. With these default values, the software calculates every possible tool design capable of achieving these requirements (Fig. 4).

The result in this case is a combined total of 7,040 variants. Due to the given limitations, 3,968 variants are determined and shown. In the different columns, different values are presented. In Figure 4, the variant ID for the identification (Var ID); the cost-per-part (total); the primary processing time (t_h); the tool outside diameter (d_{a0}); the number of starts (z_0); the number of gashes (n_i); the gradient direction of the spiral (*Ri*/*Le*); the axial feed (f_a); the manufacturing direction—climb or conventional cutting—(*Clb*/*Con*); and the maximum chip thickness ($h_{cu,max}$) are visible. Next to these values different other values are selectable. Every column can be sorted in descending or ascending order. In this way the opportunity presents itself to look for a variant with, for example, the lowest processing time or the lowest cost. The data for the tool and resharpening costs—plus the cost for the machine tool-per-hour—are input data and must be supplied by the user.

The result of the tool and process optimization shown (Fig. 3) is presented (Fig. 5). For the cemented carbide tool variant, the variant chart is shown (Fig. 4). After this variant calculation the machining cost-per-part for gear hobbing could be decreased about 15%. It seems to be that the cemented carbide is now competitive with the PM-HSS tool. But, optimization of the PM-HSS tool (Fig. 5) leads again due to lower machining costs. In this case the analysis of the process could show which tool material and design fits best.

Process Force Calculation Based on a Manufacturing Simulation

Next to the economic values of a process, knowledge of the forces in gear hobbing is important regarding tool, machine tool and workpiece clamping dimensioning. So the tool and machine tool manufacturer—as well as the production plant owner—have keen interest in that topic.

The need for a process force calculation is industry-driven and implemented in the manufacturing software. The calculation is based on a cutting force model for gear hobbing provided by Gutmann (Ref. 3).

The approach of cutting force calculation with *SPARTApro* is illustrated (Fig. 6); the basis of the approach is the dependence of cutting forces on the chip thickness and the cutting speed (Ref. 3).

Earlier in this paper it was explained that the software calculates all appearing chip geometries via penetration calculation. The single-chip geometries are split in cross-section elements. The result is a graph over the unrolled cutting edge for discrete hob rotation angle steps. This graph is divided again in discrete volume elements with a defined chip thickness. For each volume element, the force is calculated with the aid of a cutting force characteristic diagram. A characteristic diagram considers chip thickness—h_{cu}—and cutting speed—v_c. The data basis for the force calculation—and thus for the characteristic diagram—is generated based on turning trials. In this quasi-static trial the cutting forces in each spatial direction are measured. The measurements are carried out for different cutting speeds, chip thicknesses (realized by the feed) and materials.

After the force values for each volume element of a single-hob-rotation-angle-step along the cutting edge are determined, the resulting forces in the cutting speed direction—i.e., in both radial and axial directions—are calculated. This procedure is required for every discrete hob-rotation-step and blade. Results of these calculations are shown in Figure 6, as in the "force-progress-per-blade-contact" over the hob rotation angle, for example. The sum-of-force progress for each blade is in turn the "force progress for the hob."

With the trials data in hand, this method of force calculation is verified; the trials involved hobbing operations on an industrial hobbing machine tool. A dynamometer is mounted between hobbing tool and main bearing of the tool-holder axis; with the dynamometer, the torque and forces in every spatial direction can be measured. In Figure 7, a comparison between calculated and measured spindle torque over a single hob rotation is presented. The medium values for both graphs are quite similar. The main difference between them is the amplitude—i.e., it is much higher for the measured torque, due to the higher dynamic influence of an actual process, as compared to the static summation provided in the calculation algorithm. Therefore, although the software cannot simulate the dynamic behavior of a real-time hobbing process, it does in fact generate good results regarding the medium values. Visible in both graphs is the effect of a two-start hobbing tool ($n_i = 2$). This results in a wavelike envelope and a second, lower peak next to each of the 17 main peaks. The 17 main peaks result from the number of gashes ($Z_0 = 17$).

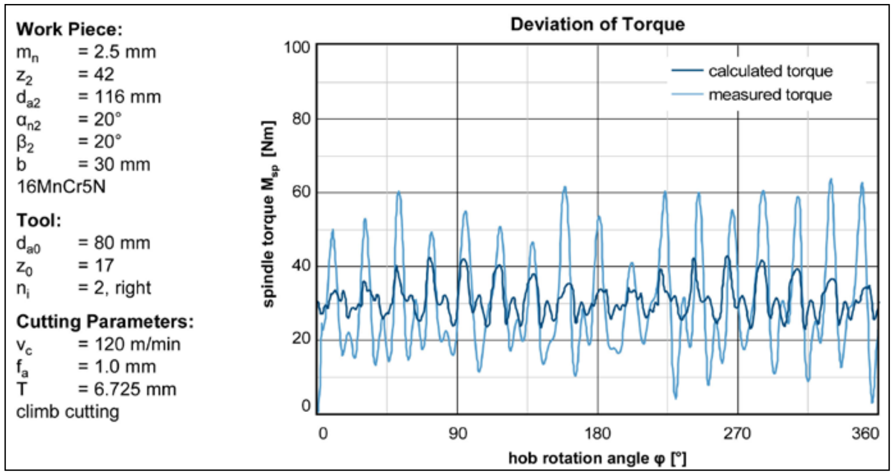


Figure 7—Comparison of calculated and measured torque: process example.

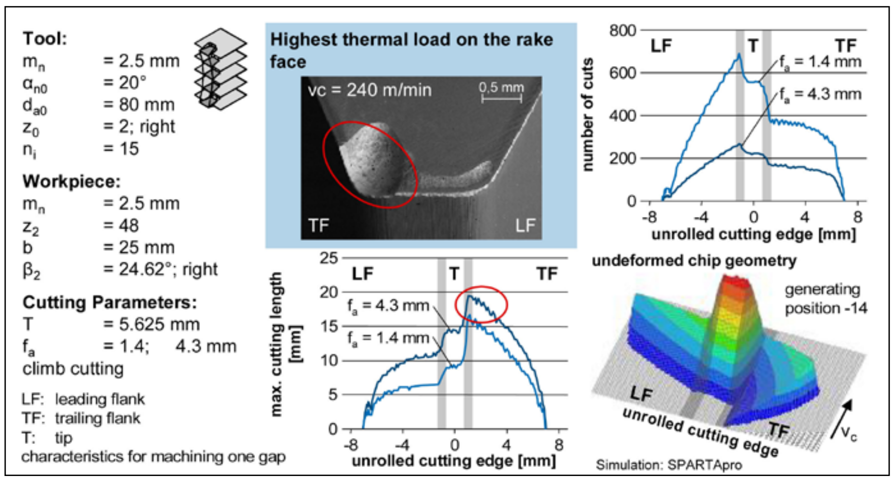


Figure 8—Chip-forming characteristics calculated by *SPARTApro*.

Further Benefit of Gear Hobbing Analysis

It has been demonstrated that manufacturing simulation provides economic analysis and force calculation capabilities. Nevertheless, it cannot replace the experienced engineer. With that in mind, following are two applications demonstrating the value-added benefit of manufacturing simulation when combined with process knowledge.

1. *Optimization of wear behavior.* This first example shows the primary advantage in use of the software. Two of the most desired goals of the manufacturing process are 1) low tool wear and 2) long tool life. The reality is that a combination of reasonable cutting parameters and medium tool life are most typical in industrial production. Especially in processes with complex kinematics and the attendant, various single-chip geometries, it is difficult to estimate the correct cutting parameters. In Figure 8 the chip-forming characteristics and an SEM photograph of a PM-HSS tool are shown. Results for the wear behavior are based on a hobbing trial with a single blade; note the high crater wear at the transition between the tip and trailing flank; note as well that the chip-forming characteristic for the maximum cutting length and the number of cuts over the unrolled cutting edge for varying axial feeds are presented. There are two peaks of particular interest: 1) the characteristic number of cuts, the peak at the transition from tip to leading flank; and 2) the characteristic maximum cutting length—the peak at the transition from tip to trailing flank. With a detailed view of the wear at the cutting edge, wear caused by thermal load is examined. The maximum cutting length characteristic correlates well with the wear occurrence. The result is that a decrease of the cutting length peak leads to optimized wear behavior, which can be achieved via another tool design; e.g., lower outside diameter, higher number of gashes. The general result is that no single, special characteristic can be taken to analyze a process. But together with the knowledge of wear behavior and the occurrence of wear, analysis can begin, in turn lead-

Figure 9—Surface defects.

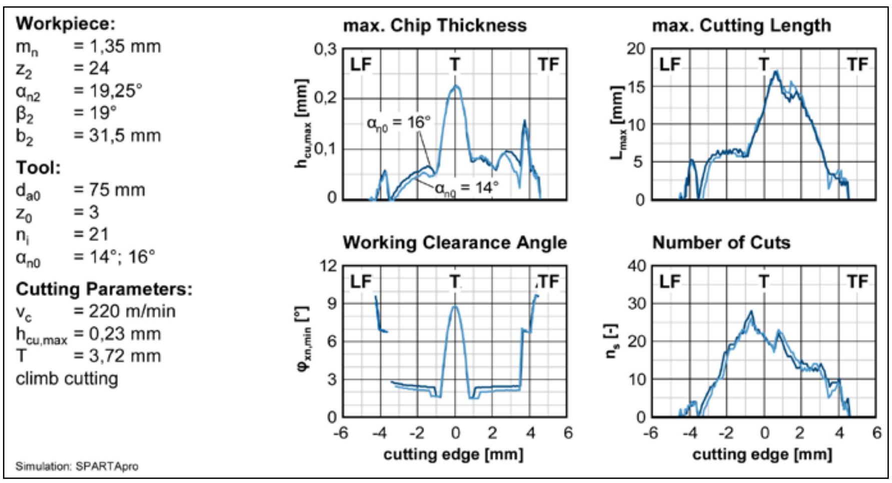


Figure 10—Changing of the chip geometry characteristics by modification of the pressure angle.

ing to a faster process optimization by reducing the number of trials.

2. *Software simulation to avoid surface defects.* The second example for the advanced use of manufacturing simulation is the topic of surface defects on spur gears. For specific gears the appearance of surface defects is observed (Fig. 9). Surface defects are smeared areas, scratches or welded-on chips. These defects are not acceptable for various reasons and therefore the parts are scrapped.

One reason for this is that surface defects—especially welded-on chips—cause a local raised stock. This decreases stability in subsequent manufacturing processes like gear shaving, grinding or honing.

A second reason is the minimization of local stock by pitting or similar occurrences of surface defects. Welded-on chips can rip out material by breaking out of the flank, and scratches can be so deep that the stock is reduced significantly. This reduction or increase in stock must be avoided when following manufacturing steps with a low stock, as in, for example, gear shaving. At minimum, such surface defects are a visual impairment; worst-case is that surface defects decrease process reliability.

One approach to avoiding such mistakes in tool and process design is manufacturing simulation. Figure 10 shows the result of a theoretical process analysis of the chip-forming characteristics of two different tool designs based on an industrial process. The examined gear reveals a surface defect characterized by smeared areas on the flank. The displayed chip-forming characteristics are the maximum chip thickness, cutting length, working clearance angle and number of cuts; each characteristic is plotted over the unrolled cutting edge.

The difference in tool design variation is the varied pressure angle, i.e.—$\alpha_{n0} = 14°$ and 16°. The initial tool design reflects pressure angle of $\alpha_{n0} = 14°$. After the occurrence of smeared areas on the flank with the starting pressure angle, a pressure angle correction is made. Production continues with a pressure angle of $\alpha_{n0} = 16°$, resulting in sufficient gear quality regarding surface defects.

By analyzing chip-forming characteristics, first approaches for optimization can begin. In the case at hand, chip thickness increases slightly at the leading flank with a higher pressure angle. Likewise, the cutting length and number of cuts increase somewhat in that area. The most significant change between the two tool designs is the higher-working clearance angle at both the leading and trailing flank. The working clearance angle—especially in that area—is higher where the part of the tooth gap with smeared areas is generated. The increase of the minimum working clearance angle is $\Delta\phi_{xn,min} \approx 0,3°$.

Based on this knowledge, the smeared areas can be attributed to crushed chips built up at the flank. A too-low clearance angle—combined with a higher temperature caused by higher friction at the chip-building zone—may lead to smeared areas at the flank. In final analysis, the space between clearance and workpiece flank is insufficient and so contact with chips on the workpiece flank may in fact be unavoidable.

For now, theoretical process analysis can only provide approaches addressing surface defects. But with a variation in the tool design characteristic, a change in chip-forming values can be shown that will assist in further research.

Summary and Conclusion

In this paper, the ability to attain through simulation cheaper, faster process development for gear hobbing is demonstrated. As such, the operating mode of manufacturing simulation software for gear hobbing is explained.

Following that was a discussion of tool design, process force calculation and usage of chip-forming characteristics. Using the tool optimization feature of the software showed that—with *existing* processes—tool and process optimization are possible, although the process can be more productive.

The method for force calculation was presented in detail, after which the calculated values were compared with measured values for the spindle torque; the comparison showed good correlation. The main deviation is caused by not accounting for the dynamic behavior of a real hobbing process within the calculation model.

To conclude, two examples of the main function of a manufacturing simulation were given.

In the first example, the tool wear behavior was compared with chip-forming characteristics. It could be shown that the software supports the engineer by designing gear hobbing processes that address both wear behavior and productivity.

In the second example, surface defects were examined. Also shown and demonstrated in this example were the existing support opportunities available for the process designer in response to challenges in the design process.

References

1. Brecher, C., C. Gorgels and T. Röthlingshofer. "Manufacturing Simulation of Beveloid Gears for Use in General Tooth Contact Analysis Software," *Production Engineering Research and Development 3,* 2009, pp. 103–109.
2. Weck, M., C. Brecher, F. Klocke and U. Rütjes. "Analysis of a Bevel Gear Cutting Process by Manufacturing Simulation," *Production Engineering–Research and Development XII,* 2005, pp. 107–110.
3. Gutmann, P. "Shear Force Computation with Hobs," Dissertation, RWTH Aachen, 1988.

Authors' note: Parts of this paper are based on the IGF–Project N04271/09 of the Research Association for Machine Tools and Manufacturing Technology (FWF) e.V., funded by the AiF within the program collective research for small and medium enterprises (IGF) of the Federal Ministry of Economics and Technology (BMWi) based on a decision of the German Bundestag.

Fritz Klocke *studied manufacturing engineering at the TU Berlin, and earned his engineering doctorate in 1982. He was a research fellow there at the Institute for Machine Tools and Manufacturing Technology until 1981, and subsequently head engineer until 1984. Klocke worked in industry from 1984 until 1994, at Ernst Winter & Sohn in Hamburg. In 1995 he was called to the RWTH Aachen as Professor of Manufacturing Engineering Technology and has since served as Chair of Manufacturing Technology, co-director of the WZL Laboratory for Machine Tools & Production Engineering at the RWTH Aachen and as head of the Fraunhofer Institute for Production Technology IPT in Aachen. Klocke was awarded the Otto-Kienzle Memorial Coin in 1985 by the Manufacturing Engineering University Group; the title of Dr.-Ing. E.h. was bestowed upon him by the University of Hannover in 2006 for his outstanding achievements and contributions in science and manufacturing; and in 2009 he was awarded the title Dr. h.c.by the University of Thessaloniki for his achievements in production science, his engagement in international cooperation and his talents as a teacher and supervising tutor of student engineers.*

Christof Gorgels *is chief engineer, gear technology, at the Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University. Gorgels began his career as a research assistant in 2003 at the Chair of Manufacturing Technology, investigating gear profile grinding with a special emphasis on grinding burn. Since 2008 Gorgels has headed the Gear Technology department at RWTH; he was awarded his doctorate in 2011.*

Dipl.-Ing. Rolf Schalaster *is a research associate and doctoral candidate under Prof. Klocke in production engineering at the Gear Research Center at RWTH Aachen University. His principal field of work is gear hobbing and especially process optimization of gear finish hobbing processes.*

Dipl.-Ing. Arne Stuckenberg *is a research associate and doctoral candidate under Prof. Klocke in production engineering at the Gear Research Center at RWTH Aachen University. His principal research activities are in gear hobbing. He works on tool reconditioning of hobs and process forces in gear hobbing.*

Application of the First International Calculation Method for Micropitting

Dr. Ulrich Kissling

Management Summary

The first edition of the international calculation method for micropitting—ISO TR 15144–1:2010—was just published last December. It is the first and only official, international calculation method established for dealing with micropitting. Years ago, AGMA published a method for the calculation of oil film thickness containing some comments about micropitting, and the German FVA published a calculation method based on intensive research results. The FVA and the AGMA methods are close to the ISO TR, but the calculation of micropitting safety factors is new.

In this paper, ISO TR 15144 is explained briefly and presents two calculation rules: method A and method B. Method A requires Hertzian pressure on every point of the tooth flank. This is based on an accurate calculation of the meshing of the gear pair that considers tooth and shaft deflections to establish the load distribution over the flank line in every meshing position. Such a calculation is very time consuming when using an FEM tool. Alternatively, specific analytical programs that are commercially available—e.g., *LDP*, *RIKOR*, *KISSsoft*—may be used. In either case the use of method A without such an advanced tool is impossible. Method B is much simpler in that the load distribution is defined for different cases as spur or helical gears—with and without profile modifications. Method B can be programmed as standalone software, maybe even in *Excel.* However, a restriction that arose in the last meeting of the ISO working group responsible for this topic limits considerably the application of method B: i.e., if gears with profile modification have to be verified, the tip relief C_a must correspond exactly to a proposed value C_{eff}. If not, the method for gears without any profile modification has to be used. As modern gear design specifies profile modification of different kinds, this is a critical limitation for the application of method B in ISO TR 15144.

Introduction

An ISO TR is a technical report that—typically after a 3-year period—will become an international standard. With the considerable number of new wind turbine installations over recent years, micropitting has become a critical issue in gearbox design. Indeed, even before its official publication, evaluation of micropitting risk based on ISO 15144 is a hot topic among authorities such as Germanischer Lloyd, the Hamburg-based classification society and technical supervisory organization.

The potential for micropitting is highly influenced by profile and flank line modifications. A newly available software tool can evaluate the micropitting risk by automatically varying different combinations of tip reliefs, other profile modifications and flank line modifications in combination with different torque levels, using method A. The user can define the number of steps for variation of the extent of modification; for example, tip relief C_a from 30 to 70 µm in 4 steps, crowning value C_β form10 to 40 µm). Then all possible combinations $C_a = 30$ (with $C_\beta = 10, 20, 30, 40$), $C_a = 40$ **(...),** etc., are checked combined with different user-defined torque levels. Any modifications including flank twist, arc-like profile modifications, etc., can be combined. The result is presented in a table, showing the safety factor against micropitting for different subsets of profile/flank modifications, depending on the torque level. Additionally, peak-to-peak transmission error, maximum Hertzian stress, wear, etc., are documented. This tool enables the possibility of reducing micropitting risk with profile modifications and is very helpful for designing an optimum gear modification for varying torque levels.

Three different gear sets with micropitting problems—example *D* (spur gear, module 10.93 mm, *Z* 18:18); example *U* (helical gear $\beta = 19.578°$ module 4.5 mm, *Z* 33:34); and example *F* (helical gear $\beta = 9°$, module 30 mm, *Z* 19:76) will be discussed.

Micropitting as Phenomenon

As explained in ISO TR 15144 (Ref. 1), micropitting is a phenomenon that occurs in Hertzian types of rolling and sliding contact that operate in elastohydrodynamic or boundary lubrication regimes. Micropitting is influenced by operating conditions such as load, speed, sliding, temperature, surface topography, specific lubricant film thickness and chemical composition of the lubricant. Micropitting is more commonly observed on materials with high surface hardness.

Esssentially, micropitting is the generation of surface cracks; the cracks grow at a shallow angle to the surface and form micropits. The micropits are small relative to the size of the contact zone, typically of the order of 10–20 µm deep. The micropits can coalesce to produce a continuous fractured surface that appears as a dull, matte surface during unmagnified visual inspection (Fig. 1).

Micropitting is the preferred term for this phenomenon, but it has also been referred to as "grey-staining," "grey-flecking," "frosting" and "peeling." Micropitting may stop on its own, but if allowed to progress it may result in reduced gear tooth accuracy, increased dynamic loads and noise. If it does not stop and continues to propagate it can develop into macropitting (classic pitting) and other modes of gear failure.

Classic pitting, however, is a completely different phenomenon. In this case the cracks start at a certain depth under the surface where shear stress—due to Hertzian pressure—is highest. This effect is well explained in the ISO 6336–2 standard.

ISO Technical Report 15144

The ISO Technical Report 15144–1 provides principles for the calculation of the micropitting load capacity of cylindrical, involute, spur and helical gears with external teeth. The basis for the calculation of micropitting load capacity of a gear set is the model of the minimum, operating-specific lubricant film thickness in the contact zone, $\lambda_{GF,min}$. For calculating micropitting risk, a safety factor S_λ is defined as the ratio between $\lambda_{GF,min}$ and the permissible, specific film thickness λ_{GFP}.

The permissible, specific lubricant film thickness λ_{GFP} is calculated from the critical, specific lubricant film thickness λ_{GFT} which is the result of any standardized test method applicable to evaluating micropitting load capacity of lubricants or materials by means of defined test gears operated under specified test conditions. λ_{GFT} is a function of the temperature, oil viscosity, base oil and additive chemistry and can be calculated in the contact point of the defined test gears where the minimum, specific lubricant film thickness is found, and for the test conditions where the failure limit concerning micropitting in the standardized test procedure has been reached. The most widely used test procedure is the FVA–FZG micropitting test (Ref. 2). Several oil providers already document the micropitting load stage following the FVA test in their oil specification.

The ISO TR 15144–Part 1, was published in December 2010; Part 1 contains the basic calculation method. The ISO committee responsible for this topic is currently working on Part 2, which will contain some examples of gear sets with micropitting. Part 2 will be very helpful in better understanding the application of the calculation rules as described in Part 1.

The technical report presents two calculation rules—methods A and B. The report stipulates that for method A, experimental investigations or service experience relating to micro-

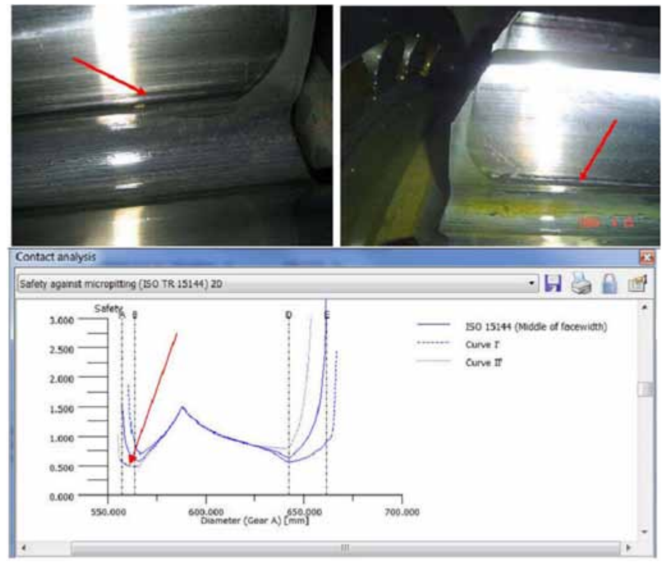


Figure 1—Traces of micropitting at the root of the flank of the pinion (photo courtesy CMD France); corresponding result of safety against micropitting (method A). Curves for left-side, middle and right-side of face width; gear Example F (helical gear, m_n = 30 mm, ß = 9°, Z 19:76).

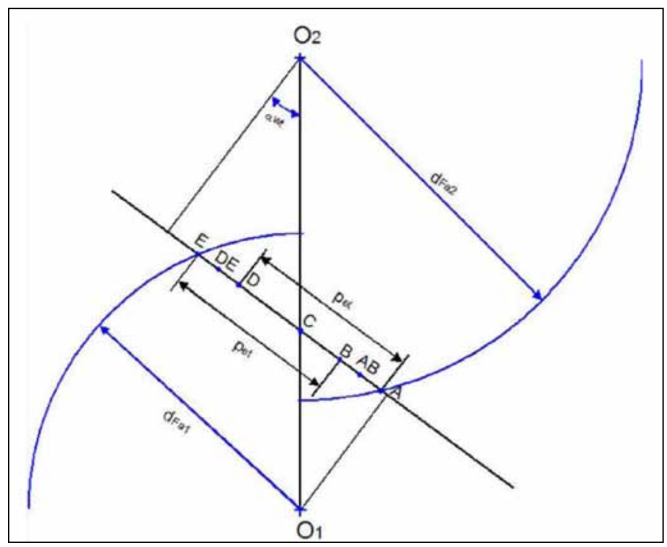


Figure 2—Significant points on path of contact where micropitting must be checked if using ISO 15144, method B; (Point A: beginning of contact, *SAP*; Point E: end of contact, *EAP*.)

pitting require that real gears are used. But this is not very practical when designing new gears; as will be shown in Part 2 of the technical report, a more practical approach when using method A is to first calculate the load distribution over the flank line in every meshing position, and then the Hertzian pressure on every point of the tooth flank, based on an accurate calculation of the meshing of the gear pair and considering tooth and shaft deflections. This is a most complicated contact analysis problem that could be solved using an FEM tool, but such a calculation is very time consuming. Alternatively, specific commercially available analytical programs may be used. Once the local Hertzian pressure and sliding velocity are determined, the local specific lubricant film thickness *GF* is calculated using the equations from the technical report.

The use of method B is much simpler; Hertzian pressure is defined by equations for such cases as spur or helical gears, with and without profile modifications. The equations for the calculation of the local pressure and velocities are based on an unmodified involute tooth form. The calculation is performed for some of the critical points in the tooth meshing cycle, i.e.—points *A*, *AB*, *B*, *C*, *D*, *DE* and *E* (Fig. 2; Refs. 1 and 3). In these points the specific lubricant film thickness λ_{GF} is then calculated.

The technical report states that there are many influencing parameters for micropitting, such as surface topology, contact stress level and lubricant chemistry. And while these parameters are known to affect the performance of micropitting for a gear set, it must be re-stated that micropitting remains a topic of new research; the science has not yet been developed to allow these specific parameters to be directly included in the calculation methods. Also, since the correct application of tip and root relief (involute modification) has been found to greatly influence micropitting, application of the suitable values should be the rule.

Surface finish is another crucial parameter; at present, *Ra* is used but other aspects such as *Rz* or skewing have been observed to have significant effects that could be reflected in the finishing process applied.

Overview of Calculation Procedure

Calculation of micropitting safety factor. For calculating the risk of micropitting, safety factor S_λ is defined as follows:

$$S_\lambda = \frac{\lambda_{GF,min}}{\lambda_{GFP}} > S_{\lambda,\ mi} \tag{1}$$

$\lambda_{GF,min}$ = min ($\lambda_{GF,Y}$) is the lowest specific film thickness over the meshing cycle

λ_{GFP} = the permissible specific film thickness; it may be determined by different methods

$S_{\lambda,min}$ = the required safety factor, to be agreed on between supplier and purchaser of the gearbox

The lowest specific film thickness ($\lambda_{GF,min}$) is defined as the minimum of all locally calculated film thickness values $\lambda_{GF,Y}$ (Eq. 2); the permissible film thickness λ_{GFP} is calculated (Eq. 5). The ratio between these two values ($\lambda_{GF,min}/\lambda_{GFP}$) results in a safety factor against micropitting S_λ, which then has to equal or surpass the required safety factor $S_{\lambda,min}$. As the calculation method is quite new and relatively few known data points are available, the general idea for the interpretation of the micropitting safety S_λ is to have a range between low- and high-risk limits:

Safety $S_l > 2$	Low risk
$1 \leq$ Safety $S_l \leq 2$	Limited risk
Safety $S_l < 1$	High risk

Calculation of specific film thickness. For calculation of the safety factor S_λ, the local film thickness in the contact of the gears h_y must be known for the entire meshing cycle. It is then compared to the effective surface roughness:

$$\lambda_{GF,Y} = \frac{h_Y}{R_a} \tag{2}$$

where:

$$R_a = 0.5\,(R_{a1} + R_{a2}) \tag{3}$$

$$h_Y = 1600\ \rho_{rel,Y}\ G_0^{0.6}\ U_Y^{0.7}\ W_Y^{-0.13}\ S_{GF,Y}^{0.22} \tag{4}$$

$\lambda_{GF,Y}$ = local specific film thickness

R_a = arithmetic surface roughness of the contact

R_{a1} = arithmetic surface roughness of the contact of gear 1

R_{a2} = arithmetic surface roughness of the contact of gear 2

h_Y = local film thickness

$\rho_{rel,Y}$ = relative radius of curvature of the flanks in point *Y* (the point of contact between the gears)

G_0 = parameter for pressure viscosity describing the influence of the equivalent Young's modulus E_r and the pressure viscosity of the lubricant at mass temperature $\alpha_{\theta 0}$

U_Y = local velocity factor

W_Y = local relative load factor

$S_{GF,Y}$ = local sliding factor

Determination of permissible specific film thickness λ_{GFP}. Determining permissible specific film thickness λ_{GFP} is the most difficult part to understand when referencing the technical report. There is a simple but inaccurate way to identify this value using a diagram (Ref. 4) where, for mineral oils, the permissible specific film thickness λ_{GFP} as a function of the viscosity of the lubricant ν and the load capacity number *SKS* of the lubricant (Fig. 3) are found.

$$\lambda_{GFT} = 1.4\ W_W \lambda_{GFT}\,(\nu, SKS) \tag{5}$$

λ_{GFT} = specific lubricant film thickness ascertained by tests

W_W = material factor (Table 1)

SKS = property of the lubricant; must be measured similar to the FZG number against scuffing; modern lubricants like those used in wind turbine gearboxes typically have an *SKS* number of *SKS* = 10, but the data needs to be checked with the oil supplier on a case-by-case basis

The *SKS* number is determined according to the FVA information sheet (Ref. 2) and may be found on the lubricant data sheets of the leading suppliers. Note that Figure 3 is

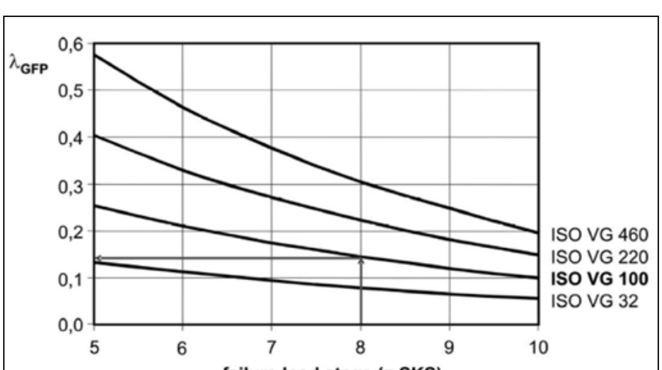


Figure 3—Required specific film thickness λ_{GFP} for mineral oil.

Table 1—Material factor W_W (ISO TR 15144)

	W_W
Case hardening steel, austenite ≤25%	1.00
Case hardening steel, austenite > 25%	0.95
Gas nitrided (HV > 850)	1.50
Induction -- or flame hardened steel	0.65
Through hardening steel	0.50

valid for mineral oils; synthetic oils will give (for the same viscosity and *SKS* number) a different, typically lower, permissible specific film thickness λ_{GFP}. Furthermore, it should be observed that the values given for λ_{GFP} are valid for case-carburized gears.

The accurate way to determine a value for the permissible specific lubricant film thickness is to use data of the oil performance from an FZG test rig. Many oils are tested on such a test rig, with gear-types FZG C–GF. In the oil specification you will then find the declaration, "Failure load stage (*SKS*) for micropitting test C–GF/8, 3/90'=*n* (*n*=5…10)". The *SKS* number corresponds to the torque level at which the gear in the rig with the test oil shows micropitting. If the *SKS* number of the oil is known, the micropitting calculation of the test rig gear is performed with:

Gear data as specified for the C–GF/8,3/90' test rig gear (Ref. 2)

Torque and Hertzian pressure as specified by Table 2.

Oil data as viscosity, density UC = D, V and D

Oil temperature θ_{oil} of the actual gear reducer (*not* the oil temperature used on the FZG test rig); note that it is recommended that the FZG test should be performed with the same oil temperature as used in the gear reducer. Typically, however, the FZG test is executed with 90°C oil temperature. Therefore data published by oil providers are valid for 90°C (if not otherwise declared).

The calculation of the test gear with this input data is done for point A because the minimum specific lubricant film thickness for the FZG type C test gear is always at point A. The resulting specific lubricant film thickness λ_{GF}, as per Equation 2 of ISO procedure, is the specific lubricant film thickness ascertained by tests λ_{GFT} (Eq. 5).

Unfortunately, the description of the method to get λ_{GFT} is missing in ISO TR 15144 Part 1; there will be more information in Part 2.

Recommendations for the Use of ISO TR 15144

Using method A. A problem when using method A—one that is more difficult than it may first appear—is calculation of the Hertzian pressure distribution over the tooth flank. It is well known that if different FEM tools are used to calculate the tooth contact, differences in the resulting pressure may be 30% and more. This depends on the mesh, boundary conditions and solution model. Similar problems are present when using commercially available software written to resolve specifically the tooth meshing contact.

Citing one of the problems encountered: a gear with a linear profile modification in the tip area has a small edge

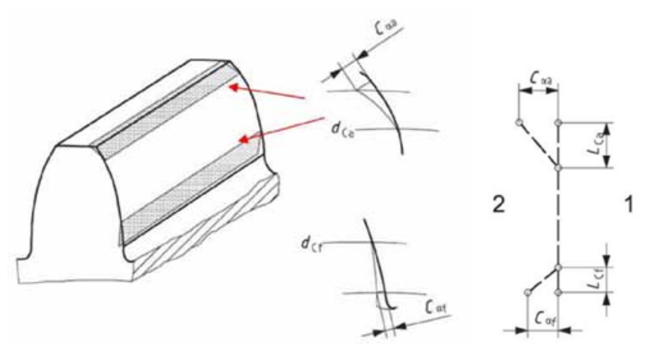


Figure 4—Tip and root relief as defined in ISO21771 (Ref. 5); at the point where the profile modification starts (arrow), a small edge in the tooth flank is formed.

at the point where modification begins (Fig. 4). In this point the radius of curvature is theoretically zero, so the Hertzian pressure is infinitely high. In reality, the edge does not exist because it is rounded during the grinding process, or the edge is reduced after some cycles due to wear. Therefore the pressure is much lower than theoretically assumed. A similar effect is encountered on the gear tip area, at the beginning of the chamfer. Very high pressure will result in low micropitting safety. As there is no "official" method available to deal with this problem, the abovementioned programs provide individual solutions that will result in somewhat different pressure values for the same tooth form.

Using method B. Within method B the local Hertzian pressure is calculated with equations. This is relatively simple for involute gears having no profile modification. In this case it is easy to get the load distribution over a meshing cycle. For gears with profile modifications, the load distribution is more complex; i.e., depending on the amount of tip relief C_a (Fig. 4), load at the beginning and end of the contact is reduced. Method B currently proposes two different methods to determine load distribution—one for non-modified gears and one for gears with optimum tip relief on one/both gears.

This begs the question: What is an optimum tip relief?

This is defined in the technical report with the "effective tip relief" C_{eff}. If the tip relief of the pinion C_{a1} is equal to C_{eff}, then the load distribution for optimal tip relief can be adopted; it is the same for the gear if C_{a2} is equal to C_{eff}. If the gears have a tip relief smaller than C_{eff}, the technical report recommends interpolation between the load distribution—with and without profile modification. This may change in the future, as many experts insist that load distribution equations for gears with profile modification can only be applied if the modification is "optimal." If not, the equations for non-modified gears must be adopted.

The upshot here is that non-modified gears can be calculated with method B, but not modified gears. For modified gears, the question is whether the modification is indeed optimal or not. As indicated later in this report, a study using method A to

Table 2—Torque T_1, line load F_{bb} and corresponding Hertzian pressure on FZG test rig [Fig. 2]

SKS number	Torque T_1 (Nm)	Line load F_{bb} (N/mm)	Hertzian pressure at the pinion at point A (N/mm^2)
5	70.0	63.3	764.0
6	98.9	89.1	906.4
7	132.5	119.0	1047.6
8	171.6	153.7	1191.0
9	215.6	192.7	1333.0
10	265.1	236.3	1476.2

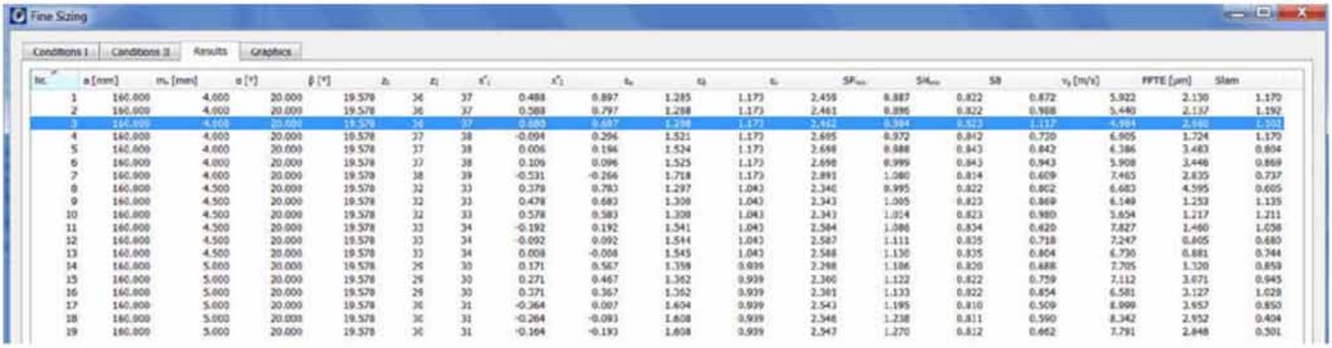


Figure 5—Result of the fine-sizing procedure, possible variants to gear Example U (corresponding to number 13 in the list, $S_\lambda = 0.744$); No. 3 shows best result for micropitting $S_\lambda = 1.302$; i.e., safety factor is increased by 75%.

find the best micropitting safety factor by varying C_a shows that the optimum C_a is not at all equivalent to C_{eff} (Figs. 7–8).

So, what is an optimum modification?

As profile modifications are considered crucial in anticipating the risk of micropitting, it can be a real problem for an engineer with no access to a tool using method A, as method B may not provide realistic results in such a situation.

Furthermore, profile crowning or long tip relief (not short tip reliefs as used for method B) yield better results in mitigating micropitting risk. This type of modification is not covered by method B.

Optimization of Micropitting Safeguards

How to optimize. Micropitting is most critical in areas of high pressure and high sliding velocity. Sliding velocity is always highest at the beginning and end of the meshing contact. Combined with high pressure in the same areas, micropitting risk is increased. In response, optimization of the macrogeometry (as module, tooth number, profile shift) intended to reduce the sliding velocities is a good strategy. Included in the *KISSsoft* calculation software (Ref.7) is a tool developed in 1987 for optimizing gear pairs and planetary stages (Ref. 8) called "fine-sizing-routine." Based on a user-defined range of parameters (module range, helix angle range, etc.), the software presents a large number of possible solutions covering the full parameter space and presents a list of calculated data (geometry, safety factors, characteristics such as sliding, losses, weight, transmission error); also included is the micropitting safety factor according to the user's choice of method B or A. As shown (Fig. 5), by keeping the center distance, face width and helix angle unchanged, and with reduction a ratio variation smaller than 0.5%, the safety factor against micropitting can be raised from 0.744 up to 1.302 simply through variation of module (from 4.0 to 5.0 mm) and the profile shift coefficient x_1. It should be noted that the best variant has the lowest sliding velocity of all variants.

Using Method A with contact analysis for every variant is clearly a large calculation task; total calculation time for these 19 variants was about 10 minutes. Note that doing the same using an FEA tool would require days.

It is quite possible to improve the safety factors even more if a wider range of module and/or pressure and helix angle is used. There are of course limits in what can be achieved, as when module or tooth number should or cannot be changed. In this case further optimization can be achieved with profile modifications.

Optimization of profile modifications. The risk of micropitting is highly influenced by profile and flank line modifications. A new extension in *KISSsoft* (Ref. 8) can evaluate the risk of micropitting for gears by automatically varying different combinations of tip reliefs, other profile modifications and flank line modifications in combination with different torque levels and using method A. The user can define the number of steps for variation of the amount of modification; for example: tip relief C_a from 30 to 70 µm in four steps; crowning value C_β from 10 to 40 µm (Fig. 6). Then all possible combinations $C_a = 30$ (with $C_\beta = 10$, 20, 30, 40), $C_a = 40$ (...), etc., are checked and combined with different (user-defined) torque levels. Any modifications including flank twist, arc-like profile modifications, etc., can be combined.

The result is presented in Figure 7, which displays the safety factor against micropitting (method A) for different subsets of profile/flank modifications, depending on torque level. Additionally, peak-to-peak transmission error, maximum Hertzian stress, wear, etc., are documented. This table is very helpful in showing the possibilities for reducing the micropitting risk with profile modifications and to find an optimum gear modification for different torque levels.

The effect of different variants of profile modification on the micropitting safety factor is obvious (Figs. 7–8). It is

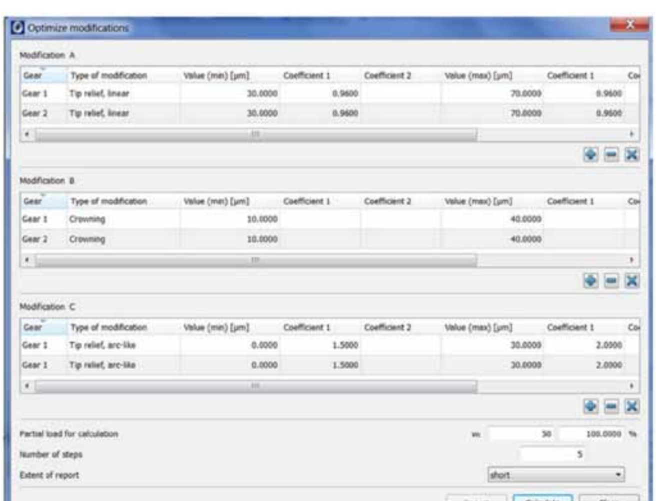


Figure 6—User interface for the optimization of profile modifications for best micropitting performance.

interesting to see that in these examples the highest safety factor S_λ is reached at a tip relief C_a, which is significantly lower than the optimum relief C_{eff}, as defined by ISO TR 14155. This is another indication that method B (based on C_{eff} for teeth with profile modifications) is of limited accuracy when using profile modifications. In the case of the spur gear (Fig. 9), a surprisingly small effect of the different modifications is found.

It is also noteworthy that profile crowning or long (linear or arc-like) profile modifications have normally higher safety factors than short profile modifications. Best results are obtained with profile crowning.

AGMA 925–A03

AGMA 925–A03 (Ref. 5) is an enhancement of ANSI/AGMA 2101–D04, Annex A. Various effects of gear surface distress are included, such as scuffing and wear, and micropitting and macropitting. Both methods use the Blok (Ref. 11) equation for the determination of the flash temperature. As not all factors used are exactly identical, the flash temperature (increased gear surface temperature in the contact) calculated following AGMA or ISO is slightly different (Fig. 10). The difference is due mostly to a different definition of the mean friction coefficient.

In AGMA 925 the micropitting calculation of the lubricant and specific lubricant film thickness is defined, but not a resulting safety factor. Although calculation of specific lubricant film thickness does not provide a direct method for assessing micropitting load capacity, it can provide an evaluation criterion when applied as part of a suitable, comparative procedure based on known gear performance. The calculation procedure for the local film thickness h_y (Eq. 4) ISO TR15144 and the line contact central film thickness in AGMA 925 h_c (Ref. 5) are both based on the same theory developed by Dowson (Refs. 6 and 10), with some factors slightly different. The main difference in ISO is the local sliding factor S that takes the flash temperature into account. AGMA typically uses the mean tooth temperature θM for local lubricant viscosity, while ISO uses the local contact temperature θB. The contact temperature is the sum of the mean tooth temperature plus the flash temperature. Therefore, in the meshing point C (where the flash temperature is zero), there is a smaller difference between AGMA and ISO, but in points with high flash temperature, AGMA calculates a much higher oil film thickness (Fig. 11; Ref. 7). It is known that the central film thickness is about 32% greater than the minimum film thickness; refer also to factor 1.316 in AGMA 925 (Ref. 5) that is used to obtain the risk assessment for wear. When we compared the two methods we found this approximate difference between the values in ISO and AGMA for the oil film thickness (Fig. 11).

Conclusions

The first edition of an international standard for micropitting—ISO TR 15144:2010—proposes a method for predicting potential micropitting. The concept and most important equations are explained. But method B, although relatively simple to apply, is of limited use for gears with profile modi-

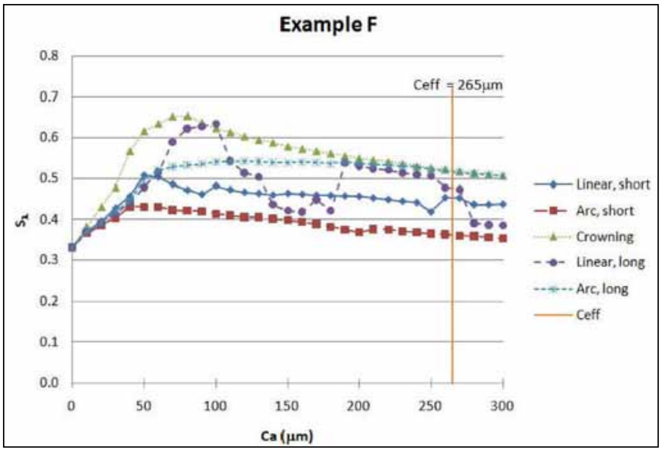


Figure 7—Effect of different tip relief C_a and profile modification type on micropitting safety factor S_λ, Example F (helical gear, m_n = 30 mm, ß = 9°, Z 19:76).

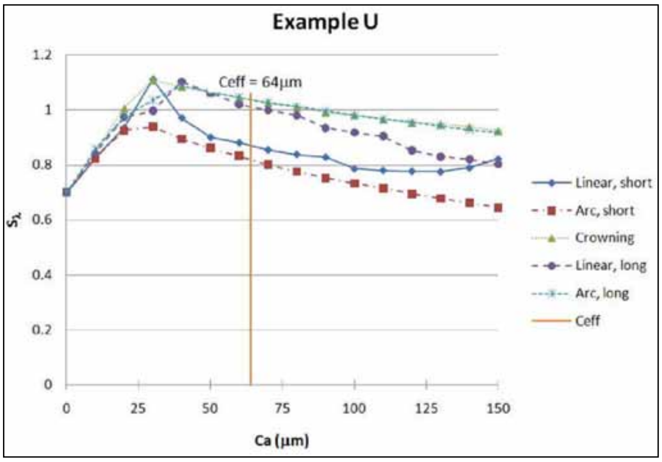


Figure 8—Effect of different tip relief C_a and profile modification type on micropitting safety factor S_λ, Example U (helical gear, module 4.5 mm, ß = 19.578°, Z 33:34).

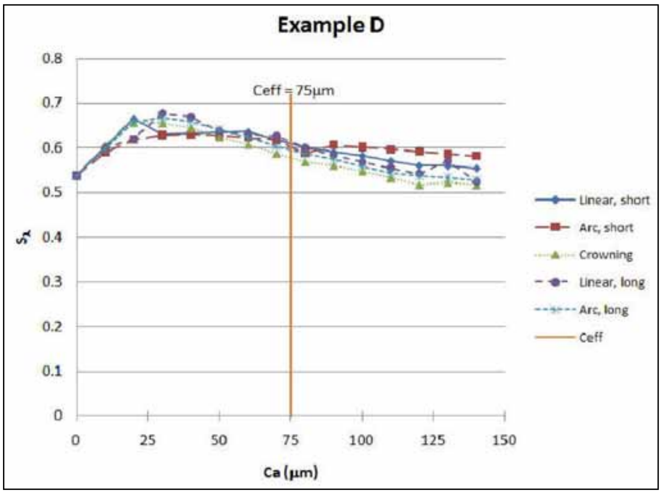


Figure 9—Effect of different tip relief C_a and profile modification type on micropitting safety factor S_λ, Example D (spur gear, module 10.93 mm, Z 18:18).

fications; for such gears method A must be used. Yet method A needs a software tool able to model the tooth contact to arrive at the local Hertzian pressure distribution—a complex task.

Mitigation of micropitting can be improved through macrogeometry optimization; the example presented here has shown that without changing the overall dimensions of the gear set, the micropitting safety factor can be improved significantly—by 100% and more. A generally used method in this regard is to use profile modifications. In some examples the effect of the variation of the tip relief and of the type of modification is shown. To simplify this optimization a new software tool was developed that automatically allows checking of many variants automatically. Profile crowning or long (linear or arc-like) profile modifications have normally higher safety factors than short profile modifications. Ergo, best results are obtained with profile crowning.

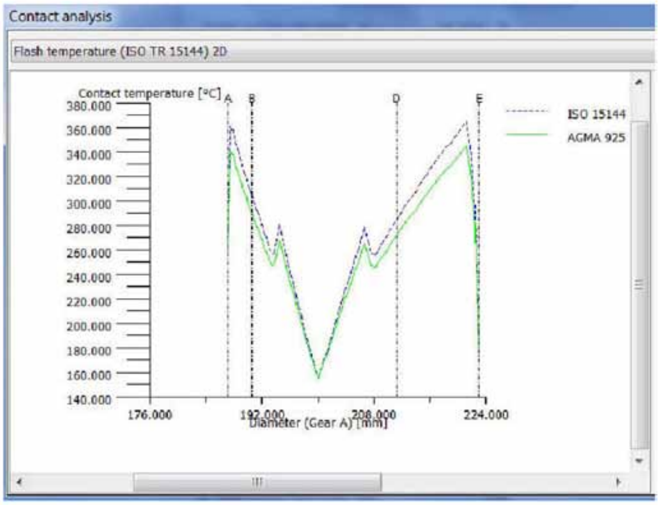


Figure 10—Calculation of the local tooth temperature according as ISO 15144 and AGMA 925; data used of Example D (spur gear, m_n = 10.93 mm, Z 18:18).

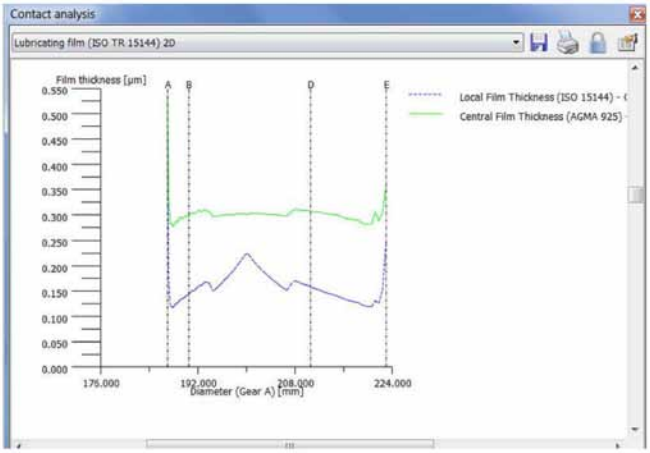


Figure 11—Calculation of the oil film thickness according as ISO 15144 (local film thickness) and AGMA 925 (central film thickness); data used Example D (spur gear, m_n = 10.93 mm, Z 18:18).

References

1. ISO TR 15144–1:2010: Calculation of Micropitting Load Capacity of Cylindrical Spur and Helical Gears.
2. FVA Information Sheet 54/7: Test Procedure for the Investigation of the Micropitting Capacity of Gear Lubricants, 1993.
3. ISO 21771:2007/Gears: Cylindrical Involute Gears and Gear Pairs—Concepts and Geometry.
4. Theissen, J. "Computation of Security against Grey-Spotting of Industrial Transmissions on the Basis of the New Computing Procedure FVA 259," DMK 2003.
5. AGMA 925–A03: Effect of Lubrication on Gear Surface Distress.
6. Dowson, D. and G.R. Higginson. *Elastohydrodynamic Lubrication—the Fundamentals of Roller and Gear Lubrication*, Pergamon Press (London), 1966.
7. Beermann, S. "KISSsoft Calculates Micropitting for the Wind Energy Sector," *Wind Energy System* magazine, October 2010.
8. *http://www.kisssoft.com*
9. Kissling, U. "Concept for the Efficient Interpretation and Optimization of Planetary Gears According to Different Criteria," VDI–Berichte No.1460; VDI–Verlag, Düsseldorf, 1999.
10. Dowson, D. and S. Toyoda. "A Central Film Thickness Formula for Elasto-Hydrodynamic Line Contacts," *Fifth Leeds–Lyon Symposium Proceedings*, Paper 11, 1978.
11. Blok, H. "Surface Temperatures under the Conditions of Greasing without Extreme Pressure," *Second World Petroleum Congress*, Paris, June 1937.

Dr. Ulrich Kissling *studied mechanical engineering at the Swiss Federal Institute of Zurich (ETH). His doctoral thesis, in collaboration with a leading Swiss textile machines company, was completed in 1980. From 1981–2001, he worked as a calculation engineer, technical director and then as managing director of Kissling Co., a Swiss gearbox company located in Zurich focusing on planetary, turbo and bevel-helical gearboxes for industrial applications and in the ski business. In 1998, he founded KISSsoft AG and acts as CEO. Dr. Kissling is chairman of the NK25 committee (gears) of the Swiss Standards Association (SNV) and voting member for Switzerland in the ISO TC 60 committee. He has published over 50 publications on calculation procedures for machine design and has been involved in numerous engineering projects ranging from micro plastic gears to large open gears.*

Longitudinal Tooth Contact Pattern Shift

J.B. Amendola, J.B. Amendola III and D. Yatzook

Management Summary

After a period of operation, high-speed turbo gears may exhibit a change in longitudinal tooth contact pattern, reducing full face width contact and thereby increasing risk of tooth distress due to the decreased loaded area of the teeth.

But this can be tricky—the phenomenon may or may not occur. Or, in some units the shift is more severe than others, with documented cases in which shifting occurred after as little as 16,000 hours of operation. In other cases, there is no evidence of any change for units in operation for more than 170,000 hours.

This condition exists primarily in helical gears. All recorded observations here have been with case-carburized and ground gear sets.

This presentation describes phenomena observed in a limited sampling of the countless high-speed gear units in field operation. While the authors found no existing literature describing this behavior, further investigation suggests a possible cause. Left unchecked and without corrective action, this occurrence may result in tooth breakage.

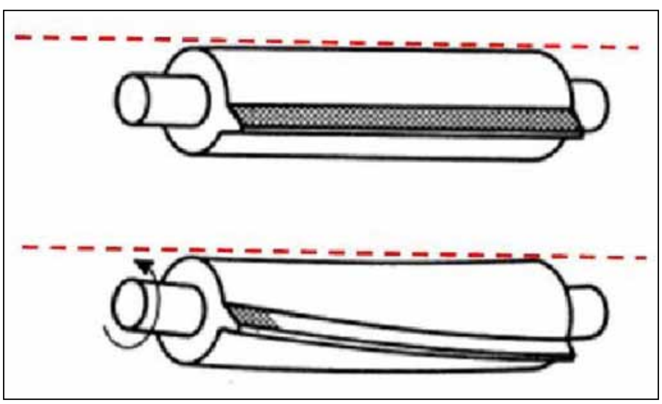


Figure 1—Tooth contact patterns of a spur-toothed pinion without longitudinal correction at rest (top) and with load (bottom) applied.

Introduction

Field inspection of high-speed turbo gears after an undefined period of operation may detect a change in the mating contact pattern of the gear mesh.

This has been observed on gear rotors with the following characteristics:

- Case-carburized and ground gear elements
- Relatively large face widths (greater than 300 mm)
- Pitch-line velocities greater than 100 m/s
- Modified leads accounting for both mechanical deflections and thermal deformation
- Operating hours with as little as 16,000 hrs to as much as 170,000 hrs

Lead Corrections for High-Speed Gear Sets

Every gear set is subject to torque, resulting in elastic deflection of the gear tooth parts as well as the entire rotor body. Individual teeth bend, while pinion and wheel bodies twist, bend and expand under the effect of the torque, load and centrifugal forces (Fig. 1).

For high-speed gear sets, the mechanical deflections described herein are compounded with additional factors that result in further deformation of the gear teeth, i.e.:

A churning of the lube oil and frictional losses in the bearings cause the rotor bodies to overheat and consequently expand.

The pumping action of the oil and air entering the gear mesh produces an increased asymmetrical temperature gradient of the gear tooth along the length of the tooth flank, resulting in added deformation.

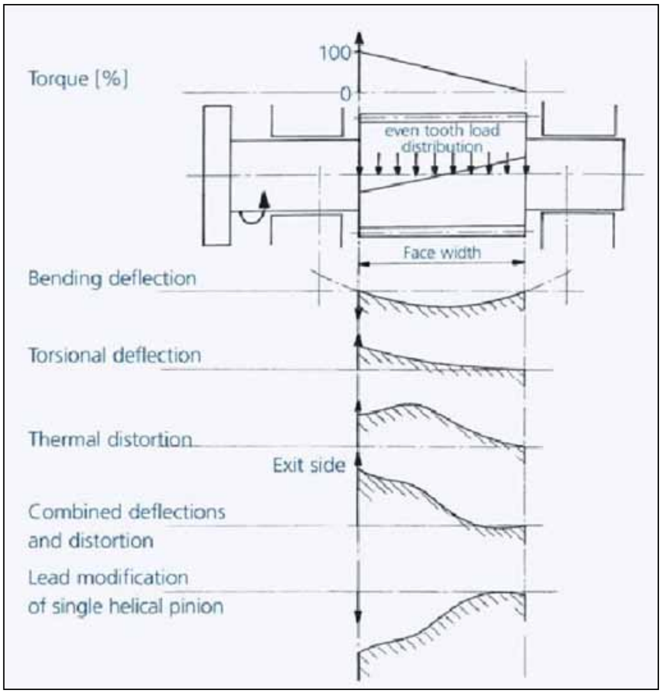


Figure 2—Schematic of single-helical tooth deflection with added parameter for thermal deformation and the associated lead correction.

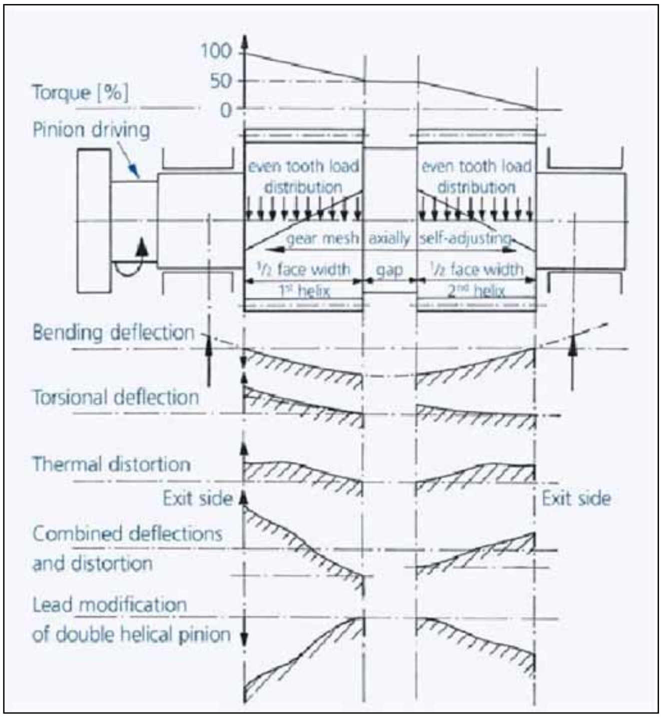


Figure 3—Schematic of double-helical tooth deflection with added parameter for thermal deformation and the associated lead correction.

Special consideration must therefore be given to compensate for these mechanical deflections and thermal distortions so that the load across the gear face is uniformly distributed under normal operating conditions.

Tooth modification for gear sets with pitch-line velocities greater than 100 m/s require careful awareness of thermal distortion. The resulting thermal deformation, in addition to the mechanical deflections, requires a composite profile and longitudinal modification to achieve proper load distribution under operating conditions (Figs. 2–3).

Investigations by Martinaglia (Ref. 9) were performed to accurately determine temperature conditions in a high-speed pinion (Fig. 4).

The dimensional parameters of the rotor configuration define how the lead is modified; its derivation is specific for a continuous, single- or double-helix. Therefore this dimension is largely dependent on the experience gained by years of observation of tooth-bearing patterns at nominal loads, in turn leading to accumulated, empirical values.

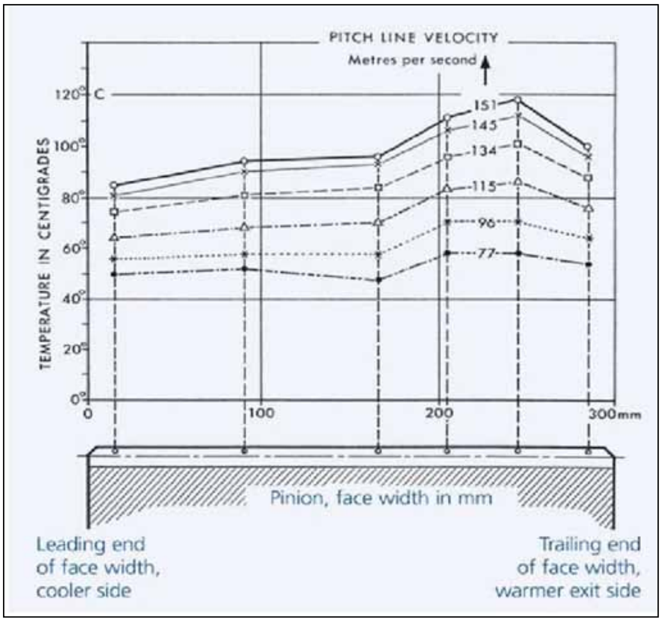


Figure 4—Effect of pitch-line velocity on tooth flank temperature and establishment of an asymmetrical speed/temperature gradient.

Early Observations

Evidence of a longitudinal tooth contact shift was first observed by Artec Machine Systems in the early 1990s. When first observed, it was thought to have resulted from changes in the foundation or other external influences of the gear unit inducing a small misalignment in the mesh. However, subsequent experience revealed a curious shift of the contact pattern. Since this observation did not consistently manifest itself when inspecting other installations, the cause of the phenomenon remained questionable for a num-

Figure 5—Varnish deposits on gear teeth.

ber of years. When a contact shift *was* observed, oftentimes heavy varnishing of the lubricant on the gear teeth in the vicinity of the contact face was noted in the area of the highest temperature gradient (Fig. 5).

This is also the area where the deepest correction is required (Fig. 6). The phenomena had been observed in both gear sets where the thermal corrections were nearly negligible, as well as in units with significant thermal corrections.

Phenomena

In all cases upon inspection, the contact pattern on both the loaded and non-loaded flank exhibited a contact shift deviating from the originally designed tooth contact pattern. In some units the contact shift is more severe than others. If left unattended this contact shift of the intended-design contact pattern may progress, resulting in ever-increasing, locally high-loaded segments of the rotor flanks that may eventually result in gear failure.

***Case study—example of installation verifying longitudinal contact shift*:**

Application: Driving: gas turbine (4,670 rpm)
Driven: centrifugal compressor (2,926.5 rpm)

c–c	center distance	= 580 mm (22.853 in)
B	face width	= 500 mm (19.764 in)
β	helix angle	= 10° (single-helical)
α	pressure angle	= 20°
--	rotor material	= carburizing alloy steel
P	power	= 37,285 kW (50,000 hp)
PLV	pitch-line velocity	= 109 m/s
m	module	= 9.25

Field Observations: Inspection After 12 Years and 105,000 Hours of Continuous Operation

Dynamic: After 105,000 hours the gear set showed no signs of tooth surface distress—i.e., scuffing, micropitting—and virtually no signs of pitting (a few pits were found on the dedendum of the pinion). Varnishing (on both pinion and wheel) was noted to be heaviest in the flank section with the deepest lead correction. However under observation it was readily noted that the "dynamic" load clearly favored the turbine end, and little or no load appeared to have been transmitted over the first ~150 mm of tooth face nearest the compressor end.

Static: The tooth contact pattern of the old rotors prior to removal was found to be in very poor condition and not in accordance with the original manufacturer's protocol. The tooth contact was found to be heavy in the central-left portion of the tooth flank in a centralized area 100–175 mm from the pinion drive-end of the flank. In this region, contact was found to be symmetrical to the pitch line—as in distributed evenly along the profile—with equal load-sharing along the addendum and dedendum.

Attempt to Correct in the Field

In this case the unloaded static tooth contact pattern of the drive flank was originally designed to be at the (NDE) compressor side of the mesh. After 12 years of continuous operation, this static pattern shifted toward the (DE) gas turbine side. Subsequently, the non-loaded tooth flank (originally designed with an unmodified straight contact pattern) shifted toward the (NDE) compressor side.

An attempt was made in the field to correct the no-load static tooth contact by shifting the static contact toward the NDE of the pinion. Only a fractional improvement was realized—even with a relatively large adjustment. Improved contact was possible only if the longitudinal correction was no longer in accordance with the original specification. This had confirmed that the tooth form had become distorted with time.

On this basis a decision was made to replace the rotor set with an unused, spare set of rotors. The new rotors were installed and the no-load tooth contact was recorded and confirmed to be according to the original-configured protocol. An operational check of the new spare rotors (dynamic tooth contact) via inspection revealed full-load tooth contact after the operation reached steady-state conditions. The observed contact was 100% consistent across the entire tooth flank.

Confirmation of Hypothesis

The old pinion and gear removed from service were placed on a lead- and profile-checking machine to determine the as-found lead and profile measurements. Figure 6 describes the original corrective values as made on the gear set-loaded tooth flanks prior to operation. Figure 7 describes the as-found, loaded-tooth-flank-measured values. Comparison of these figures demonstrates tooth flank expansion that shifted the original no-load, static contact pattern and provided obvious evidence of permanent deformation of the gear teeth.

Permanent deformation was also evident on the non-loaded tooth flanks (back side). Figures 8 and 9 provide a comparison of each rotor's non-loaded tooth flanks showing the amount of change that took place for both the pinion and wheel.

The expansion is remarkable insofar as it has a magnitude of nearly 75% of the amount of the design lead modification.

Theory as to Cause

During gear unit operation, there is a high-velocity axial flow of lube, oil and air across the helix (or helices) of the mesh. Through mesh engagement, oil and air are mixed and compressed, resulting in an asymmetrical (uneven) tooth flank temperature gradient (Fig. 4).

In the case study, highly localized temperatures had reached levels that caused a metallurgical transformation by which entrained austenite was transformed to martensite. This transformation resulted in an expansion of the case material, thereby affecting the tooth thickness, which in turn resulted in a contact pattern change on both the loaded and non-loaded flanks. The mechanism of expansion is due to the density difference between austenite and martensite. As noted in Figure 9, this expansion does not occur in a uniform manner since the temperature rise from the meshing action is asymmetrical over the tooth length.

Citing (D.W.) Dudley's *Handbook of Practical Gear Design*: "After quenching, steels are usually tempered or stress-relieved. The tempering operation may be used to reduce the hardness of a part and increase the toughness. By

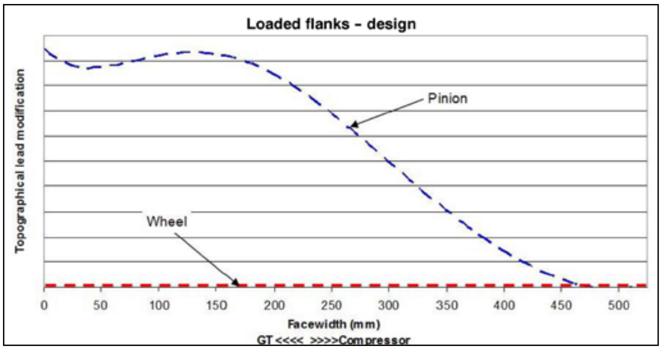


Figure 6—Original tooth modification plan (ordinate values intentionally omitted for proprietary reasons).

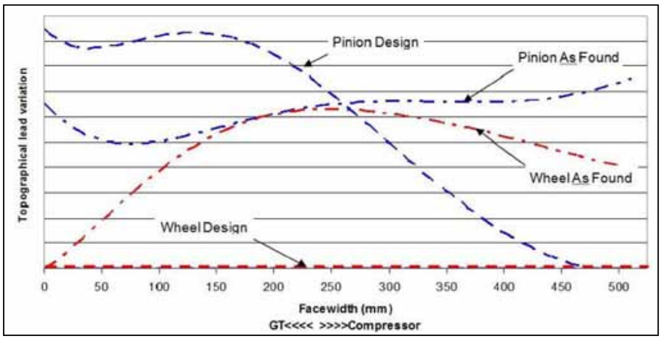


Figure 7—Loaded flank: design and as-found (ordinate values intentionally omitted for proprietary reasons).

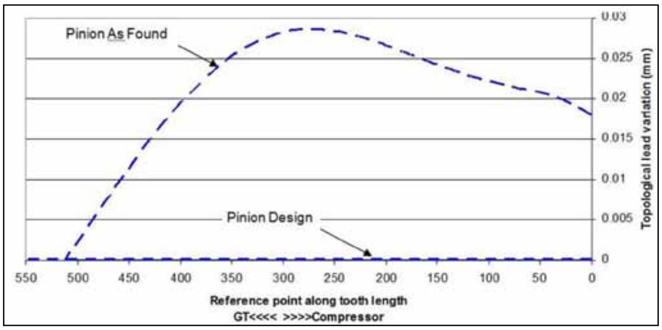


Figure 8—Pinion unloaded flank: design versus as-found.

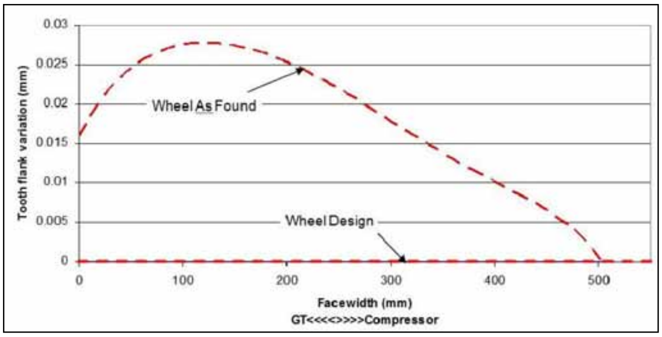


Figure 9—Wheel unloaded flank: design versus actual.

properly adjusting the tempering temperature, hardness values can be obtained over a wide range. Even when no reduction in hardness is desired a low-temperature (250–350 °F) tempering operation is desirable to reduce stresses in the steel and produce a kind of martensite that is tougher than the kind produced immediately upon quenching."

This temperature range may be achievable in the operational environment of some running gear units.

Load conditions, partial loads vs. full load, tooth module and the level of operating stress numbers relative to gear tooth design may also have contributing influences. An improper design lead correction, manufacturing errors, an improperly set up gear tooth contact pattern during the original installation or changes due to uneven bearing wear or soft foot may also contribute to the described phenomena.

Considering the successful length of service in the noted example, it can be determined with certainty that the gear set was furnished with an optimized lead and, at the outset of service, the unit operated with uniform contact across the entire full face width of the teeth. As service time was accumulated, a segment of the tooth flank increased in temperature and reached the tempering temperature range. This most likely was the result of accumulated varnish staining of the gear teeth. Transformation occurred slowly at first and then increased at a faster rate, reducing flank contact over time. The appearance of significant varnishing of the gear teeth was the cause of this rise in tooth temperature.

Varnishing does two bad things. Varnish is an insulator on the gear teeth, thereby reducing the efficiency of the lube oil to cool them. As the varnish builds up, a worsening condition develops. As a result, the gear teeth will become hotter, thereby encouraging tempering of the gear teeth in that regime of the flank.

Varnishing increases the frictional effects of the compressed lube oil and air as they travel longitudinally across the flank, thereby adding additional heat to the tooth flanks.

Regardless of the means of entrainment, the action that leads to varnishing is in place. From here, the failure can proceed with adiabatic compression in the load zone of a lubrication system. Diabatic compression occurs when air bubbles travel from low pressure to high pressure. The air bubble compresses rapidly (implosion), resulting in intense entrapment of the heat and an extreme rise in temperature.

In this example, during the earlier years of service prior to the slow-developing tooth varnishing, the maximum temperature along the tooth length was most likely below the tempering temperature range. As varnish began to deposit on the gear teeth, the temperature gradient increased and gradually entered the tempering temperature range, thus beginning the process of transforming retained austenite to martensite and its attendant expansion. What was ultimately discovered was that the result of what may have occurred over a period of operation was not consistent in a linear sense with the running life of the gear set. In fact, the major transformation period likely started quite some time after the start of service and then changed rapidly— most likely in the last few years of service. So while there had not been a failure, evidence of surface distress was beginning to develop; the small pitting located on the dedendum of the pinion indicated a failure may have been imminent and was caught in time. Inspection of the rotors revealed an increase in surface hardness of 3–4 Rc (original 58–59 Rc, now 61–62 Rc) as measured at various points on several gear teeth. This is the result of un-tempered martensite transformed from retained austenite. While the transformed surface is harder than the earlier starting condition, it could not possibly sustain the load over such a narrow portion of the face for very much longer. Considering the locally high loads, no additional surface distress was observed, such as more pitting or scuffing. We attributed this to the improved surface condition over running time.

It was reported to us that a small increase in hardness has been observed on many high-speed gear sets inspected after years of running without any measured shift in the contact pattern (hence no expansion of the gear set teeth). We conclude such gears were at the early stages of transformation and/or the retained austenite was less than the reported case study.

It has been observed that even with properly applied design corrections (i.e., correctly designed and manufactured tooth lead, as well as proper alignment in the field) that result in more uniform and distributed longitudinal load, it is not enough to assure this phenomenon can be avoided. From all indications, it would appear this application had an effective lead correction based on the dynamic tooth contact check after commissioning. It is believed that this gear did not varnish or temper for some time, considering the number of load cycles (operating hours). Rather, the high-temperature gradient segment of the gear tooth inclined to reach the highest operating temperatures was mostly responsible for inducing the highest stress on the lube oil film. This in turn began the varnish deposit on the gear flanks, inducing the material transformation.

Solutions Based on Presented Theory

Consideration is given as follows:

Provide sufficient lubrication for mesh cooling, as this is essential to avoid the tempering effect.

Utilize lube oil with a high resistance against oxidizing under load and, if possible, change routinely (every 25,000 hours).

Install improved filtration systems that reduce or even eliminate varnish deposits. Electrostatic filtration is reputedly a method for treating the problem. With oils of relatively low viscosities, a considerable amount of the sub-micron resinous material can be stripped out of the oil using charged particle separators. Also known as electrostatic filters or precipitators, these units separate carbon and oxidized particles by field-induced electromechanical forces (charges) on polar carbon and oxide insolubles. The charged suspensions precipitate to the collection media or plates of the opposite charge, to which they adhere tightly.

Avoid too much retained austenite in the rotors in heat treat at the time of manufacture; there is a diminishing set of returns in transformation of austenite to martensite. Rotors with 30% retained austenite should be re-tempered. Sufficient iterations of tempering may be required. While care is needed to avoid too much loss in hardness, cold treatment may provide a suitable method after temper and quenching.

Some retained austenite is desirable for good gearing. A recommended target of maximum 20% is advised to minimize the transformation effects during operation. With routine inspections, small amounts of operational transformation can be addressed in the field by small adjustments in the tooth contact. (*Authors' note*: *Many of the gear units inspected with high operational hours but without evidence of tooth pattern creep are credited with gear rotors where retrained austenite had been properly controlled to lower percent levels*. *This document reports longitudinal tooth contact pattern shift of high-speed gears caused by an asymmetrical expansion of the rotor teeth width. It reports the mechanical consequences of such phenomena and measures that if implemented may prevent the phenomena. It is not a metallurgical report and therefore does not explain how to effectively limit the amount of retained austenite in carburized rotor forgings*.)

Deepen the lead correction in the region of the highest temperature gradient, particularly for wide face width gears and gears with high PLVs (pitch-line velocities). While this may not be the optimum lead correction, it eases the stress on the lube oil film as it is squeezed through the mesh in the hottest section of the flank, thereby reducing the tendency of varnished particles adhering to the gear teeth in that regime. It will not, however, appreciably change the heat gradient or shift the hot section. For existing gear sets in operation where the tooth expansion has occurred and regrinding is possible, it is reported a deeper correction may benefit potential, continued expansion of the gear set rotor over time. Added life expectancy, rotor condition and operating environment need to be evaluated in determining corrective action.

Super-finishing reputedly can significantly reduce the quenching losses in the mesh by reducing the coefficient of friction along the line of contact. In the convergent zone ahead of the contact area, the sliding component wipes the lubricant sideways over the tooth flanks as the lube oil rapidly travels longitudinally across the tooth flanks.

Encourage periodic shutdown inspections, allowing the gear teeth to be cleaned of any varnish deposits according to the manufacturer's recommendations.

References

1. Amendola, J.B. "Defeating Tooth Flank Deformation," *Gear Solutions*, June 2006.
2. Amendola, J.B. "Lead Correction Derivation Method for High-Capacity Turbo-Gears with High-Pitch Line Velocities for Both Single- and Double-Helical Gears," March 2008.
3. Amendola, J.B. III. Field Service Report, August 31, 2010, Unpublished.
4. Dudley, D.W. *Handbook of Practical Gear Design,* CRC Press, 1994, Sect. 4.10–4.11.
5. Pirro, D.M. and A.A. Wessol. *Lubrication Fundamentals,* Marcel Dekker, 2nd Edition, 2001, pp. 211–216.
6. Fitch, J. "Using Oil Analysis to Control Varnish and Sludge," *Machinery Lubrication*, 2010.
7. MAAG. *MAAG Gear Book*, January, 1990, pp. 185–186.
8. MAAG. Tooth Flank Modifications, 1000.09.03.
9. Martinaglia, L. "Thermal Behavior of High-Speed Gears and Tooth Corrections for Such Gears," October 1972, *AGMA FTM*, San Francisco, CA.
10. Swiglo, A. "Principal Associated with Size Changes in Carburized Steel," Artec Machine Systems, January 12, 2011, Unpublished.

John B. Amendola *holds a 1964 Bachelor Mechanical Engineering degree from Villanova University and a Master Degree from Brooklyn Polytechnic in 1971. He founded Artec in 1972 and held a long relationship with MAAG Gear until their closing. Amendola is active on the AGMA TDEC, serves on AGMA technical committees and is chairman of the HS Committee.*

John B. Amendola III, P.E., *received his Bachelor Marine Engineering degree in 1982 from the Maine Maritime Academy. He served in the U.S. Navy for four years in Europe and the Atlantic fleet before working in merchant shipping—SUNY Maritime, on board the Empire State—and then joining MAAG Gear AG Zurich. Amendola joined Artec in 1993. He is a commander in the USN Active Reserve and is an active AGMA technical committee member.*

Dereck Yatzook *received his Bachelor of Science Mechanical Engineering degree in 2004 from the University of New Haven. He joined Artec in 2002 as an apprentice and gained full employment there in 2004. Yatzook is an active AGMA technical committee member.*

In Memoriam

RICHARD E. BREIDENSTEIN (1935–2012)

Dennis Richmond, vice president at Reishauer, recently commented on the passing of Richard E. Breidenstein: "The gear manufacturing community is deeply saddened with the recent passing of Richard E. Breidenstein, one of the industry's pioneers in gear manufacturing and technology application.Breidenstein lost his fight with his CHF illness on Saturday, March 10, 2012. Those who knew Breidenstein understood his passion for dancing, playing the accordion, traveling, golfing, playing with his cat Mandy and enjoying his family. Some of his happiest and fulfilling moments were playing with his 10 grandchildren.He got his start in the gear industry just out of high school in 1953 as an apprentice for Oliver Gear in Buffalo, New York. His first assignment was cutting gears on a hobbing machine. Oliver thought so much of Dick that they encouraged him to seek additional education to advance his skills; they even paid for his tuition. After earning his degree in Tool Design from Erie County Technical Institute in 1961, he was promoted to estimator for Oliver Gear. He worked at Oliver gear until 1971. After that he moved to the Chicago area to take a position with Illinois Gear. Later in 1977 he opened his own shop: Geometric Machine in Bensenville, Illinois. Unfortunately, due to poor economic conditions, he was forced to close the doors in 1981. He then went to work for Chicago Gear as a manager of production. In 1985 when the desire to be his own boss again was overwhelming, he formed the company Rebco Industrial Products."

Richard E. Breidenstein

He is survived by his loving wife of 57 years, three daughters, Michelle (Michael) Klave of Pahrump, Nev., Denise Beaudoin of Marengo and Rene (Kevin) Wolke of Crystal Lake; three sisters, Betty (Perry) Erhard of Concord, N.C., Ruth (Louis) Pondolfi of Depew, N.Y., and Barbara (John) Marillo of Concord, N.C.; his grandchildren, Melissa, Mary and Mason Klave, Matthew, Eric and Jessica Beaudoin, and Christopher, Malerie, Andrew and Daniel Wolke; and numerous nieces, nephews and cousins. He was preceded in death by his parents, Henry and Charlotte; and a sister, Joyce (Frank) Sette.

"Over the decades, he was able to use his vast knowledge of the industry along with his numerous contacts to build a successful business in the gear industry selling new and used gear cutting tools. We salute his achievements," Richmond says.

Condolences can be made to his wife Beverly Breidenstein at 12355 Laurel Lane, Huntley, Illinois 60142.

AGMA Awards Key Members at Annual Meeting

The American Gear Manufacturers Association recently announced that Bipin and Linda Doshi, of Schafer Gear Works, Inc. have been named the recipients of the AGMA Lifetime Achievement Award. This award is bestowed "to the rare individual or individuals who have demonstrated superior vision, leadership and dedication in advancing the gear industry and the American Gear Manufacturers Association." This is only the seventh time that the award has been presented in the Association's 96 year history.

Bipin and Linda Doshi, of Schafer Gear Works, Inc. were recipients of the AGMA Lifetime Achievement Award.

Presenting the award in Bonita Springs, Florida, AGMA chairman Matt Mondek commented, "Leadership is the lifeblood of an association like AGMA, and everyone should aspire to be like the couple that receives the AGMA Lifetime Achievement Awards tonight. Bipin and Linda Doshi have independently and together been major contributors to AGMA's transformation and growth over the last quarter century."

Schafer Gear joined AGMA in 1943 and was acquired by the Doshis in 1988. Immediately after the acquisition, Bipin, president of Schafer Gear and Linda, corporate secretary of Schafer Gear, began participating in AGMA's Annual Meeting, Marketing Council, Small Business Council and others.

In the early 1990s Bipin and two other members were leaders in the creation of the Training School for Gear Manufacturing. This one-week course blends theory with hands-on experience at the Daley College in Chicago. This course has been responsible for introducing hundreds of employees to the theory of gearing and has helped each one apply that knowledge by making a gear during the hands-on portion of the training. He received the Administrative Division Executive Committee Award in 1994 for his leadership in education programs.

In 1994, Bipin joined the AGMA Board of Directors and served as chairman of the association from 1999 to 2000. In that role, in addition to his advocacy for improving AGMA's education offerings, he helped create useful statistical reports for benchmarking gear companies against the rest of the industry. Subsequently, Bipin has served as a trustee to the AGMA Foundation and currently serves as the foundation's treasurer.

While Bipin has been very active in AGMA, Linda has been just as active in the industry and with the AGMA Foundation. She served two terms on the AGMA Foundation's Board of Trustees, from 1997 to 2004. She was elected chair of the foundation from 2002 to 2004. Under her leadership, the foundation sponsored the development of the three online courses for worker training. These courses are still used a decade later as the introduction for many to the gearing industry.

In their personal lives they are both highly involved in their local community in South Bend, Indiana, chairing several boards of philanthropic organizations. Linda is the past president of the Center for History; a past board member of the Penn Harris Madison school foundation board; a current board member of the South Bend Century center; a board member of the South Bend Community Foundation and a board member of the Mishawaka public library.

Bipin is a board member for the local South Bend Memorial Hospital; He served as chairman of the board in 2006 and 2007. He continues to serve on the board and has chaired several committees. Bipin is also is very active with his alma mater, the Missouri University of Science and Technology (formerly Missouri School of Mines and Metallurgy).

Two additional AGMA leaders were honored during AGMA's 2012 Annual Meeting, held March 15–17 in Bonita Springs, Florida. Sulaiman Jamal, managing director of Bevel Gears India was awarded the AGMA Chairman's Award; and Rustin Mikel, vice president of operations for Forest City Gear, was awarded the Next Generation Award.

CHAIRMAN'S AWARD

Earlier in February 2012, AGMA held a trade delegation to India. The group of 18 individuals traveled about 2,000 miles in five days - visiting seven cities, seven companies and one coffee plantation. According to AGMA executives, this trip would not have been possible without the help of Jamal. He is a member of the AGMA board of directors and one of the reasons AGMA has more members in India than any country outside of North America. He was instrumental in the creation of the International Power Transmission Exposition which opened in Mumbai two years ago and was held again this February. He was part of the advisory group that developed the program for AGMA's first International Business Conference. To recognize his leadership and hands-on assistance with AGMA's activities internationally and especially in India, he was presented with the Chairman's Award.

NEXT GENERATION AWARD

In the six short years since Mikel has joined the gear industry and Forest City Gear, he has become very active within AGMA as a leader of both the Strategic Resources Network and the Annual Meeting Planning Committee. He has demonstrated significant leadership skills guiding the members of the Annual Meeting Planning Committee over the last three years. He has kept the group on target and engaged as they brainstorm ideas for speakers and events for the Annual Meetings, and also worked with the staff of AGMA and ABMA to execute the committee's ideas. He has taken time away from his young family, copious duties at Forest City Gear, and his studies for his MBA to guarantee the success of the combined annual meeting the last few years.

In addition to his duties as Annual Committee Chair, he was instrumental in the formation of AGMA's Strategic Resources Network, a group of younger industry executives who promote professional development opportunities and networking within the gear industry. And for this Annual Meeting he married his involvement with the SRN with his duties as Annual Meeting chairman, gathering a dozen of his SRN colleagues together to help sponsor the Capitol Steps. Mikel was assisted in this effort by last year's Next Generation Award winner, Cory Sanderson from Koepfer America. He has been a willing participant in many other AGMA endeavors. For more information, visit *www.agma.org*.

Stadtfeld

RELEASES GLEASON BEVEL GEAR TECHNOLOGY

Gleason Bevel Gear Technology (Expert Verlag; ISBN: 978–3–8169–2983–3; 500 pp.), by Dr. Hermann J. Stadtfeld, vice-president/bevel gear technology–R&D at Gleason, is now available in bookstores (The English version will be available at the end of the year). *Gear Technology* readers, with Dr. Stadtfeld's and Gleason Corp.'s kind permission, were privy to advance access to the work in an eight-part serialization that took place from August 2010 to August 2011. The book discusses the various tribology aspects of angular gear drives including cylindrical, conical, bevel, crossed helical, worm, hypoid gears and more. Dr. Stadtfeld has published more than 300 technical papers and several books on bevel gear technology. He holds more than 50 international patents on gear design and gear process, as well as tools and machines.

Schafer Gear Welcomes Basham and Miller

Jeffery Basham

Jeffery Basham has joined Schafer Gear Works, Inc., as advanced manufacturing engineer in the company's South Bend office. Basham will be responsible for all advanced planning of new parts, including CNC programming, tooling design and application of the latest technologies in cutting tools and machine tools. Basham has over 18 years of experience in manufacturing. Prior to joining Schafer Gear, he worked as a machining manager and programming engineer. In making the announcement, Paresh Shah, Schafer Gear's vice president of engineering and business development, said, "We are excited to have Jeff join our team. With his expertise, he will be able to oversee all new parts throughout Schafer's production process and smoothly implement cutting-edge technology."

Additionally, Rodney Miller has joined Schafer Gear Works, Inc. as manufacturing engineer in the company's South Bend office. Miller will be responsible for engineering support for all gear manufacturing processes. Prior to joining Schafer Gear, Miller worked as a manufacturing engineer at B&J Medical in Kendallville, Indiana. He also has extensive experience in manufacturing/design and CNC programming in automotive devices as well as in the recreational vehicle industry. Miller has an associate's degree in industrial manufacturing from Indiana Tech. In making the announcement, Schafer's production manager, Dennis Sharp, said, "Rodney brings a strong manufacturing background to Schafer Gear and will be a valuable asset in providing engineering support and process improvement for our shop floor."

Rodney Miller

NTN Develops Technology for Powder Metal Gears

NTN Corporation has developed a manufacturing technology for sintered alloy, capable of manufacturing alloy with an absolute density ratio of 95 percent or higher, and endurance strength of 300 MPa or higher (maximum stress 700 MPa). This allows drivetrain components such as gears that require precision and durability, which had been manufactured with cutting processes until now, to be replaced with sintered alloy.

The powder-metallurgy process is one manufacturing method that is available to reduce waste of materials and energy consumption while manufacturing mechanical components as a means of addressing recent environmental and energy issues. Yet as this process involves compressing metal powder together, micropores can easily develop inside the components, resulting in a decrease in fatigue characteristics compared to components manufactured using cutting process of solid metals. The use of sintered alloys in drivetrain components that require excellent fatigue characteristics had been limited due to this reason.

NTN has made improvements to the powder material and forming and sintering conditions to manufacture high-density sintered compact with an absolute density of ratio 95 percent or higher, using a relatively low casting pressure of 6 to 10 ton/cm^2. The combination with NTN's proprietary heat treatment technology results in an endurance strength of 300 MPa or higher under single press, single sintering process. When used for gears, this high endurance strength results in 2 GPa or higher strength (1.5-times conventional products) at the tooth surface, as well as better durability at the base of the tooth. Different combinations of technologies such as metal powder, forming and heat treatment allow high-precision, high-density sintered alloy to be manufactured with a much easier process, making use of the alloy in drivetrain components and other applications.

NTN will coordinate with group company Nippon Kagaku Yakin Co., Ltd. into the future to accelerate the development of products using sintered alloy, as well as the research and development of stronger, higher precision sintered alloy or composite materials. These developments will be used to improve yield, shorten processing times and reduce energy consumption, and applied to the entire product lifecycle in areas such as materials, manufacturing and functionality to help reduce the impact on the environment.

Mazak Announces Midwest Open House

As part of its ongoing commitment to American manufacturing, Mazak will host a special three-day Discover More with Mazak open house at its Midwest Technology Center in Schaumburg, Illinois. Slated for June 26–28, the event will highlight the facility's recent 18,000-square-foot expansion, cutting demonstrations on the latest productivity-improving machine tools and industry expert presentations. Mazak will also offer a sneak peek of its plans for IMTS 2012 and the expansion of its Kentucky manufacturing operations.

The Midwest Technology Center expansion allows Mazak to further support the continuous upswing of manufacturing business throughout the region as well as provide its customers with even more advanced technology, support and training for increasing their competitiveness. The expansion also offers an increased opportunity for collaboration with local manufacturers with respect to new technology and process development and improvement.

"The vibrant manufacturing market and our long-term commitment to our customers in the Midwest convinced us to accelerate our expansion plans for our Technology Center in Illinois," said Brian Papke, president of Mazak Corporation. "Business across all industry segments, including automotive, aerospace, medical and energy, is improving in the Midwest and nationwide. The expansion of our Midwest Headquarters and Technology Center gives manufacturers more resources to improve their productivity."

The Midwest Technology Center's new 124-seat auditorium and two state-of-the-art training rooms give Mazak the means to host more events with its VIP technology partners. In fact, an incredibly diverse array of no-charge classes and seminars will ensure customers achieve a maximum return on their machine tool investments and achieve greater effectiveness in meeting their customers' needs.

Visitors to the expanded Midwest Technology Center will also find spacious areas for turnkey projects and test cuts, as well as expanded machine tool technology demonstration facilities. Such additions give Mazak customers even more opportunity to process actual industry components from various materials, including polymers, steels, aluminum and high temperature alloys, using the latest machine tool technology.

For more information, visit *www.mazak.com.*

June 3-6—Windpower 2012. Georgia World Congress Center, Atlanta. Sponsored by the American Wind Energy Association (AWEA), Windpower 2012 offers various ways to gain knowledge, exposure and value to all the wind energy segments. This is the largest annual wind-focused exhibition in the world, featuring more than 1,000 exhibitors. It is the place to see products and services, learn industry brand names, network with leading industry decision makers, and generate numerous high-quality business leads. The conference program features more than 50 educational sessions with topics on community wind, supply chain, development in a seasoned market, state and regional policies and more. Entrepreneur and philanthropist Ted Turner returns to Windpower 2012 to deliver opening remarks. New to the 2012 exhibition is the Windpower Industry Essentials program. These hybrid educational/networking opportunities provide information on the global wind market, operations and maintenance and manufacturing and the supply chain. For more information, visit *www.windpowerexpo.org*.

June 4-6—Hexagon 2012. Las Vegas. This international conference from Hexagon Metrology offers the chance to preview technologies, attend presentations by industry experts, participate in targeted tracks, break-out sessions and hands-on training and hear inspiring keynotes from today's thought leaders. Hexagon 2012 will ignite your imagination with creative solutions to your business challenges. Attendees will experience technology previews, customer testimonials, hands-on training including technical demonstrations and workshops, one-on-one guidance from industry experts, panel discussion and keynote presentations. The Hexagon TechExpo will provide a one-stop shop to see the latest products, solutions and sponsor exhibits while networking with industry peers. For more information, visit *www.hexagonconference.com*.

June 10-13—PowderMet2012. Nashville. This 100-booth international marketplace will present more than 80 leading companies featuring the latest PM equipment, powders, products, and services. The opening general session "America's New Auto Industry," will be presented by Drew Winter, editor-in-chief at *WardsAuto World* magazine. Additionally, the exhibition will offer more than 150 worldwide experts to present the latest technical programs on subjects such as powder production, refractory metals, PM titanium, lubrication, magnetic materials and many more. A number of management-focused sessions will also be available throughout the exhibition. The PM Design Excellence Awards Luncheon returns on Tuesday June 12 with the latest innovations in PM. The main social event at PowderMet2012 includes a southern-style dinner outdoors followed by a trip to the Grand Ole Opry. For more information, visit *www.mpif.org*.

June 13-15—Gleason Gear Solutions Forum: Systems for Gear Manufacturing. Ludwigsburg, Germany. Machine tools, workholding equipment and new technologies in bevel and cylindrical, small and large, external and internal and soft/hardened gears will be available to attendees as well as comprehensive services offered by Gleason Global. Each day, The Gear Solutions Forum will present a series of in-depth presentations and demonstrations on topics such as the efficient machining of automobile gears, highly productive machining of large gears, machining of bevel gears, gear measuring and gear cutting tools. A complete program agenda is available on request. For more information, visit *www.gleason.com*.

June 19-20—International VDI Congress Drivetrain for Vehicles 2012. Friedrichshafen, Germany. Sustainable driving, lower CO_2 consumption, a paradigm shift towards electromobility: the automotive industry has some difficult demands to satisfy. Vehicle transmission developers and users will be gathering at this important industry meeting-point now in its tenth incarnation. The conference will be directed by Dr.-Ing. Hans-Joerg Domian, director of new products and methods, design tasks, ZF Friedrichshafen AG. Opening papers tackle the subjects of the future of driveline development, potential CO_2 savings and the role of electrification as well as electromobility. Alongside future-oriented transmission components for electric and hybrid vehicles, the program will also include current developments in the fields of double-clutch and automatic transmissions, manual transmissions and all-wheel drives, efficiency, components, materials and production engineering as well as clutches and operating strategies. The machines section is entirely new: here attendees can learn about, for example, technical trends in agricultural machines, new developments in construction machinery drives, infinitely variable power take-off drives or improvements in the ease of gear shifting. For more information, visit *www.transmission-congress.eu*.

June 19-20—Human Error Prevention Seminar. Holiday Inn Express, Garden Grove, California. The principles and practices of human error prevention are universally applicable regardless of the type of industrial, commercial or governmental enterprise, and regardless of the type of function performed within the enterprise. This seminar is truly unique and up to date with the latest developments in human error prevention. Ben Marguglio's new taxonomy of human error causal factors and his human error-related models demonstrate his leadership in this subject. Examples and case studies amply reinforce the human error prevention principles and practices. This seminar covers: classifications of human error; quality and safety culture and the quality- and safety-conscious work environment; leadership responsibilities; the total quality and safety function and much more. For more information, contact Ben Marguglio at (845) 265-0123 or e-mail *ben@hightechnologyseminars.com*.

June 20-21—WZL Gear Conference. Schaumburg, Illinois. For more than 50 years the annual WZL Gear Conference in Aachen, Germany, has been the basis for the exchange of experiences and close cooperation between the members of the WZL Gear Research Circle. The WZL Gear Conference takes place for two days which are exlusively devoted to the latest research on gear design, manufacturing, and testing. Seven years ago, WZL started to present exclusive content of the Aachen conference in the United States. This 4th conference is hosted by Reishauer and provides the opportunity for American companies to get in touch with WZL and learn about current research activities. For more information, visit *www.getriebekreis.de.*

June 21-22—Root Cause Analysis Seminar. Holiday Inn Express, Garden Grove, California. This seminar covers all of the elements of a problem/condition reporting, root cause analysis and corrective action system with emphasis on the following root cause analysis techniques: Failure Mode and Effects Analysis for hardware problems and Hazard-Barrier-Effects Analysis for management and technical process problems. This seminar will also cover a modified Hazard-Barrier-Effects Analysis technique that allows the root cause analysis resource expenditure to be proportional to the significance of the problem, while still enabling the analyst to identify human performance root causes. Persons who are responsible for identifying and reporting off-normal conditions, evaluating the conditions and their effects, identifying causal factors, recommending various types of corrective actions, tracking the implementation of corrective actions, and managing the overall system should consider attending this seminar. For more information, contact Ben Marguglio at (845) 265-0123 or e-mail *ben@hightechnologyseminars.com.*

June 23-27—NLSC 2012. H. Roe Bartle Hall Convention Center, Kansas City. The National Leadership and Skills Conference (NLSC) boasts 16,000 high school and college students that meet key decision-makers in vocational-technical and school-to-work education and leaders from business and industry. SkillsUSA TECHSPO is held in the midst of the SkillsUSA Championships, where 5,400 students, America's best entry-level workers, compete in 96 hands-on skill and leadership contests. On the cutting edge of technology, these contests are run with the help of industry, trade associations and labor organizations, and it's all open to the public. SkillsUSA TECHSPO includes a Career Fair, where students and company representatives can exchange information and talk about employment opportunities. For more information, visit *www.skillsusa.org.*

GEAR TECHNOLOGY®

If you want the printed version, but your mailing address is outside the USA, Canada or Mexico, please visit our subscription page online at ***www.geartechnology.com/subscribe.htm***

Sign Up for **YOUR** Free Subscription

Gear Technology offers free electronic subscriptions anywhere in the world, and free printed subscriptions in the USA, Canada and Mexico.

1) ☐ YES I want to receive/continue to receive ***Gear Technology*** **FREE.**
☐ No thank you.

2) I want to receive the ☐ PRINT version ☐ *DIGITAL version ☐ *BOTH print and digital

(*Please include your e-mail address for DIGITAL or BOTH versions.) ______________________________
(Please print e-mail address)

3) Name: ______________________________ (print) Job Title/Position: ______________________________

4) Signature ______________________________ Date: ______________

5) Please tell us about your company:

Company Name: ______________________________
Company Address: ______________________________
____
City: ______________________________
State/Province: ______________________________
ZIP/Postal Code: ______________________________
Telephone: ______________ Fax: ______________
E-mail: ______________________________
Co. Internet Address: ______________________________

6) What is your primary job function responsibility? (Check one)

- ❑ Corporate Executives (B)
- ❑ Manufacturing Production Management (C)
- ❑ Manufacturing Production Department (D)
- ❑ Manufacturing Engineering Management (E)
- ❑ Manufacturing Engineering Department (F)
- ❑ Product Design, R&D Management (H)
- ❑ Product Design/ R&D Personnel (I)
- ❑ Purchasing (L)
- ❑ Marketing & Sales, Communications (M)
- ❑ Quality Control Management (P)
- ❑ Quality Control Department (Q)
- ❑ Other (N) ______________

7) How is THIS LOCATION involved in the gear industry? (Check all that apply)

- ☐ WE MAKE GEARS (or Splines, Sprockets, Worms, etc.) (20)
- ☐ WE BUY GEARS (or Splines, Sprockets, Worms, etc.) (22)
- ☐ WE SELL NEW MACHINES, TOOLING OR SUPPLIES TO GEAR MANUFACTURERS (24)
- ☐ WE provide SERVICES to gear manufacturers (25) (please describe) ______________
- ☐ WE distribute gears or gear products (including agents and sales reps. (26)
- ☐ WE are a USED MACHINE TOOL dealer (30)
- ☐ Other (please describe) ______________ (32)

8) Which of the following products and services do you personally specify, recommend or purchase? (Check all that apply)

Machine Tools

- ☐ Gear Hobbing Machines (50)
- ☐ Gear Shaping Machines (51)
- ☐ Gear Shaving Machines (52)
- ☐ Gear Honing Machines (53)
- ☐ Gear Grinding Machines (54)
- ☐ Gear Inspection Equipment (55)
- ☐ Bevel Gear Machines (56)
- ☐ Gear/Spline Roll-Forming Equipment (57)
- ☐ Broaching Machines (58)
- ☐ Heat Treat Equipment (59)
- ☐ Deburring Equipment (60)
- ☐ Non-Gear Machine Tools Turning, Milling, etc.) (61)

Tooling & Supplies

- ☐ Functional Gages (62)
- ☐ Workholding (63)
- ☐ Toolholding (64)
- ☐ Cutting Tools (65)
- ☐ Grinding Wheels (66)
- ☐ Gear Blanks (67)
- ☐ Lubricants/Cutting Fluids (77)

Service & Software

- ☐ Heat Treat Services (69)
- ☐ Gear Consulting (70)
- ☐ Tool Coating (71)
- ☐ Tool Sharpening (72)
- ☐ Gear Design Software (73)
- ☐ Gear Manufacturing Software (74)

Power Transmission Components

- ☐ Gears (75)
- ☐ Gear Drives (76)
- ☐ Bearings (78)
- ☐ Motors (79)

9) What is the principal product manufactured or service performed at **THIS LOCATION?**

____

10) How many employees are at THIS LOCATION (Check one)
☐ 1-19 ☐ 20-49 ☐ 50-99 ☐ 100-499 ☐ 500+

❑ **YES,** **I would like to receive *Gear Technology's* monthly e-mail newsletter**

❑ **YES,** **I would like to receive 3rd-party e-mails from *Gear Technology's* advertisers and partners**

❑ **YES,** **I would like to receive subscription renewal notices by e-mail**

❑ **No,** **I do not wish to be contacted by e-mail.**

FAX TO 1-847-437-6618 OR
VISIT US ONLINE AT
WWW.GEARTECHNOLOGY.COM

ADVERTISERS INDEX

ADVERTISER	PAGE	PHONE	E-MAIL	WEB SITE
Ajax Rolled Ring	6	(800) 727-6333		www.ajaxring.com
ALD-Holcroft	32	(248) 668-4130	sales@ald-holcroft.com	www.ald-holcroft.com
American Gear Tools	75	(734) 961-0300	leon@americanbroach.com	www.americangeartools.com
B&R Machine & Gear Corp.	IBC	(731) 456-2636, (800) 238-0651	inquiry@brgear.com	www.brgear.com
Bevel Gears India Pvt. Ltd.	73	+ (91) 80-2841-0312	jamalgrp@vsnl.com	www.bevelgearsindia.com
Cincinnati Gearing Systems	44	(513) 527-8600	gearsales@cst-c.com	www.cincinnatigearingsystems.com
Circle Gear & Machine Co.	78	(708) 652-1000		www.circlegear.com
Clifford-Jacobs Forging Co.	35	(888) 352-5172	sales@clifford-jacobs.com	www.clifford-jacobs.com
Delta Gear	10	(734) 525-8000	sales@delta-gear.com	www.delta-gear.com
Dontyne Systems	71	+(44) 191-206-4021	namerica@dontyne.com	www.dontynesystems.com
Drake Manufacturing	12	(330) 847-7291	info@drakemfg.com	www.drakemfg.com
DTR Corp.	37	+ (82) 32-814-1540, (847) 375-8892	dragon96@kotis.net, alex@dragon.co.kr	www.dragon.co.kr
Erasteel	36	(800) 365-1152		www.erasteel.com
ESGI Tools Pvt. Ltd.	4	+ (91) 175-223-3991	esgi@esgitools.com	www.esgitools.com
Excel Gear	78	(815) 623-3414	chinn@excelgear.com	www.excelgear.com
Forest City Gear	7	(815) 623-2168	fyoung@forestcitygear.com	www.forestcitygear.com
Gear Consulting Group	79	(269) 623-4993	gearconsulting@aol.com	www.gearconsultinggroup.com
Gear Machinery Exchange	79	(847) 437-6605	michael@goldsteingearmachinery.com	www.gearmachineryexchange.com
Gear Motions Inc.	78	(315) 488-0100	ron.wright@gearmotions.com	www.gearmotions.com
The Gear Works—Seattle, Inc.	78	(206) 762-3333	sales@thegearworks.com	www.thegearworks.com
Gleason Corp.	40-41, 79	(585) 473-1000	dmelton@gleason.com	www.gleason.com
Goldstein Gear Machinery	79	(847) 437-6605	michael@goldsteingearmachinery.com	www.goldsteingearmachinery.com
Hans-Jürgen Geiger Maschinen-Vertrieb	27	+ (49) 7123-18040	geiger@geiger-germany.com	www.geiger-germany.com
Hexagon Metrology	18	(401) 886-2422		www.leitz-metrology.com
Höfler	OBC	(734) 416-9300	info@hofler.com	www.hofler.com
Index Technologies	79	(440) 331-0038		www.gallenco.com
Ingersoll Cutting Tools	13, 15, 17, 19	(815) 387-6600	info@ingersoll-imc.com	www.ingersoll-imc.com
Ipsen International	24	(800) 727-7625		www.ipsenusa.com
John Deere	72			www.johndeere.jobs
Kapp Technologies	3	(303) 447-1130	info@kapp-usa.com	www.kapp-usa.com
KISSsoft	73	(815) 363-8823	info@kisssoft.com	www.kisssoft.com
Liebherr	5	(734) 429-7225	info.lgt@liebherr.com	www.klingelnberg.com
McInnes Rolled Rings	14	(800) 569-1420	sales@mcrings.com	www.mcinnesrolledrings.com
Metal Finishing News	70			www.mfn.li
Midwest Gear & Tool Inc.	45	(586) 779-1300	midwestgear@sbcglobal.net	
Mitsubishi	8	(248) 669-0614		www.mitsubishigearcenter.com
Niagara Gear	4	(800) 447-2392	info@niagaragear.com	www.niagaragear.com
Ontario Drive & Gear	28	(888) 662-2840		www.odg.com
Overton Chicago Gear	78	(630) 543-9570	sales@oc-gear.com	www.oc-gear.com
Precipart Corp.	23	(631) 694-3100	sales@precipart.com	www.precipart.com
Presrite Corp.	31	(216) 441-5990		www.presrite.com
Process Equipment	45	(800) 998-4191		www.gearinspection.com
Proto Manufacturing	20	(519) 737-6330		www.protoxrd.com
PTG Holroyd	26	+(44) 0-1706-526590	info@holroyd.com	www.holroyd.com
Quality Transmission Components	71	(516) 437-6700	QTCsupport@qtcgears.com	www.qtcgears.com
Riverside Spline & Gear	34	(810) 765-8302	valerief@splineandgear.com	www.splineandgear.com
Sandvik Coromant	61	(800) 726-3845		www.coromant.sandvik.com/us
Schafer Gear Works	42	(574) 234-4116		www.schafergear.com
Schnyder S.A.	69	(630) 595-7333	hanikcorp@aol.com	www.hanikcorp.com
Seco Tools	21	(248) 528-5200	secotools.us@secotools.com	www.secotools.com/energy
Sicmat	29	(847) 649-1450	sales@star-su.com	www.star-su.com
Sigma Pool	5	(734) 429-7225	info.lgt@liebherr.com	www.sigma-pool.com
SMT—Smart Manufacturing Technology	72	+(44) 115-941-9839	info@smartmt.com	www.smartmt.com
Star SU LLC	IFC–1, 29, 79	(847) 649-1450	sales@star-su.com	www.star-su.com
Stock Drive Products/Sterling Instrument	69	(516) 328-3300	SDP-SIsupport@sdp-si.com	www.sdp-si.com/e-store
Tokyo Technical Instruments USA	16	(201) 634-1700		www.tti-geartec.jp
Toolink Engineering Inc.	39	(303) 776-6212		www.toolink-eng.com
Yager Gear Enterprise Ltd.	78	+(886) 4-2407-6223, ext. 30	sa02@yagergear.com	www.yagergear.com


QUALITY CUSTOM GEARING!
Documented
Quality Control Program
Inspection Lab
including Complete
Gear Tooth Diagnostics
Tooth Cutting, Grinding & Shaving Services Available
All Sizes & Configurations
• Reverse Engineering
• Design Analysis
• Complete Machine Shop Including CNC Machining
CIRCLE GEAR CO
C G C
Circle Gear and Machine
Since 1951
1501 South 55th Ct. • Cicero, IL 60804
Ph: 708-652-1000 • Fax: 708-652-1100
Please email your inquiries to sales@circlegear.com • www.circlegear.com


OVERTONCHICAGOGEAR
PROCESS-DRIVEN PRECISION
ALL YOUR GEARING NEEDS
IN VOLUMES FROM 1-1000
Herringbone
Large internal
Worm gearing
Gear boxes
Spur & helical
Bevel gearing up to 100" in diameter
Spiral bevel gears up to 2 meters in diameter
CHICAGO
ADDISON
LOMBARD
(630) 543-9570
sales@oc-gear.com
www.oc-gear.com
100% Employee Owned


gear motions, inc.
Gear Grinding
and Cutting Services
GEAR MOTIONS, INC.
An Employee Owned Company
Learn about one of the most modern fleets of Gear Grinders, including the Höfler 700 and Gleason Tag 400 at Oliver Gear. See the latest Reishauer and Kapp Gear Grinding technology, at ISO 9001-2000 registered Nixon Gear, as well as the latest in CNC Gear Hobbing and cellular manufacturing.
PH: (315) 488-0100
www.gearmotions.com


Spiral Bevel Gears
for Electric and Pneumatic Tools,
Machine Tools, Agricultural
Machinery and Automobiles
Gear Grinding for Coupling
Gear DA Turret
ISO 9001:2008
Yager Gear Enterprise Co., Ltd.
No. 57, Shigu Ln., Guozhong Rd., Dali Dist.,
Taichung City 412, Taiwan
Tel: +886-4-24076223 EXT. 30
Fax: +886-4-24076218
E-mail: sa02@yagergear.com
http://www.yagergear.com


THE Gear Works
Ingenuity in Motion
Gearbox Repair
Gear Metrology
Gear Grinding to 2600 mm
Industrial Gears
Custom Gearboxes
Turbo Compressor Gears
Machining
Emergency Service
ISO 9001 Certified
Seattle, Washington | 206.762.3333
www.thegearworks.com


BIG Gears
EXCEL GEAR, INC.
A TOTAL SERVICE COMPANY
BIG Gearboxes
OPTIMIZATION
Software
EXCEL-LENT™
See it all at www.excelgear.com


GEAR
TECHNOLOGY
Gear Technology is accepting article submissions for the following departments:
• Product News
• Industry News
• Calendar and Events
Send your latest press releases to Matthew Jaster at
mjaster@geartechnology.com

Siemens Plant Management 101

Plantville Boasts 21,000 Players in more than 160 Countries

Once upon a time there was a computer. This computer served as a conduit to waste a great deal of time through social networking and online video games. Still, there was always potential to turn these rather sedentary activities into something more positive and useful to mankind. Siemens may have stumbled upon such a concept.

"Siemens was looking for a way to leverage the online world to engage customers, prospects, employees and students to showcase the breadth and depth of our portfolio," says Michael Krampe, director, media relations at Siemens. "We wanted to help our employees better understand the overall, integrated value that Siemens Industry can bring to its customers and prospects. We were also looking for a way to reach and inspire the next generation of plant managers and engineers and make manufacturing cool again."

Plantville, an online gaming platform that simulates the experience of being a plant manager, was released in March of 2011. In the game, players are faced with the challenge of maintaining the operation of their plant while trying to improve the productivity, efficiency, sustainability and overall health of their facility.

In Plantville, players can select which of the three virtual plants they would like to manage first: a bottling plant, a vitamin plant or a plant that builds trains. At the start of the game, each type of plant is faced with different challenges. The players must identify the challenges facing their plant and implement solutions to improve the plant's key performance indicators (KPIs). Gamers will compete with one another on a number of levels, including plant-to-plant and on specific KPIs. Pete, an interactive plant manager, keeps track of a leader board that details which players are performing the best on each of the levels. It's Farmville for the manufacturing/engineering crowd.

"One year since the launch, more than 700 educational institutions—high schools and universities—are playing Plantville, and several have held competitions among their students," Krampe says. "By playing Plantville, students are able to hone their problem solving and critical thinking skills, as well as their ability to collaborate as a team. These are vital 21st century skills and abilities that are in high demand by employers today." Krampe believes the beauty of using Plantville as a platform to promote the nuances, intricacies and relevancy of manufacturing for the United States is that students are experiencing the real world complexities of operating a plant in a virtual gaming environment.

"Plantville, like the plants within it, will continue to undergo updates and changes to reflect the continuing advancement of Siemens' technologies, as well as other elements that change or have an impact on industry and infrastructure."

Though the most challenging aspect of the project is to accurately simulate the day-to-day experiences of a plant manager, Krampe says that the participants (currently 21,000 players in more than 160 countries) enjoy the various daily challenges the game offers.

"Students really have to use their critical thinking skills to be successful in the game," Krampe says. "But when you can have students apply math and science standards in a fun, engaging way that provides measureable feedback through a reward system, you bring excitement to education."

For more information, visit *www.plantville.com.*