GEAR TECHNOLOGY

August 2010

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The Journal of Gear Manufacturing

IMTS 2010 PRE-SHOW ISSUE

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August 2010

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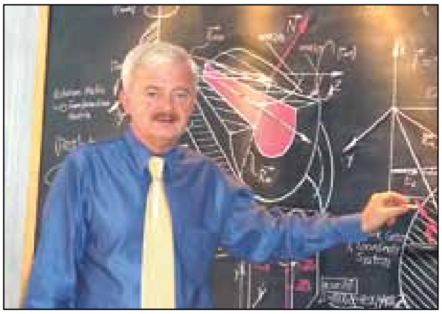

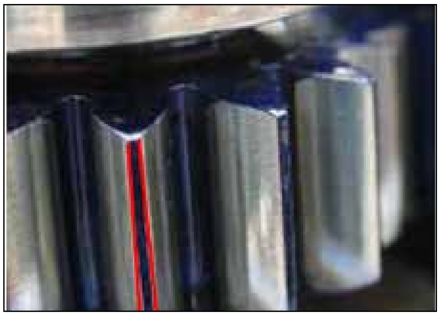

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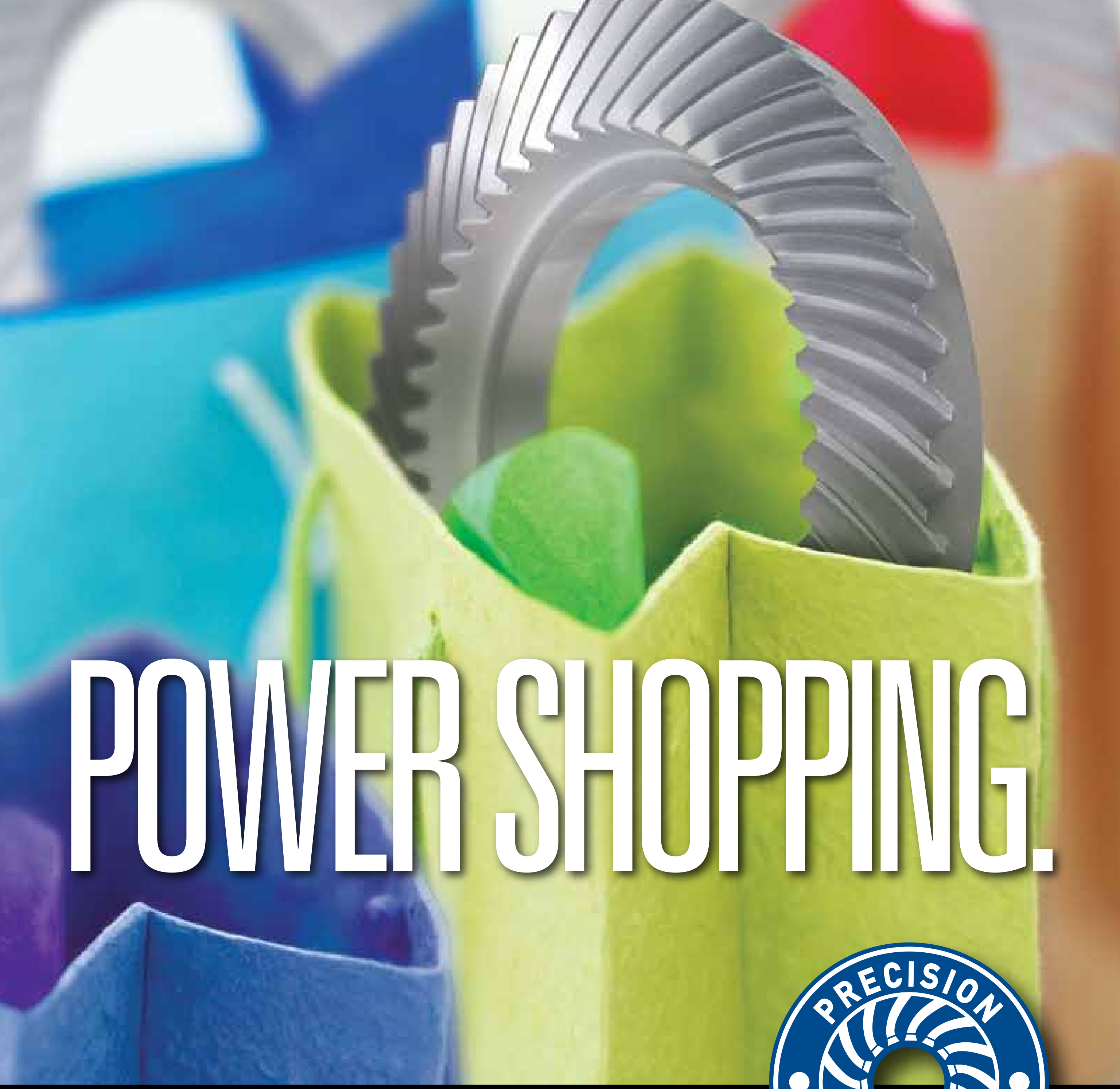
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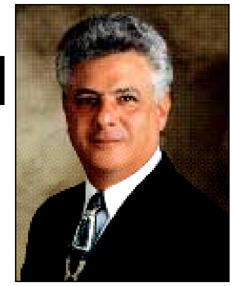

Ready or Not, Here it Comes

Everyone who's ever been a kid knows the rules of hide-and-seek. When you're "it," you have to cover your eyes and count to twenty (or a hundred, depending on how tough your neighborhood is). When you're done counting, you have to shout, loud enough for everyone to hear, "Ready or not, here I come." You have to shout it. It's in the rules.

Well, it's August, and IMTS is "it." North America's biggest manufacturing event takes place September 13–18, and the big show on the block is almost finished counting. I get the sense that some of you might not feel like going to IMTS. You're probably very busy, and buying machine tools may be the last thing on your mind. But ready or not, IMTS is coming.

Over the past month, I've talked to a lot of people in the gear industry, including gear manufacturers, tooling suppliers and machine tool manufacturers. Each of those groups represents a different part of the economic cycle of the gear industry.

Many gear manufacturers are cautiously upbeat. They're taking orders and hiring employees. A couple of months ago, I spoke with an executive at one of the major manufacturers of industrial gear drives. He told me that they've had the largest order intake in the history of the company. Then just a few days ago, he told me that the orders keep on coming. I've recently spoken with several others, in different parts of the market, who are experiencing similar upticks in business. Most of them aren't ready to celebrate just yet, mostly because they're not certain that what they're experiencing within their own companies is widespread or sustainable. In the general economy, there are plenty of sectors--housing is one example--that are still dead. But I've heard the same thing from too many different sources for it to be coincidence. From my anecdotal evidence, at least, the demand for gears in the United States appears to be on the rise.

Suppliers of cutting tools, workholding and other consumables are also very busy. They are working very hard to keep up with the increase in demand from gear manufacturers. If gear manufacturers are cutting more teeth, they're using up more hobs, shaper cutters, grinding wheels and so on. When gear demand goes up, the demand for tooling goes up almost immediately.

But the demand for machine tools is another thing. Although machine tool sales are up considerably over last year, not many machine tool manufacturers are celebrating just yet. Their business cycle tends to lag considerably behind the gear manufacturing and tooling sectors of the gear industry.

What that tells me is that although many of you are extremely busy right now, you may not be ready to buy machine tools. You're getting busier, your sales are up, but you aren't yet to the point where you need to add manufacturing capacity or upgrade existing technology.

So I understand if you're a little bit reluctant to go to IMTS. You probably are busy meeting orders and training employees—or retraining those you've hired back. But the show is coming, whether you're ready or not. And IMTS represents a great opportunity to explore the latest technology. We've previewed much of that technology here in our pre-show issue. Our coverage begins on page 26, and you'll find that many suppliers to the gear industry are promising new machines and new technology at this year's show. We've done our best to highlight some of the most important new equipment, but we didn't have room for it all, so there will be additional booth previews in our September/October show issue. Of course, none of this is any substitute for going to the show yourself, where you will have the opportunity to talk to the people who engineer, build and install the latest technology all around the world.

Even if buying new equipment is the least of your priorities, going to the show will give you a lot of perspective and insight, especially by talking to suppliers, who have been talking to customers in a wide range of industries and from a variety of companies. Those suppliers often have a better idea than you do of what's going on in various parts of various markets.

So I encourage you to make the most of this opportunity. IMTS only comes around once every two years, and you don't get many chances like this to survey the best new technology. Even if you're not quite at the point where you're ready to buy new machinery, you'll at least be able to learn about ways to improve your product quality, increase your productivity and expand your capabilities. Even if you're not a full-time gear manufacturer, make sure you visit the gear pavilion to learn as much as you can about the latest technology. Take the time and go to IMTS.

Ready or not, here it comes.

Michael Goldstein,
Publisher & Editor-in-Chief

Raising the Standards

Dr. Phil Terry, Chief Metallurgist
Lufkin Industries, Inc.

One of the original purposes of the AGMA was to create standards to specify and manufacture gear products. That work is carried out by the AGMA Technical Division, which is currently composed of 25 active committees. The division deals with a wide variety of subjects, including gear accuracy, cutting tools, gear rating and plastic and powder metallurgy gears.

The Technical Division is overseen by the Technical Division Executive Committee (TDEC), of which I am the current chairman. The other members of the committee are John B. Amendola, Sr. of Artec Machine Systems; Terrance Klaves of Milwaukee Gear Company; Robert F. Wasilewski of Arrow Gear Company; Thomas J. Maiuri of The Gleason Works; Dan Phebus of Fairfield Manufacturing Co. and until recently, James W. Mahan of Lovejoy, Inc (Jim retired after the May 2010 TDEC meeting and Todd Schatzka of Rexnord will be joining the committee).

The TDEC supervises the development and maintenance of AGMA standards and other publications. There are currently 55 AGMA standards and 31 information sheets. In 2009, AGMA released five new standards dealing with marine drive materials, enclosed gear drive components and flexible coupling design.

Standards developed through the Technical Division are more than just specifications. They are also valuable tools that are used by designers, gear manufacturers and—just as importantly—users of power transmission products. For example, the Computer Programming Committee is in the final stages of development of the next version of AGMA's *Gear Rating Suite* software. We are proud of the acceptance this valuable engineering tool has received by engineers worldwide. Besides performing load capacity calculations in strict adherence to the AGMA and ISO standards, the next version will contain a graphical output feature, so the user can actually see the meshing of the gears being designed.

The Metallurgy & Materials Committee is working on a revision to AGMA 2007 on surface temper etch inspection. This standard, which has been adopted by ISO, is used literally throughout the world to define metallurgical quality requirements.

The Bevel Gearing Committee has undertaken the project to update AGMA 2008, the standard on assembling bevel gears. This document has gained wide use by gear manufacturers and plant maintenance personnel alike to assist in performing these critical assembly procedures.

Many of our committees have the responsibility to serve as the United States Technical Advisory Groups to programs within ISO TC 60. Participating on these committees gives members an opportunity to stay abreast of developments on an international level that can impact their companies.

AGMA is the secretariat of ISO TC 60 and procedurally oversees all the standards programs that are undertaken. It's a two-way street – many ISO standards get their roots from AGMA standards. Examples include the standards for cylindrical gear accuracy and bevel gear geometry.

All AGMA standards have the status of being American National Standards as defined by the American National Standards Institute. To maintain this status, AGMA's Technical Division operations are audited by ANSI every five years to ensure compliance with our own Policy and Practices, and with ANSI's requirements.

The audit consists of answering the question, "Do you do what you say you do?" Five standards are chosen at random, and records that we retain during the development process are reviewed. This includes the minutes of all committee meetings, ballot results and necessary approvals along the way. The audit also requires us to meet ANSI's Essential Requirements.

The audit was conducted last summer, and as a result, changes to our internal procedures will be required. The most significant change that is being proposed at this time will be in the composition of our consensus body—those who have the opportunity to receive the General Ballot of all AGMA standards, to review the contents of new standards, provide comments, and vote on its acceptance.

Since its inception, the opportunity to participate in the General Ballot of AGMA standards has been a unique benefit of membership in the association. However, it is recognized that in an industry such as ours, with companies having a broad range of interest in the types of products they produce and the many various application sectors they serve, that not all standards are of interest to, or are applicable, to the products produced by all our members.

After extensive review and discussion of our current balloting process, a revision is being proposed that redefines the composition of the consensus body. For many years the recipients of a General Ballot have been the official representatives of all AGMA member companies. The consensus body would now be configured to capture companies within the association that express an interest in reviewing and voting on a new standard's project or on the reaffirmation of an existing standard. A survey will be taken prior to launching a General Ballot to identify these companies that will then comprise the consensus body for that particular standard.

The standards AGMA produces could not exist without the help and expertise from member companies, and I encourage all in the industry to consider participation. Being involved in the standards development process gives you the opportunity to learn while at the same time, contributing to the industry. It also provides you with the opportunity to study the art of gearing at a much more in-depth and technical level than you would otherwise have. Finally, participation allows you to stay abreast of what's going on in the industry, both domestically and internationally.

Technical committee participation is a value-added proposition—with immediate payback to your organization.

Sincerely,
Dr. Phil Terry, Chief Metallurgist
Lufkin Industries, Inc.

Heller

INTRODUCES GEAR MANUFACTURING ON FIVE-AXIS MILLING MACHINES

Heller has developed a process that enhances the productivity of milling operations on a 5-axis machining center.

Manufacturers of gear components and bevel gears have been looking for alternatives to traditional manufacturing processes for larger gears. In addition, improving machine tool flexibility has become more important because many gear-makers can no longer afford to depend on dedicated gear machine tools. They want the capability and flexibility typical of a machining center.

In co-operation with Voith, a major transmission manufacturer in Germany, Heller has developed a process that significantly enhances the productivity of pre-milling and gear milling operations performed on a single 5-axis machining center. Both companies have applied for a patent on the jointly developed process.

The process is aimed at manufacturers of vehicles, machines or machine components that can use the machining center for lower-volume production of larger gears as well as other machining tasks.

Gear milling has recently been an interest of some machine tool builders as it is more efficient to use the existing capability of a five-axis machining center for new applications beyond those typical for machining centers. According to Heller, gear milling provides an ideal opportunity to use the full potential of its 5-axis machining centers from its new F series machines to its heavy-duty MCH-C series.

Heller pointed out that traditional gear-making machine manufacturers continue to concentrate on special-purpose machines and tools dedicated to gear machining, but that manufacturers of machining centers can provide complete machining for a wide range of applications as well as solutions for gear modeling using special software. The software permits the user to generate an ideal gear geometry from which the gear-making process can be developed.

Gear Data Drives the Program

Technical literature on gear technology says there is no comprehensive mathematical model for bevel gear tooth systems. Therefore, every CAD model used for the CAD/CAM process is an approximated model. Traditional gear cutting machines are based on a specific machine structure with corresponding kinematics. The machine generates the appropriate tooth shape based on the setting parameters entered into the machine.

The approach taken by Heller is a totally different one, although it resembles the process used with most dedicated gear machines: i.e., the gear parameters specified on the drawing are directly input into the machine control. The control then uses the data to generate the 5-axis paths for roughing and finishing in real time. As a result, no mathematically accurate 3-D geometry model is required. Instead, the pre-defined gear data from the drawing are used.

The measuring machine reports compensation data that can be directly entered in the machine control for pro-

cessing. Another major benefit of this approach is that current tool data, such as tool wear, can be incorporated into the ongoing process in real time. As a result, precision is enhanced. Also, the process provides users with flexibility and productivity without creating a new dependency on special software.

Besides tooth space machining, Heller also provides a process solution for pre-milling/turning of blanks. Complete pre-machining of external and internal contours is possible in the first setup, while tooth milling takes place in the second. Specially adapted NC cycles have been developed to facilitate process control. As a result, the complete workpiece can be machined on a single machine.

New Type of Cutter Raises Productivity by 300 Percent

There are other 5-axis machining centers claiming to be equally versatile and suited for gear milling when programmed accordingly. The use of an end milling cutter, for instance, provides high flexibility.

But according to Dr. Hannes Zipse, business development manager at Heller, the method is not particularly efficient or productive. "We operate in fields with high chip removal rates and aim to achieve the same in gear milling. We cooperated with Sandvik Coromant to develop a customized crown-milling cutter with indexable inserts, resulting in a type of hob. This had a major role in increasing productivity by the factor of three compared to conventional methods. The wider the tooth space, the more productive we will be."

The level of productivity essentially depends on the static and dynamic stability of the machine. For Reinhold Siegler, head of technology development at Heller, this is the most important point of all. "Very compact clamping is essential. That means that the position of the pallet chuck in the Heller solution is very close to the upper pallet edge to enable deep clamping of the gear or bevel gear.

"Additionally, our extremely robust spindles and highly rigid machine elements plus the use of short tools designed for roughing are key benefits. For this reason, we achieve higher productivity in the roughing

operation than can a vertical machining process," he said.

Versatility

The new process is for workpieces of different sizes starting from gear module 4: the smaller Heller 5-axis machining center model FP 2000 for diameters of up to 720 mm, the larger model FP 4000 for diameters of up to 900 mm, the model MCH-C with HSK100-spindle taper for diameters of up to 1,800 mm and an upcoming new machine range for diameters of up to 3,000 mm.

Despite the time-consuming changeover required, the use of a special-purpose machine is still more efficient for the manufacture of small gears produced in high volumes. Therefore the Heller/Voith process is not directly aimed at classic contract gear manufacturers producing a small variety of workpiece types in high volumes.

Instead, the Heller solution is for system suppliers; e.g., manufacturers of vehicles, machines or machine components that can also use the machine for other machining tasks. The process will also be of interest to gearbox manufacturers, whose products also include complete assemblies. This applies in particular to large gears, since the machines and the technology provided by Heller are suited for a wide range of machining tasks and provide the additional benefit of enabling efficient machining of gears and bevel gears.

Kenneth Sundberg, global business development manager at Sandvik Coromant, considers this a very interesting market opportunity. "The recent past has shown that the market continually comes up with machining solutions for gear components and bevel gears. For this reason, Sandvik Coromant has modified standard tools and incorporated new developments in the milling cutters. We are extremely satisfied with the machining results achieved so far. In a second step, we will focus on hard-milling processes.

"Although it is possible to use solid carbide end milling cutters for this purpose, we and Heller believe that using special crown milling cutters and side milling cutters will provide higher productivity and economic efficiency," he concludes.

For more information:

Heller Machine Tools
1225 Equity Drive
Troy, MI 48084
Phone: (248) 288-5000
www.heller-us.com

Low Inertia, Zero-Backlash Gear

DESIGNED FOR TIMING CRITICAL APPLICATION

Intech Corporation was approached by a customer with a dilemma involv-

ing a new machine for corrugating paper products. The customer was attempting to maintain precise timing between two shafts with corrugating steel teeth to prevent them from smashing into each other. Intech focused on a backlash-free, low inertia gear design as the solution.

The traditional backlash-free gear design consists of two gears, typically spur gears, with one split in two halves. Once both gears are installed on the shaft, the two halves of the split gear are rotated manually in opposite directions until both touch the opposite tooth flanks of the wider mating gear, eliminating any backlash. The two narrower gears are then fastened together, usually by bolts.

The Intech zero-backlash design is based on the same principle of eliminating backlash by engaging the opposing flank of a wider gear with two halves of a split gear. The gears are helical, and instead of rotating the narrower gears around their axis, they are forced apart in an axial direction. This is accomplished by a spring placed axially between the split gears, and cylindrical guiding pins that are securely anchored in the metal core of one of the narrower gears are fit into the counter bores machined into the all-plastic second half of the split gear. The spring force pushes the gears apart, and the pins force the gear to move axially to prevent any rotation.

The principle behind the design is that one-half of the split gear engages the wide gear on the load carrying flank, the front flank and the other half. These are guided by the pins to move axially and will be stopped by the rear flank of the second tooth blocking the axial movement with the helix angle. For the preload of the split gear in opposing direction, Intech relies on the elasticity of the Power-Core polymer material used. By designing all gears in the gear train with Power-Core, inertia was reduced in the drive by 65 percent.

When pressed against the helical flank of the wider gear, the tooth of the narrower gear will deform slightly to allow engagement along the full length of the flank. Both halves of the split gear, as well as the spring load, are calculated to develop enough preload for carrying the entire torque with enough safety to guarantee a backlash-free mesh, even during an emergency stop. Intech uses proprietary software to calculate expected gear life.

For installation and the preceding gear hobbing, the two halves of the split gear are fastened together with the provided bolts to form a helical gear. This gear is then installed on the shaft and meshed with the wider helical gear. The gear half of the split gear with the metal hub is attached to the shaft by a keyway and a key. Once the installation of all gears is complete, the fastening bolts are removed, and the spring does the rest. With this design, the backlash adjustment is automatic, as the spring pressure is permanent, and there is no need for manual readjustment when tooth wear occurs.

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www.intechpower.com

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ECM Process

DEBURRS INJECTION SYSTEM COMPONENTS

Deburring may not be a core process in machining, but it is still considered a necessary evil. Although other machining operations have been optimally coordinated, deburring is still not included in the process stream from the start, but EMAG introduces this capability with its Electro-Chemical Machining (ECM) process.

Workpieces with complex contours feature sectors that are note simple to machine because they are difficult to access. Undercuts, pockets and internal, overlapping bores present no major challenges to mechanical machining operations, but this can change when these sectors require deburring. The mechanical, thermal and waterjet-based technologies used up to now cannot guarantee intended output rates, economic viability and repeatability. Medium size and large batch production specifically require high component quality. Internal burrs and lugs can seriously affect this component function. When burrs are removed using standard machining processes, a secondary or "turned down" burr can form and leave further finishing to be needed.

ECM—unlike spark erosion—is a gentle, electro-chemical metal removal process that does not involve spark formations. An electrode is connected to a DC or pulse source to act as a cathode while the workpiece represents the other

electrode and is poled as an anode. The charge in the electrode gap between cathode and anode flows in a watery electrolyte solution (sodium nitrate or sodium chlorite, for example) and dissolves metal ions on the workpiece.

The material thus removed can later be filtered out from the electrolyte solution as metal hydroxide. The contour of the cathode is made to fit the machining requirement. This ensures that deburring, without causing mechanical or thermal stresses, takes place only at the point of the workpiece where it is necessary to remove material. This is where the main advantage of the process lies. This pinpoint machining process allows for the most delicate components to be deburred with high accuracy and repeatability.

It is important to define the machining direction from the start when deciding on the machining layout and the sequence of operations. If this is done, burrs can later be removed precisely and economically. The big challenge of the past was that deburring occurred at the end of the machining process. Using ECM, the whole machining process, including the interlinking of machines, will be performed from the start.

ECM is economically viable because as cycle times can be reduced and output rates increased in line with the number of components that can be accommodated in a single fixture, cycle times per component can be set at below 10 seconds.

EMAG's scalable power electronics allow for individual cathodes in a group of workpieces to be monitored separately for quality control. This ensures that the size of the charge in the solution and the volume of metal removed by each cathode can be monitored. ECM is wear resistant, precise and contactless.

ECM is enhanced by the PECM process. The P indicates precision that is

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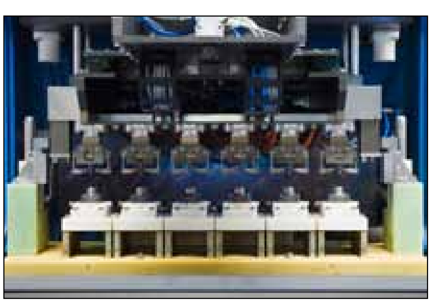

achieved with a pulsed current, an oscillating cathode and pulse-packets. Quality depends on an efficient pulsed current source and a rigid machine. The ECM and PECM processes are used in the automotive industry, aerospace and the medical equipment industries.

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EMAG GmbH
Austraße 24
D-73084 Salach
Phone: +49 7162-17-267
Fax: +49 7162-17-199
www.emag.com

Measuring System

GOES WIRELESS

The MikroCAD Lite measuring system from GFMesstechnik is now available without a PC, so all data acquisition and evaluation is performed within the system's sensor head. This development in optical 3-D measurement was released at the Control 2010 show in Stuttgart, Germany.

Since the MikroCAD Lite is wireless and pre-programmed, there is less equipment and no set-up involved. The system consists of an optical 3-D sensor, a screen for viewing measurement data and a tool holder. It is appropriate for high volume production lines since

measurements are completed in less than two seconds.

The MikroCAD Lite measures complex geometries using a high resolution CCD camera and digital stripe projections to generate 3-D data in the one micron range. Measurable geometries include radii, angles, chamfers, chipping and wear along the tool edge.

For more information:

PAT Gauge Inc.
Phone: (734) 449-8461
patgauge@earthlink.net

Transmission Analysis

ADDED TO ROMAXDESIGNER

Design engineers are increasingly presented with more challenging scenarios, especially given automotive industry trends towards more efficient, quieter and higher performing vehicles. The need for confidence in simulation technology has never been greater.

Romax's latest release of *RomaxDesigner R12.7* delivers such confidence by offering a more in-depth level of analysis than ever before. The new edition includes advanced capabilities such as accounting for thermal expansion, test duty cycles, improved NVH, gear whine analysis and gear root stress prediction, as well as other features and improvements.

When designing transmissions, thermal expansion is a major factor, and users can now account for this with *RomaxDesigner*. The software calculates the thermal expansion for all components, enabling users to visualize how this affects the whole system at the same time as considering clearances, deflections and preloads. This capability considers the thermal expansion of shafts and bearings, as well as housings, planet carriers and other imported finite element components.

Testing of transmissions is an essential part of the design process, and *RomaxDesigner*'s capability for test duty cycle generation, users benefit from reduced rig testing times. *RomaxDesigner* generates a test duty cycle from road load data with con-

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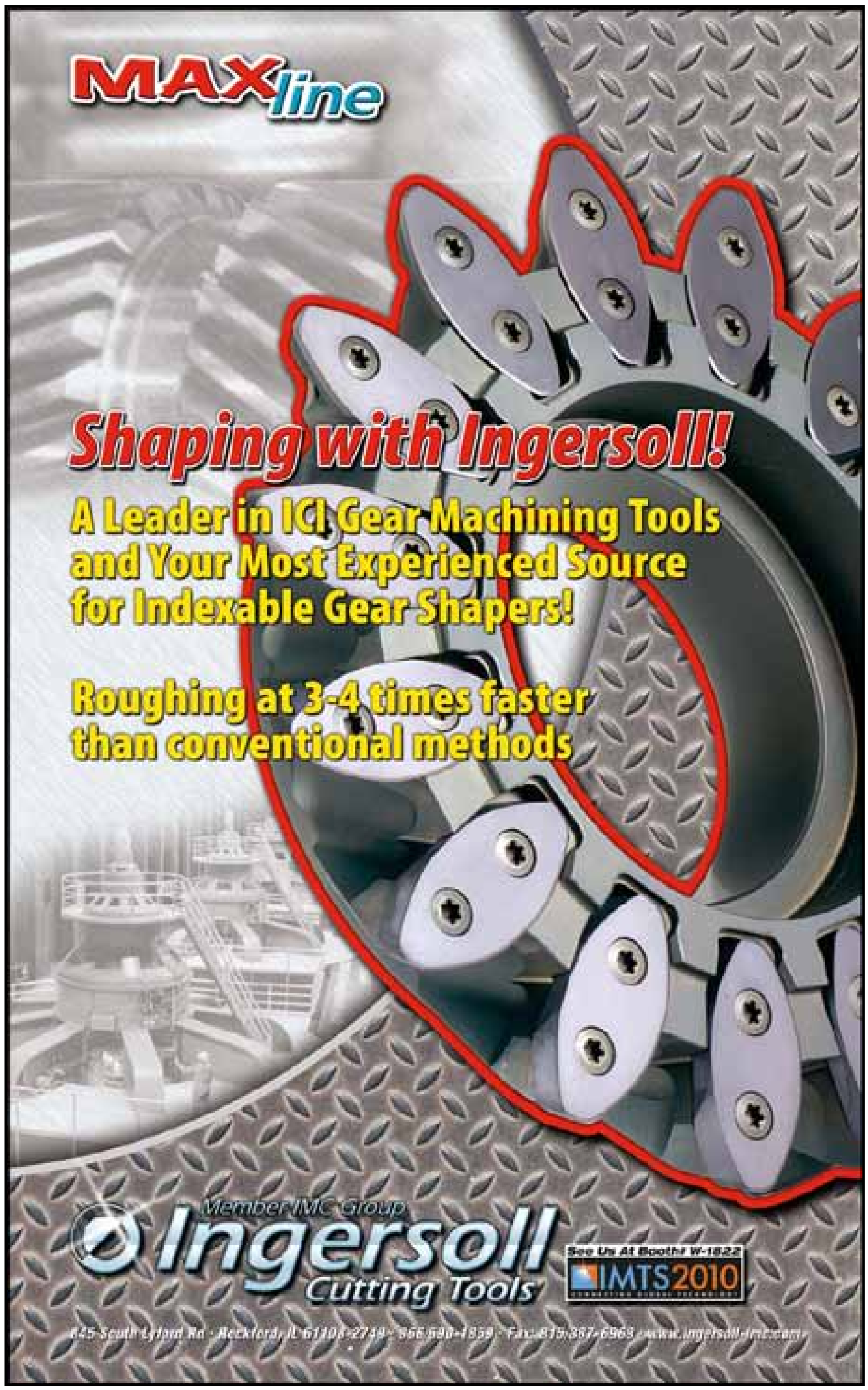


densed damages. This matches for gear contact, gear bending and bearing damages within one duty cycle, reducing the need for additional testing time.

RomaxDesigner can perform a root stress analysis, predicting root stress due to gear mesh loads and system deflections. A critical gear performance parameter, users can calculate this in *RomaxDesigner* without having to resort to time-consuming and specialized finite element analysis. As the demand for NVH technology grows, Romax has improved the usability and robustness of all *RomaxDesigner* NVH functions, increasing the ease of use for customers. Another enhancement is the improved third party links and development into time domain based analysis software such as *ANSYS* and integration to other dynamic analysis packages.

For more information:
Romax Technology
www.romaxtech.com

Infrared Touch Probe for CNCs

OPERATES WITHOUT CABLE

The TT 449 tool touch probe from Heidenhain serves as the company's first infrared tool probe offering. Designed for use with numerically controlled machine tools, the TT 449 is appropriate for applications where unlimited movements are necessary, such as with tilting or rotating work or rotary tables or with five-axis machining centers. It will be on display for the first time in North America at IMTS in booth E-5131.

This infrared touch probe offers increased mobility without the need for a cable. For tool measurement and inspection right on the machine, it is a simpler alternative than the complex laser measurement systems common to a five-axis machine.

One benefit of the wireless infrared touch probe is that the unit can be placed anywhere on a work table. It is also possible for an operator to move and re-mount without the need to handle cabling. Once mounted and put into

operation, the disk-shaped contact of the TT is deflected, and the signals are transmitted to the control over an infrared light beam. The generated trigger signal is then transmitted via an SE 646 transmitter/receiver unit to the control, where it is further processed. The SE 642 can also be used for a spindle probe. The control ultimately saves the measured tool length and radius in the tool memory.

The Heidenhain TT 449 tool touch probe has IP 67 protection and continuous duty of 200 hours with a lithium battery. A rated break point protects the touch probe from damage due to operator error.

For more information:

Heidenhain Corporation
333 E. State Parkway
Schaumburg, IL 60173
Phone: (847) 490-1191
www.heidenhain.com

Gleason

DELIVERS LARGE GEAR HOBS FASTER

With a major investment in equipment and processes, Gleason Corporation has optimized the manufacture of large module gear hobs. These cutting tools are used to manufacture large gears for wind energy, mining and various industrial gearbox applications. The Gleason

continued

Cutting Tools facility in Loves Park, IL can now produce hobs up to 450 mm in diameter, 530 mm in length and up to 40 module. Large module hob manufacturing lead times now range from 7–9 weeks. Gleason can produce DIN and AGMA AAA class hobs.

The multi-million dollar investment includes customized equipment with on-board inspection, fast change-over, accuracy and repeatability. According to Robert Phillips, senior vice president of Gleason's tooling products group, "This investment allows us to extend our global

leadership in gear cutting tools and serve the fast growing markets such as wind energy with the shortest lead times in our industry."

Gleason also has a Fast Track delivery program that has immediate delivery options available on some machines, including the Gleason-Pfauter P 1600, the Gleason 650 GMM Gear Inspection System and Gleason 1500GMM.

For more information:

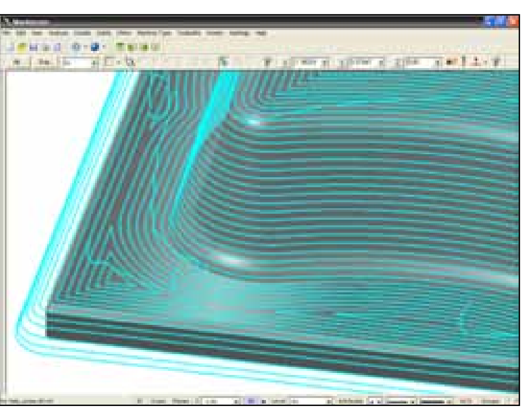
Gleason Corp.
1000 University Ave.
P.O. Box 22970
Rochester, NY 14692-2970
Phone: (585) 473-1000
Fax: (585) 461-4348
sales@gleason.com
www.gleason.com

Mastercam X4

CERTIFIED FOR AUTODESK INVENTOR 2011

CNC Software, the developer of *Mastercam* CAD/CAM software, announces that *MastercamX4* CAD/CAM software has been certified for *Autodesk Inventor 2011* 3-D mechanical design software by the Autodesk Inventor Certified Applications Program. To be certified, the product must meet certain guidelines and demonstrate a high level of quality, as well as compatibility with *Autodesk Inventor* software. Certification is given only after the product has been tested and approved.

"We are very happy to be certified for *Autodesk Inventor 2011*. Many *Mastercam* customers receive Inventor files, so both communities can be assured of the seamless integration between our two products," says Gary Hargreaves, director of business development for CNC Software. "The flow from design to manufacture becomes easier for both *Inventor* and *Mastercam* customers, where the designer can be assured that the part designed in *Inventor* is precisely the part that is machined with *Mastercam*. Both companies are working together to provide customers with the best in CAD and CAM software. The Mastercam and *Autodesk Inventor* integration offers users a way to easily work between the two products and stay ahead of their competition."



Mastercam X4 has a direct add-in for *Autodesk Inventor* to boost productivity. *Autodesk Inventor* mechanical design software takes engineers beyond 3-D to digital prototyping by enabling them to design, visualize and simulate products before they are ever built. Free to the *Mastercam* and *Autodesk* communities, *Mastercam Direct* allows users to open a model in *Mastercam* while in an Inventor session, and then update toolpaths to reflect changes to the model. *Mastercam X4* is able to read in native Inventor files for design purposes and toolpath generation.

"*Autodesk Inventor* software users can import part files and manufacture them quickly using *Mastercam X4*," says Tim Gray, director of Inventor product management at *Autodesk*. "Having partners, such as *Mastercam*, in the *Autodesk* Certified Application Program assures users that the same standards of product quality we want for *Autodesk Inventor*

continued

are being extended to the *Mastercam* suite of solutions."

Another new feature to *Mastercam* is the ability to open native *Unigraphics/NX* part or assembly files without a *Unigraphics/NX* license requirement using UG Read. UG Read allows users to import product manufacturing information data, such as properties, datums, dimensions, notes, geometric tolerances and datum targets.

For more information:
CNC Software Inc.
671 Old Post Road
Tolland, CT 06084
www.mastercam.com

Artec Machine Systems

INSTALLS BEAD BLASTING BOOTH

The CrossFlow Booth is a drive-in paint and bead blasting booth installed by Artec Machine Systems. It measures 10 feet wide by 12 feet long and 12 feet in height, and it draws fresh air through filters installed in the drive-in doors. The clean, filtered air is pulled through the booth and then exhausted through an environmentally friendly filter system.

All external casings and covers of gearbox and component rebuilds Artec performs are now bead blasted clean by the CrossFlow Booth. The final finish includes a corrosion-resistant sprayed undercoat followed by an oil resistant top coat.

Artec, headquartered in North Branford, CT, supplies customized gear drive systems to various industries. It is the North American sales and service agent for Renk-Maag GmbH, Kissling AG and Euroflex Transmissions.

For more information:
Artec Machine Systems
26 Commerce Drive
North Branford, CT 06471
Phone: (203) 484-2002
www.artec-machine.com


Sandvik Coromant
IMTS 2010
Booth W-1500
SMART HUB

IMTS2010
CONNECTING GLOBAL TECHNOLOGY

IMTS 2010: Pumping Blood into the International Manufacturing Community

Lindsey Snyder, Assistant Editor

If the free iPad giveaway from FANUC doesn't draw you in, the wall-to-wall new machine tool technology displays should have you stopped dead in your tracks. To be exact, there will be 1.2 million square feet of exhibit space that may have your jaw dropping. IMTS may be the last show you want to forget to bring walking shoes to.

Almost 50 exhibitors will keep you busy in the Gear Pavilion, but there will be no shortage of technology and potential business opportunities luring you into the other eight pavilions. The Industry and Technology Conference brings a wealth of technical information to the table. It serves as a great learning tool to bring employees to even for non-exhibitors. Fred Young of Forest City Gear buses his employees to McCormick Place simply for these learning opportunities.

It may take months of preparation to get the most out of the IMTS experience, and both exhibitors and the show management have abundant internet resources available in advance. One such resource is through social networks online. IMTS insider news can be found on Facebook, Twitter and LinkedIn, as well as the IMTS technology e-newsletter.

The IMTS group on YouTube features 60-second exhibitor submissions about why visitors should come to their booths. Visitors can vote to rate the videos, and the highest rated one will have theirs posted prominently on *imts.com* (submit at *www.imts.*

com/60seconds). Watch Mahr Federal measure a pin bore on a piston ring groove of a high performance automotive piston; Chicago sightseeing tips from Sandvik Coromant; and gage-line inspection by Euro-Tech Corporation.

In recognition of the importance a manufacturing resurgence holds for the U.S. economy and the place IMTS has in establishing the technology for future success, the Association for Manufacturing Technology (AMT) and the National Association of Manufacturers (NAM) have joined together in a partnership to promote American manufacturing.

"AMT and NAM are two of the most important voices in the world of manufacturing today," says Douglas K. Woods, president of AMT. "Collectively, our members represent every stage of the production process—from the mind of the design engineer to the shop and factory floor to the global marketplace. Together we want to underscore the importance of a strong manufacturing sector to long-term economic growth and national security. IMTS 2010—the most important manufacturing event in America—is an ideal launching pad for our industry partnership."

John Engler, NAM president and CEO, will give a keynote address in the Emerging Technology Center on the second day of the show, September 14. He will discuss how investing in innovation, technology and technical skills are crucial to a robust manufacturing sector. He will also speak about how to create an economic climate that encourages innovation.

"We are pleased to partner with AMT on IMTS 2010, where companies will see the latest breakthroughs in manufacturing technology," Engler says. "Innovation along with research and development has long helped manufacturing in the United States maintain its global leadership. But while we continue to stand strong as the number one manufacturing economy in the world, we face strong competition from other countries."

NAM recently released "A Manufacturing Strategy for Jobs and a More Competitive America," which provides a plan for what policies lawmakers can promote to help boost manufacturing and the United States' competitiveness in the global market. This makes an especially loud statement for action supporting manufacturing when considered along with AMT's Manufacturing Mandate, calling for the national policy of collaboration between government, industry and academia for incentives on innovation and R&D in new products and manufacturing technologies; assuring the availability of capital; minimizing structural cost burdens; and enhancing and building a more educated and trained workforce.

Over 92,000 industrial decision makers are expected to flood Chicago seeking ideas and answers to manufacturing challenges and problems. IMTS is all about educating manufacturers through the accompanying conference, student summit and over 1,100 exhibits.

What follows is a detailed description of what many gear industry suppliers will display in their booths, as well as related technology available for view in other parts of McCormick Place September 13–18. Most of the products listed are new to market or being unveiled at the show. Use these summaries to pinpoint where to focus attention at the show for maximizing time and energy. Make sure to pick up the September/October issue of *Gear Technology* at the show, and say hello to the GT editors in booth N-7572.

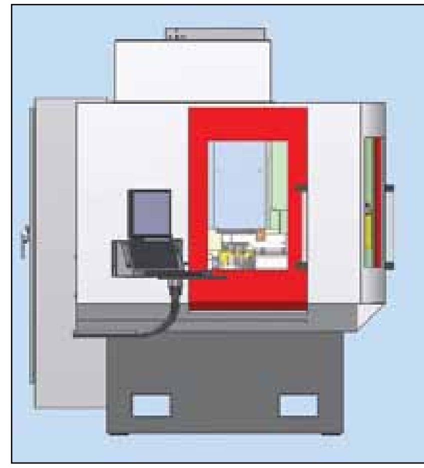
continued

Star SU (Bourn & Koch, Sicmat, Star Cutter) Booth N-6924

The Bourn & Koch 1000VBS CNC Gear Shaper is a 40 inch (1,000 mm) gear shaping machine with 8 inch (200 mm) stroke capability. It has the potential of being paired with Bourn & Koch's 1000VBT Vertical Turning Center or 1000VBG Vertical Grinder.

Features of the shaping head design offer CNC controlled quick return; CNC controlled back off and cutter offset; CNC controlled tapering, crowing and contouring; and CNC control of the helix motion of the cutter spindle (electronic guide).

The model that will be on display



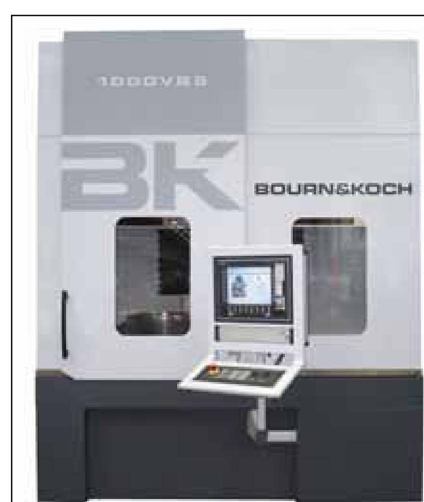
at IMTS has a base constructed from a hybrid composite. It uses CAD produced heavy beam style weldments and polymer aggregate in a heavily stabilized structure. The column also has these features.

The column is fitted to the top of the base and has a precision vertical preloaded roller way system and ballscrew to support and position the cross rail. The vertical motion of the crossrail on the column gives the machine a large range of capacity. The crossrail is clamped to the vertical column way system after positioning.

The work spindle is a self-contained unit mounted on precision radial/axial roller bearings and has infinitely variable speeds of 1–40 rpm, powered by an integral liquid cooled torque motor with 1,800 Nm continuous torque.

The patent pending shaping head is mounted to the infeed slide using the

continued

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preloaded roller rail system mounted to the crossrail. The infeed slide is positioned with a precision ballscrew.

The machine is furnished with a complete 50-gallon tank coolant system, Siemens 840D with PC front end, touch screen, and Bourn and Koch HMI.

The Raso 200 CNC shaving machine from Sicmat shaves gears with diameters ranging from six to 200 mm and module from 0.8 to 5 mm. Due to the lathe-like structure, the shaving machine provides performance levels and stiffness compared to larger machines in a smaller space.

The Raso 200 is equipped with Pilpro (piloted programming) software, which is Windows-based. Traditional cycles, mixed cycles (plunge plus diagonal), progressive diagonal cycles or combined double cycles can be programmed.

Two standard loaders are available. The Adatto 6 has a double pocket or the Adatto 8 with a drum unit. Sicmat's automated shaving cells can be configured with stand alone, rotary or SML/linear chamfer and deburring devices. Custom configurations are available.

The NTG tool and cutter grinder from Star Cutter is designed for manufacturing and reconditioning end mills, drills, step drills, taps and form cutters quickly, with accuracy. Using *NUMROTOplus* software, NTG's three-station wheel and manifold changer switches grinding wheels in ten to fifteen seconds. The high volume auto load system holds up to 288 parts. It loads and unloads tools half an inch in diameter by up to eight inches long to an automated tailstock center in fifteen seconds or less.

Linear motors on two horizontal axes eliminate the need for ball screws and reduce the number of moving parts to lower maintenance costs and improve surface finishes. Since the loader is integrated in the standard enclosure, the NTG takes up 30 percent less floor space than earlier generation machines.

For more information:

Star SU
Phone: (847) 649-1450
sales@star-su.com

Kapp Technologies (Niles) Booth N-7036

The Niles ZE 400 machine is one of the Kapp Group's most successful compact and economical machines. It is engineered for high quality with maximum grinding torque. The stable, ductile iron machine bed supports workpieces up to 2,650 pounds. The ZE 400 comes equipped with a tailstock, CNC dressing device and onboard measuring, and it uses both dressable vitrified and non-dressable CBN wheels.

The Kapp KX 160 Twin is built on a shared modular platform for continuous generating grinding of planetary and final drive gears in automobile applications with wheel drive or automatic transmissions. The machine includes two identical workpiece spindles arranged at opposite sides of an indexing table. As one spindle machines a part, the second unloads or loads and aligns another part, increasing output.

The 160 Twin machines external spur and helical gears of modules up to 4.5 mm with OD up to 270 mm (10.6 inches). An integrated profile dressing unit for conventional dressable grinding worms is included. Diamond profile roll sets are used for dressing tools, and grinding worms can be dressed for the dressing tool root machining also. A Siemens Sinumerik 840 D controls 10 NC-axes, including both workpiece spindles, the tool spindle, the swivel angle and rotary motions needed for grinding.

Kapp tools for direct grinding and coroning, diamond dressers for grinding and honing, as well as CBN and diamond-plated tools will be on display.

Another feature of the Kapp booth is live streaming videos from the facility in Boulder, CO demonstrating wet-grinding on the Kapp KX 500 Flex machine. These interactive lessons made their debut at Gear Expo 2009, where they received positive feedback from visitors. A schedule of these presentations will be posted at the booth, where Kapp and Niles personnel will be on hand to answer questions.

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

Reishauer Booth N-7018

The RZ 260, making its debut at IMTS, features Reishauer's continuous generating gear grinding and has been increased in size. All relevant components have been adapted to handle higher loads and forces to accommodate grinding larger gears (up to OD 260 mm and modules up to 4 mm).

The machine was designed to adapt to different production requirements depending on customers' individual requirements. The RZ 260 can be fitted with one or two work spindles. The two-spindle version minimizes the loading times while increasing production output. Both versions can be equipped with a fixed or CNC-controlled axis for swiveling the dressing tool. With this option, the dress-

continued

ing tools' flexibility can be increased because the same tool can be used for a range of gears compared to the fixed dresser, for which the tools are usually workpiece specific.

A changeable profile-grinding spindle is appropriate for grinding gears with space limitations or small lot sizes. This allows the use of a small plated or dressable wheel to grind gears with the discontinous profile method.

For more information:
Reishauer Corporation
1525 Holmes Road
Elgin, IL 60123
Phone: (847) 888-3828
www.reishauer-us.com

Gleason Booth N-7000

Several machines and tooling will be showcased by Gleason. These include the Titan 1200G Grinding Machine, which features the Power Grind process for high volume production to reduce manufacturing times by combining threaded wheel grinding and profile grinding in a single setup. The 1200G offers high flexibility for producing single parts on one platform.

Profile grinding machines that use the Opti-Grind process show up to 40 percent in productivity gains. The technology uses multiple grinding wheels for roughing and finishing simultaneously. Optimized contact conditions between the grinding wheel and the workpiece flank improve part quality.

The Phoenix 280C cuts cycle times up to 35 percent in comparison to other machines in its class. It features a fast part loading system and measurement device. It chamfers pinions and gears simultaneously. A quick-change cutter and arbor designs make it faster and easier to change over for new parts and tooling. As with other Phoenix machines, the 280C is built from a monolithic column design cast from a polymer composite material for high stability and damping, which is often found in high volume, dry machining production environments.

The Agilus 180TH machines shaft- and disk-shaped gears in one setup. The tool turret for locating fixed or driven tools allows turning, drilling, milling, hobbing and subsequent generating chamfering and deburring in the same setting. The CNC tailstock

clamps various workpieces with support on both sides for rigidity. The 180TH can operate automatically in conjunction with one or more turning cells.

The first in a family of GMS Series inspections systems with models available for gears up to three meters in diameter, the 1000GMS Analytical Gear Tester uses a Renishaw 3-D probe head for accuracy and flexibility to completely inspect all gears and gear cutting tools.

The Opti-Cut family of indexable insert cutting systems for gashing, hobbing and shaping can reduce cost-per-part by up to 50 percent compared to conventional high speed steel cutters. The tools are available in a range of cutter body sizes, insert types and geometries.

A range of workholding solutions for bevel gears, cylindrical gears and non-gear production machines will also be exhibited by Gleason.

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

Sigma Pool (Liebherr, Klingelnberg) Booth N-6930

The LCS 1200 Gear Grinding Machine combines generating and profile grinding while handling workpieces up to 1,200 mm in diameter.

The generating grinding method processes gears up to module 12. The machine has the capacity to produce noise-minimized gears in a two-flank grinding process to a specified twist design.

The profile grinding method grinds gears up to module 22 or a profile height up to 50 mm. Tools with electroplated CBN or dressable tools with corundum, sinter corundum or CBN basis can be used in both grinding technologies.

For the generating grinding method, the maximum OD of 320 mm on a grinding worm and the minimum usable diameter—which depends on the gear data, built in combination with the tool length of 230 mm, offers the longest tool life in this machine type class, according to Liebherr's press release.

Also on display will be the P 40 Gear Measuring Center, featuring a small footprint and appropriate for workpieces up to 400 mm OD. The center's new features include temperature sensors for ambient, machine and workpiece temperature. This allows reliable measurement in a non-climate controlled environment, extended part axis compensation and integrated surface roughness measurement of gear tooth flanks.

The P series machines are available in sizes from 260 mm to 3,800 mm. They can check cylindrical gears, spiral bevel gears, worms, worm gears, hobs, shaper cutters, shaving cutters, rotors, camshafts and crankshafts.

Dimensional measurements can be made on various rotation-symmetrical parts include roundness, rectangularity and flatness.

Liebherr is also exhibiting the PHS-1500 Pallet Handling System for automatic loading and unloading machining centers for parts mounted to fixtures; a hanging robot that was combined with a linear axis to expand its range of applications; and loading gantries from three load classes.

continued

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

Wenzel/Xspect Solutions Booth N-7436 and E-5157

The Wenzel gear measuring products are on display in the gear pavilion. The WGT 850 is a dedicated gear inspection machine that represents the highest performance in gear testing from Wenzel GearTec. All axes are made from natural dark granite for good thermal behavior. Air bearings on all axes ensure smooth running and high accuracy.

The Inova is a compact, four-axis, fully automatic CNC gear measuring machine. The Z-axis with integral rotary table is positioned independently from the X and Y-axes.

In a separate booth in the quality assurance pavilion, Wenzel is showcasing the X-Orbit CMM, which is equipped with the Renishaw PH20

probe. A typical Xspect Solutions remanufactured CMM will also be on display. Other 3-D imaging technologies at Wenzel's IMTS booth include the Wenzel ScanTec non-contact white light optical measuring system, the ExaCT integrated computed tomography workstation, MobileScan3D mobile CNC measurement system and the Shapetracer 3-D laser line scanner. This will be the first time these four 3-D imaging technologies will be on display in North America. OpenDMIS CMM software will be demonstrated on both the Wenzel and remanufactured CMMs.

For more information:
Wenzel/Xspect Solutions Inc.
47000 Liberty Drive
Wixom, MI 48393
Phone: (248) 295-4300
Fax: (248) 295-4301

Fuji Machine America Corporation Booth S-9430

The VTP-1000 vertical lathe performs hard turning without grinding. With gearless spindle technology and an RS-slide structure, the VTP-1000 achieves contour and profile cutting accuracies within ±1μm on up to 40 inches (1 meter) OD gears and bearing components. The machine is capable of precise roundness on high hardness materials (HR60 plus).

Twin Capto C6 Receivers ensure tool tip rigidity while a magnetic chuck eliminates the distortion associated with conventional workholding methods. External heat sources are insulated with containment covers for thermal stability. An optional external coolant chiller is available. Heightened finishing accuracies result in up to 75 percent shorter manufacturing time. Tool holders can optionally come with microchips to prevent offset errors and verify the tool holder is in the correct pocket.

The table diameter is 1,000 mm, maximum swing is 1,200 mm and table load is 4,000 kg. Although the machine features a small footprint, it is constructed rigidly. The column and bed, which account for 75 percent of the total machine weight, are made of heavy cast iron. These components are not affected by thermal growth.

The VTP-1000 is designed for simple integration into an automated work cell. It is appropriate for use in the gear, construction, wind power, high-speed rail, aerospace and shipbuilding industry.

For more information:
Fuji Machine America Corporation
171 Corporate Woods Parkway
Vernon Hills, IL 60061
Phone: (847) 821-2432
Fax: (847) 821-7815
info@fujimachine.com
www.fujimachine.com

Sunnen Products Company Booth N-7400

The patented multi-feed honing technology combines Sunnen's new controlled-force tool feed with its controlled-rate feed system. The two tool feed modes allow users to choose the best option to suit individual workpiece geometry, material and tool type/size. The multi-feed technology will be demonstrated and is available as an option on Sunnen's SV-1000 and SV-500 Series.

Controlled-force honing, a new feature in multi-feed, works like cruise control to ensure optimum cutting load on the honing abrasive throughout a cycle, regardless of the incoming parts' hardness, geometry or size variation. The process can cut cycle times by up to 50 percent, lengthen abrasive life for lower consumable cost and allows finer control of surface finish parameters. The controlled-force technology eliminates glazing of the abrasive due to low force and maintains a free-cutting, self-dressing condition for high metal removal in the shortest cycle time.

"In our development work, we found that more durable abrasives could often be used, resulting in more parts per set of abrasive and lower cost per part," says Dennis Westhoff, Sunnen's global business development manager.

Controlled force is an appropriate choice for applications using segmented diamond or superabrasive honing tools; also, where incoming workpieces have slight variations in hole diameters, hardness and geometry.

"An established honing process can be thrown off balance because of incoming part variations caused by

continued

upstream machining, heat treating or plating," Westhoff says. "Controlled-force honing always maintains optimum feed force on the honing abrasive under these conditions to eliminate wasteful air cutting, glazing or tool damage. The beauty is that if conditions allow, for example with a batch of parts requiring less stock removal, the honing cycle will be shortened significantly and automatically."

Controlled-force's ability to control the cutting load within a fine range also allows tighter control of finer surface finish parameters. "We have been able to cut the variation of final surface finish measurement by half or more," Westhoff says.

Sunnen's match honing process produces bore specifications to match the measured size of individual pins, plungers or pistons that may have dimensional inconsistencies due to special plating, coating or other treatment. Match honing achieves a precise fit between mating parts of fuel injectors, piston pumps, cartridge valves and similar products that use coatings or other treatments on male component parts that make achieving consistent diameter size impossible. The process reduces work-in-process inventories required when parts must be sorted by class size before assembly. Total tolerances between mating parts can be controlled to within ± 1 micron, which will be demonstrated at IMTS on a three-spindle SV-1015 honing system.

For more information:

Sunnen Products Company
7910 Manchester Ave.
St. Louis, MO 63143
Phone: (314) 781-2100
www.sunnen.com

Sandvik Coromant
Booth W-1500

The CoroDrill 854 and Corodrill 856 were launched to meet demand from the aerospace sector for hole making technology in composite materials. They were developed to withstand the harsh demands of CFRP materials and aluminum stacks, offering long life and meeting tight tolerances.

The geometrical shape of CoroDrill 854 is designed to improve hole entrance and hole exit quality on high fiber content materials. It is preferred where splintering or fraying is a problem. CoroDrill 856 is more appropriate if de-lamination proves difficult in resin-rich materials.

The insert grade GC1135 is for threading operations in stainless steels, super alloys and profiles requiring sharp cutting edges. It is available in the 0.630 inch insert for CoroThread 266. This size is appropriate for the majority of general threading applications.

The CoroMill 490 milling cutter is used to mill shoulders, faces, edges, contours, slices and slots in all materials. It can now take up to 0.393 inches depth of cut. The latest release in this cutter family is a 0.551-inch insert designed for larger depths of cut and engagements up to 0.393 inches. The insert size is introduced in a program

of cutter bodies in diameter range of 1.574 to 9.842 inches and in grades and geometries for steel and cast iron machining.

Grades S30T and S40T are available for a range of CoroMill cutters for face, shoulder, long-edge and high feed milling, plunging, profiling and slot milling. Developed with productive titanium milling in focus, the grade S30T combines the properties of micro-grain carbide and a wear resistant PVD coating. Grade S40T offers the high toughness of cemented carbide and thin CVD coating.

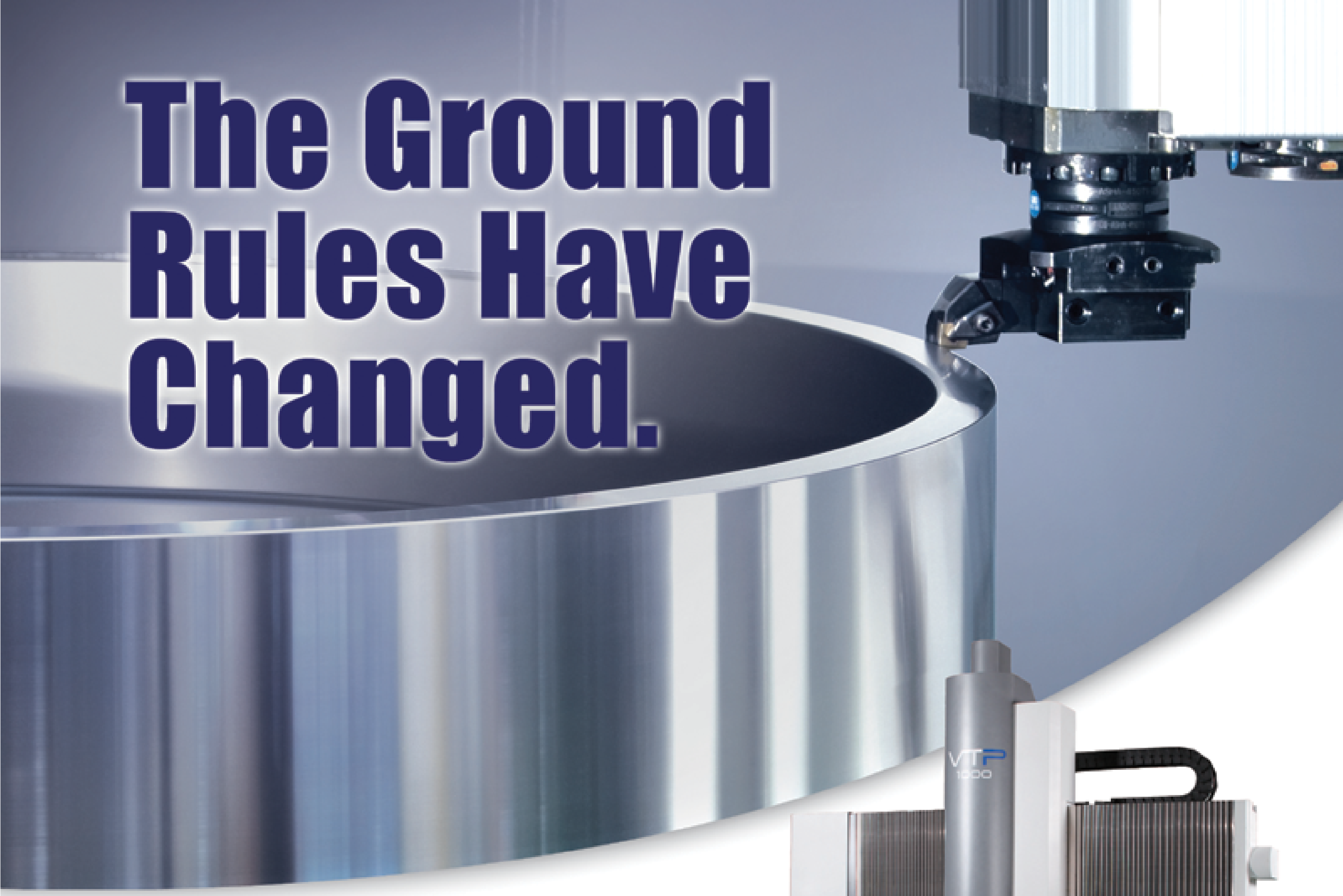
A range of integrated toolholders compatible with CoroMill 316 exchangeable-head (EH) tools achieve more secure performance than cylindrical shanks clamped in precision chucks, with comparable tool overhang, regarding torque transmission, run out and accuracy. When all machining variables are the same, integrated holders with an EH coupling provide shorter total programming length and higher stability when compared to cylindrical shank tool holders. With modular tooling possibilities, the holders can be used in many tooling combinations to suit applications and machine tools using a smaller inventory of standard items.

Sandvik is also showing hundreds of other product additions.

For more information:

www.Sandvik.coromant.com

The Ground Rules Have Changed.



Hard Turning.

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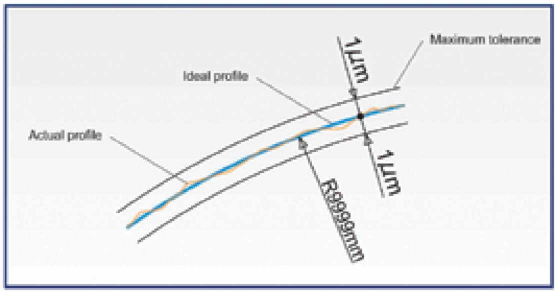
Grinding

VTP-1000 Vertical Lathe

Forget everything you know about turning limitations. Our new VTP-1000 vertical lathes perform contour and profile cutting within ±1μm on up to 40" (1m) OD gears and bearing components. Extremely precise roundness is achieved on high hardness materials (HR60 plus). Overall improved finishing accuracy adds up to 75% shorter cycle times.

For more information, visit www.fujimachine.com or call us at (847) 821-2432

Contouring Accuracy



FUJI

FUJI MACHINE AMERICA CORP

IMTS2010
CONNECTING GLOBAL TECHNOLOGY

See us in Booth# S-9430

Companies Exhibiting Products for the Gear Industry

The following IMTS exhibitors are suppliers of products or services that may be of interest to gear manufacturers who visit the show. The Booth numbers include a letter indicating which building the booth is in (N=North, S=South, E=East, W=West).

Alphabetical Listings

BOOTH	Company
N-7115	Accu-Cut Diamond Tool Co., Inc.
N-7027	American Broach & Machine Company
N-7027	American Gear Tools - Division of American Broach (DBA)
N-6437	American Stress Technologies, Inc.
E-4245	American Wind Energy Association
N-7514	AMT - The Association For Manufacturing Technology
N-6548	AMTDA
N-7414	ANCA Inc.
N-6454	Andantex USA Inc.
N-6322	Atlanta Drive Systems, Inc.
E-5747	Baldor Electric Company
E-4942	Bosch Rexroth Corporation
W-1271	Boston Centerless
N-6924	Bourn & Koch Inc.
N-7112	Broach Masters/Universal Gear
N-7229	Broaching Machine Specialties Co.
E-5115	Brown & Sharpe
E-5510	Carl Zeiss IMT Corporation
W-2446	Ceratizit USA, Inc.
N-7046	Cosen Saws, USA
S-8900	DMG America Inc.
N-7240	Dr. Kaiser
N-6536	DTR Corporation
W-1272	Dura-Bar
N-7124	Elmass Broaching Technologies, L.L.C.
N-6918	EMAG L.L.C.
N-6918	EMAG Maschinenfabrik Gmbh
W-1536	Emuge Corp.
N-7546	Engis Corporation
W-2168	Erasteel Inc.
N-6830	Erwin Junker Machinery, Inc.
W-2453	Euro-Tech Corporation
E-5435	Faro Technologies, Inc.
N-6924	Federal Broach
W-2453	Frenco GmbH
N-7220	Frömag
S-9430	Fuji Machine America Corporation
N-7127	*Gear Solutions* Magazine
N-7572	*Gear Technology / Power Transmission Engineering*
N-6740	Gehring LP
N-7000	Gleason Corporation
N-7030	Gould & Eberhardt Gear Machinery
N-6144	Gudel Inc.
S-8119	Haas Automation, Inc.
W-2338	Hainbuch America Corporation
N-7451	Hamai Company
W-2334	Hassay Savage / Magafor
S-8050	Havlik International Machinery Inc.
E-5115	Hexagon Metrology, Inc.
N-6737	Höfler Maschinenbau GmbH
N-7030	Hoglund Technology
E-4952	Hommel - Etamic America Corp.
N-7425	I-TECH International Corp.
W-1822	Ingersoll Cutting Tools
W-1916	ITW Workholding
N-6938	J. Schneeberger Corporation
N-7036	Kapp GmbH
N-6930	Klingelnberg GmbH
N-6918	Koepfer America, L.L.C.
N-6746	Leistritz Corporation
N-6930	Liebherr Gear Technology, Inc.
W-1314	LMC Workholding
E-5048	Mahr Federal Inc.
E-5521	Marposs Corporation
N-7170	Mijno Precision Gearing
E-4924	Mitsubishi Electric Automation, Inc.
N-6837	Mitsubishi Heavy Industries - MI
S-8548	Mitsubishi Heavy Industries America, Inc.
N-7220	Mitts & Merrill L.P.
S-8061	Mitutoyo America Corporation
E-5126	Mitutoyo Corporation
N-6918	Monnier + Zahner AG
W-2453	Mytec GmbH
W-1653	Nachi America Inc.
N-7036	NILES Werkzeugmaschinen GmbH
W-2108	Northfield Precision Instrument Corp.
E-4851	NSK Precision America Inc. - U.S. HQ
N-7425	Ort Italia
N-7577	Osborn International
N-7027	QC American LLC - Division of the Qinchuan Machinery Develpoment Co.
N-7030	R.P. Machine Enterprises, Inc.
N-6454	Redex-Andantex
N-7018	Reishauer Corporation
N-6571	Renold Gears
N-6918	Richardon GmbH
W-1336	Riten Industries, Inc.
N-7240	S.L. Munson & Company
N-7329	Saacke North America, LLC
E-5806	Saint-Gobain Ceramics
N-6924	SAMP S.p.A.
W-1500	Sandvik Coromant
W-2000	Schunk, Inc.
N-6625	Setco
N-6924	Sicmat S.p.A.
E-4933	Siemens Industry Inc.
E-4763	SKF USA Inc.
W-2151	Slater Tools Inc.
N-6300	Smalley Steel Ring Company
N-6414	Solar Atmospheres
N-6414	Solar Manufacturing
N-6924	Star SU LLC
S-9476	StarragHeckert SIP
W-1352	Suhner Industrial Products Corporation
N-7400	Sunnen Products Company
N-7000	The Gleason Works
E-5610	Timken - Positioning Control
N-6800	United Grinding Technologies
W-1306	Von Ruden Manufacturing Inc
N-7436	Wenzel America, Ltd.
E-5457	Wittenstein
N-7436	Xspect Solutions
N-6600	Yaskawa Electric America, Inc.

Listings by Booth Number

BOOTH	Company
W-1271	Boston Centerless
W-1272	Dura-Bar
W-1306	Von Ruden Manufacturing Inc
W-1314	LMC Workholding
W-1336	Riten Industries, Inc.
W-1352	Suhner Industrial Products Corporation
W-1500	Sandvik Coromant
W-1536	Emuge Corp.
W-1653	Nachi America Inc.
W-1822	Ingersoll Cutting Tools
W-1916	ITW Workholding
W-2000	Schunk, Inc.
W-2108	Northfield Precision Instrument Corp.
W-2151	Slater Tools Inc.
W-2168	Erasteel Inc.
W-2334	Hassay Savage / Magafor
W-2338	Hainbuch America Corporation
W-2446	Ceratizit USA, Inc.
W-2453	Euro-Tech Corporation
W-2453	Frenco GmbH
W-2453	Mytec GmbH
E-4245	American Wind Energy Association
E-4763	SKF USA Inc.
E-4851	NSK Precision America Inc. - U.S. HQ
E-4924	Mitsubishi Electric Automation, Inc.
E-4933	Siemens Industry Inc.
E-4942	Bosch Rexroth Corporation
E-4952	Hommel - Etamic America Corp.
E-5048	Mahr Federal Inc.
E-5115	Brown & Sharpe
E-5115	Hexagon Metrology, Inc.
E-5126	Mitutoyo Corporation
E-5435	Faro Technologies, Inc.
E-5457	Wittenstein
E-5510	Carl Zeiss IMT Corporation
E-5521	Marposs Corporation
E-5610	Timken - Positioning Control
E-5747	Baldor Electric Company
E-5806	Saint-Gobain Ceramics
N-6144	Gudel Inc.
N-6300	Smalley Steel Ring Company
N-6322	Atlanta Drive Systems, Inc.
N-6414	Solar Atmospheres
N-6414	Solar Manufacturing
N-6437	American Stress Technologies, Inc.
N-6454	Andantex USA Inc.
N-6454	Redex-Andantex
N-6536	DTR Corporation
N-6548	AMTDA
N-6571	Renold Gears
N-6600	Yaskawa Electric America, Inc.
N-6625	Setco
N-6737	Höfler Maschinenbau GmbH
N-6740	Gehring LP
N-6746	Leistritz Corporation
N-6800	United Grinding Technologies
N-6830	Erwin Junker Machinery, Inc.
N-6837	Mitsubishi Heavy Industries - MI
N-6918	EMAG L.L.C.
N-6918	EMAG Maschinenfabrik Gmbh
N-6918	Koepfer America, L.L.C.
N-6918	Monnier + Zahner AG
N-6918	Richardon GmbH
N-6924	Bourn & Koch Inc.
N-6924	Federal Broach
N-6924	SAMP S.p.A.
N-6924	Sicmat S.p.A.
N-6924	Star SU LLC
N-6930	Klingelnberg GmbH
N-6930	Liebherr Gear Technology, Inc.
N-6938	J. Schneeberger Corporation
N-7000	Gleason Corporation
N-7000	The Gleason Works
N-7018	Reishauer Corporation
N-7027	American Broach & Machine Company
N-7027	American Gear Tools - Division of American Broach (DBA)
N-7027	QC American LLC - Division of the Qinchuan Machinery Develpoment Co.
N-7030	Gould & Eberhardt Gear Machinery
N-7030	Hoglund Technology
N-7030	R.P. Machine Enterprises, Inc.
N-7036	Kapp GmbH
N-7036	NILES Werkzeugmaschinen GmbH
N-7046	Cosen Saws, USA
N-7112	Broach Masters/Universal Gear
N-7115	Accu-Cut Diamond Tool Co., Inc.
N-7124	Elmass Broaching Technologies, L.L.C.
N-7127	*Gear Solutions* Magazine
N-7170	Mijno Precision Gearing
N-7220	Frömag
N-7220	Mitts & Merrill L.P.
N-7229	Broaching Machine Specialties Co.
N-7240	Dr. Kaiser
N-7240	S.L. Munson & Company
N-7329	Saacke North America, LLC
N-7400	Sunnen Products Company
N-7414	ANCA Inc.
N-7425	I-TECH International Corp.
N-7425	Ort Italia
N-7436	Wenzel America, Ltd.
N-7436	Xspect Solutions
N-7451	Hamai Company
N-7514	AMT - The Association For Manufacturing Technology
N-7546	Engis Corporation
N-7572	*Gear Technology / Power Transmission Engineering*
N-7577	Osborn International
S-8050	Havlik International Machinery Inc.
S-8061	Mitutoyo America Corporation
S-8119	Haas Automation, Inc.
S-8548	Mitsubishi Heavy Industries America, Inc.
S-8900	DMG America Inc.
S-9430	Fuji Machine America Corporation
S-9476	StarragHeckert SIP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Gear Technology's IMTS coverage begins THIS ISSUE on page 65.
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Our extensive gear-related coverage continues in the next two issues—August 2010 and September/October 2010—with extensive booth listings and previews of the latest technology.
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An Interview with Thomas Koepfer

Michael Goldstein, Publisher & Editor-in-Chief

I recently had the opportunity to sit down with Dr. Thomas Koepfer, whose family company, Josef Koepfer & Söhne GmbH, was founded in 1867. Over the years, the Koepfer name has become one of the best-known in the gear industry, with company operations including the manufacture of gear machines, cutting tools and gears. Today, Koepfer is part of the EMAG group of companies.

Thomas's broad experience with the full gamut of gear manufacturing operations gives him a unique vantage point. We're pleased to bring you his insight in the following interview.

Q: Your family company, Josef Koepfer & Söhne GmbH, has gone through many changes in the last ten years. Can you describe them for us?

A: *At first, Koepfer was, I would say, a typical old family business, like many others in Europe. I'm the fourth generation. When I started with the company in 1994, there were 20 shareholders, the result of the historical development of the company passing through different generations.*

In 2005, more or less by accident, I met Mr. Hessbrüggen, CEO and shareholder from EMAG, who was looking for some knowledge in the field of gear manufacturing. They had previously cooperated with Liebherr, but discussions developed about a cooperation with Koepfer. At this time, I was also facedwith all the questions of internalization and globalization. When I started in 1994, 90 percent of our machine tool business was done within Europe, with only a few machines going to the United States, but that has changed dramatically over the years. Being faced with requirements and questions like service and sales capabilities around the world, I was always open to discuss cooperation with other companies that could help us get more access to the world market than would have been possible for us, a small, niche company.

After those discussions, the EMAG company eventually bought all the shares in Koepfer, except mine. I kept my ownership. EMAG is the majority shareholder in all the Koepfer companies. The other family members, from two or three generations back, have sold their shares. So, that's a little bit of the history of why we became a member of the EMAG Group.

Q: What are some of the business activities of EMAG? Who are they, and what do they do?

A: *EMAG is one of the largest machine tool builders. In 2008, the group's sales were a half-billion euros in machine tools.*

EMAG is a group of different mid-sized companies, originally starting with turning machines, but today offering many types of machine tools, including turning machines, gear hobbing machines—which is done by Koepfer—as well as grinding machines. So, it is a group of companies trying to offer an increasing number of products necessary for the complete work stream of manufacturing components, such as gears.

The holding organization tries to support the different group companies with central purchasing, computer business and management for the whole group, but in general, the companies are kept really independent as they originally were. We share a worldwide sales and service organization, which is important for mid-sized companies.

Dr.-Ing. Thomas Koepfer, CEO of Jos. Koepfer & Söhne GmbH.

Q: Is EMAG's main focus gears, or other processes?

A: *The focus is not primarily gears, but strategic components. EMAG started out with the turning department, but it specialized in strategic components. That's the reason why it wanted to have some knowledge and know-how in gear manufacturing. EMAG is working on manufacturing bigger components, but traditionally, it has worked in the automotive and truck range.*

Maybe one sentence would help you a little bit to describe EMAG. I think EMAG is specialized in what we call multi-functional machinery. That means we're building or adding different technology into the base machine, and that's where the EMAG Group is a formidable market leader.

Q: What is your present relationship and responsibility with EMAG and Koepfer?

continued

A: *I am the CEO of the Koepfer Gear Cutting Division as well as the Koepfer Machine Tool Division. So there was no change from the time before EMAG. The IMS Koepfer Cutting Tool Division has its own CEO, but I am on the board of directors. Since last October, I have also been a member on the board of directors of EMAG Holding. So today, I am more involved in EMAG than I was before.*

Q: What is your perception of the machine market in various parts of the world and your expectation for the next six months to a year?

A: *I think the machine tool market—both in the United States and worldwide—will recover from the dramatic downfall of a year ago. And in Europe, the German Machine Association and Oxford Economics predict that in 2012, we will have the same level of production we had in 2008. I personally doubt that we will reach that level within that time. But I'm relatively sure that it will recover in the United States, as well as in Europe. And if you look at Asia, there was not the dramatic drop as in the other countries. So, I think it will recover, but slower than we would maybe like it.*

Q: Is China part of EMAG's future?

A: *Yes, it definitely is. EMAG has four sales and service offices in China already. Last year, China was the second-biggest market for the EMAG Group, after Germany. We're really working hard to improve even that. We are considering starting with localization in manufacturing for the Chinese market. And, talking specifically about Koepfer, not the entire EMAG Group, last year Koepfer sold more than 50 percent of all its machine tools to Asia. Asia is a strong market, and we try to improve there because we believe that's more or less the only really growing region in the world.*

The EMAG/Koepfer twin-spindle VSC 400 DUO WF combines the functions of turning, gear hobbing, drilling and orientated milling on a single machine.

Q: Do you find that the Chinese are allowing you to sell there if you partner with them, so they can absorb your technology, and someday they won't need you?

A: *I'm sure there is some truth that they will absorb many of the things they get. The Chinese, especially in the machine tool business, I feel they strongly focus on their own market, and they want to use that not only to destroy all the other markets in the Americas and Europe, but also to improve their own level of productivity within a very, very short time. Therefore they want to use the technology. The gear market might be a little bit different because it's a niche market, and it's less interesting for them to manufacture specialized machines than with the turning machines. But, I think there is surely a risk that they will absorb and fight the Europeans and Americans. But, I think we are not able to avoid that and it is not a specific Chinese topic—competition today is global. You can try to participate and maybe to partner with them.*

I think maybe the Chinese are not so different from all other countries. I think the Europeans buy European if they can buy European. If you think about the Japanese, they are also trying to keep all their business internally. Also, I remember reading something about "buy American." So maybe the Chinese are not too much different.

Q: Tell me about some of the synergies you've experienced in the consolidation of EMAG and Koepfer.

A: *In the machine tool business—and I'm not talking about the gear manufacturing business, which is a completely different business, where more or less EMAG's only role is as shareholders—we take benefit and some synergies out of the group organization.*

We participate on shows worldwide, and we have local representatives worldwide. Across our product line, we can offer 24-hour service all over the world, we have service people doing some work for the EMAG Group.

Part of the idea of the EMAG Group is that they don't want to destroy the identity of the specialized companies. That's why it doesn't destroy the brand names. It wants to use the expertise out of the different fields of its business activities.

That's why, for example, Koepfer in Schwenningen, where we build the machine tools, we are responsible for all gear-related questions coming up in the EMAG Group.

Q: What innovations, changes or trends do you see in the coming years that will impact the worldwide gear manufacturing community?

A: *I think there will be the tendency toward multi-functional operations—machines that can do more than one specific operation. That might be one trend, but I think there are different trends, and the trend depends on the market. They also depend on different applications. I think you can't compare, let's say, wind craft with automotive, nor automotive with electrical power. There will be different trends, but I personally think multi-functional machines will be one strong trend.*

We started when we sold several machines based on EMAG turning machines, but we added a complete and real gear hobbing application, with gear hobbing software. It's 100 percent turning machine and 100 percent gear hobbing machine, and a gear is really finished within one machine—turning on two sides, hobbing and deburring in one operation.

People don't want to set up machinery. Saving on setup times is an important tendency. The main focus is the organization around the machine. The organizational questions will become more important than whether you cut a part in 20 seconds or 22 seconds. I think the time you lose by all the work around the actual part cutting is more important.

Q: Do you also see a trend toward fewer and fewer machines, requiring less and less floor space and fewer and fewer operators, but still producing more and more product?

A: *I think the machine tool industry is a self-killing industry. As productivity increases with the same amount of components needed, you'll need less and less machines. Because by increasing productivity and not having the same increase in the amount of components needed, you'll need less and less machines.*

Also, I think there will be different requirements of the people working on the machines. It's a question of training, of educating people. The probabilities for lower-trained and lower-educated people will become more difficult in the future.

Q: Do you foresee any new technologies that will be coming and impacting gear manufacturing?

A: *It's a shame, but I don't see too many new technologies, but rather there will be continuous improvement in all the different fields.*

The EMAG-Koepfer VSC DUO WF, a combined turning and hobbing machine, represents the synergy between the two companies.


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Tribology Aspects in Angular Transmission Systems

Part I

GENERAL EXPLANATIONS ON THEORETICAL BEVEL GEAR ANALYSIS

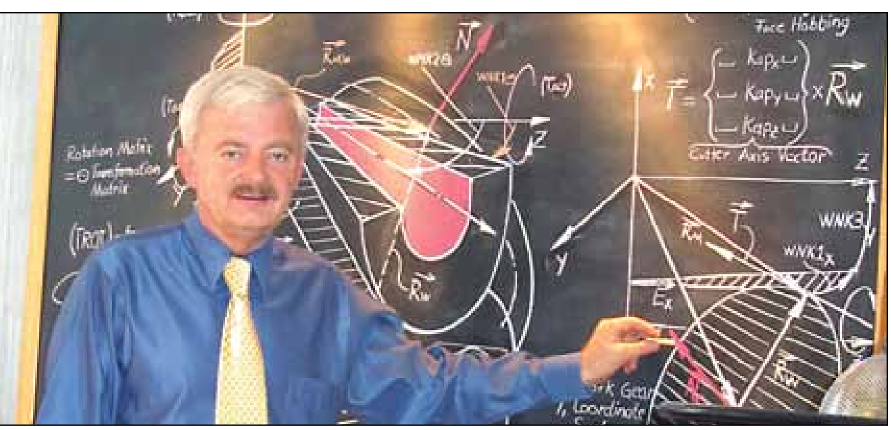
Dr. Hermann Stadtfeld

(This article is the first of an eight-part series. Each article will be presented first and exclusively by Gear Technology*, and the entire series will be included in Dr. Stadtfeld's upcoming book on the subject, which is scheduled for release in both English and German versions by The Gleason Works in 2011.)*

Introduction

Bevel and hypoid gears are complex, three-dimensional gearing systems with flank forms not easily described in conjunction with a mathematical function. As early as the 1970s, computer programs have existed to define the flank surfaces of bevel and hypoid gears. The latest bevel and hypoid gear analysis programs employ a simulation of the manufacturing process based on a virtual bevel gear generator—i.e., a virtual basic machine. This basic machine provides the correct definition of the workpiece blank, the cutting tool and all the freedoms between work and tool of a universal bevel gear generator (Fig. 1). As such, the input data define not only the work and tool but also the geometric and kinematic relationship during a pinion or a gear manufacturing process. The cutting tool represents one tooth of a generating gear while it rotates around the cutter head axis. The rotation of the cutter head center around the generating cradle axis represents the rotation of the generating gear, which is in mesh with the work gear. This in turn requires that the work gear rotates with the correct ratio between generating gear and work gear. The results of the manufacturing simulation are the surfaces of pinion and gear teeth, described as the points and normal vectors of the surface grids. These surfaces are the basis of a number of analyses, such as tooth contact analysis (TCA), sliding and rolling velocity calculation and more.

The analysis results—like ease-off and tooth contact—are plotted within the projected



Dr. Hermann Stadtfeld *received a bachelor's degree in 1978 and in 1982 a master's degree in mechanical engineering at the Technical University in Aachen, Germany. He then worked as a scientist at the Machine Tool Laboratory of the Technical University of Aachen. In 1987, he received his Ph.D. and accepted the position as head of engineering and R&D of the Bevel Gear Machine Tool Division of Oerlikon Buehrle AG in Zurich, Switzerland. In 1992, Dr. Stadtfeld accepted a position as visiting professor at the Rochester Institute of Technology. From 1994 until 2002, he worked for The Gleason Works in Rochester, New York—first as director of R&D and then as vice president of R&D. After an absence from Gleason between 2002 to 2005, when Dr. Stadtfeld established a gear research company in Germany and taught gear technology as a professor at the University of Ilmenau, he returned to the Gleason Corporation, where he holds today the position of vice president-bevel gear technology and R&D. Dr. Stadtfeld has published more than 200 technical papers and eight books on bevel gear technology. He holds more than 40 international patents on gear design and gear process, as well as tools and machines.*

ring gear tooth boundaries. Figure 2 provides the graphical explanation of the projection plane. The tooth corner points are transferred into an axial plane. Each point on a flank surface corresponds to a point on the projection plane. The projection plane is utilized in two- and three-dimensional graphics (as indicated, right) in order to ensure certain qualitative and quantitative properties are graphically visible. Those properties result from the interaction between a pinion flank and its mating gear flank. The analysis results—by definition—are only shown in the gear projection plane. The orientation within the tooth is defined as "length direction," corresponding to XG, and "profile direction," corresponding to YG (Fig. 2). Also, the definitions of "toe" and "heel," as well as "top" and "root," are provided.

A theoretical tooth contact analysis prior to gear manufacturing can be performed in order to observe the effect of the crowning in connection with the basic characteristics of a particular gear set.

Tooth Contact Analysis

Figure 3 shows the result of a tooth contact analysis of a conjugate spiral bevel gear set. The two columns in Figure 3 represent the analysis results of the coast side (left, vertical sequence) and the drive side (right, vertical sequence). The drive side is the flank pair, where the pinion concave flank meshes with the gear convex flank. The reverse direction is called the coast side. In the drive side direction, the pinion deflects away from the ring gear—which is, among other factors, the preferred condition. Transmission of torque and speed on the coast side leads to a pinion deflection toward the ring gear, thus reducing backlash in extreme cases to zero. Since this situation occurs under high load and interrupts any lubrication, it leads to surface damages that can result in tooth fracture. The recommended backlash in bevel gear sets is 0.03 times the module.

The example in Figure 3 is the analysis results of a conjugate bevel gear set—the basis of all gearing. Each flank surface point of the pinion interacts with a corresponding gear flank surface point, in accordance with gearing law—i.e., it transmits the ratio given by the quotient of the pinion and gear tooth count perfectly.

The top graphics in Figure 3 show the so-called ease-off topography in a three-dimensional representation (above the projection of the gear tooth area). The ease-off shows the consolidated amounts of crowning applied to the pinion and gear flank surfaces (versus the theoretically precise flanks). In this example of a conjugate gearset, the ease-off values above the presentation plane are zero.

continued

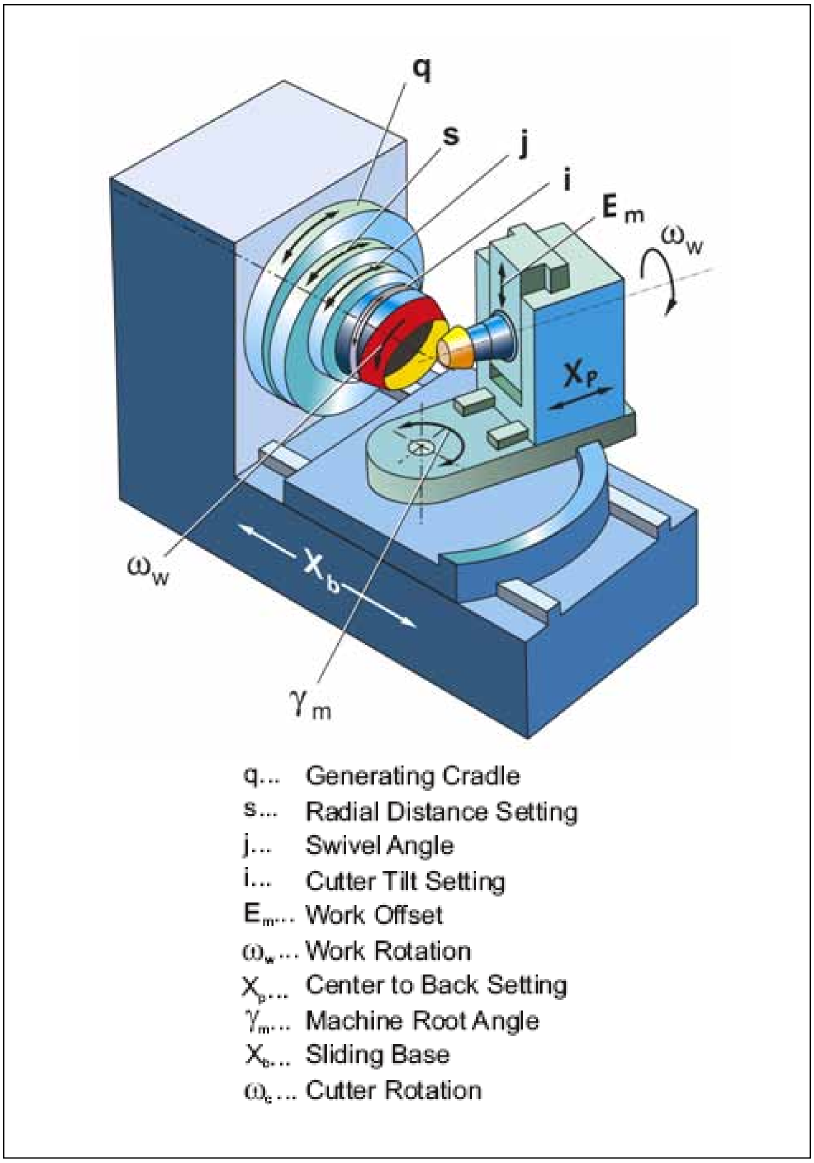


Figure 1—Universal model for bevel gear flank generation.

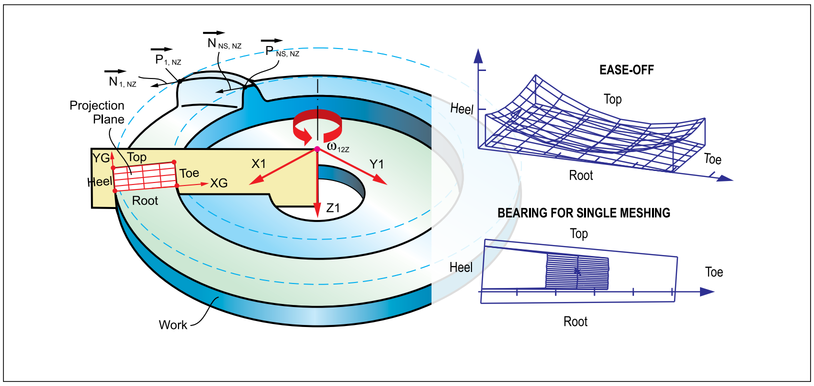


Figure 2—Definition of presentation plane.

Below the ease-offs, the motion transmission graphs of the particular mating flank pair are shown. If the pinion drives with a constant angular velocity, then the gear ideally should also rotate with a constant angular velocity but slower than the pinion by the factor of the gear ratio. The motion transmission graphs show the angular variation of the gear rotation from the ideal performance. In the present case of zero crowning, the motion transmission graph is a horizontal line (precise motion transmission).

The contact pattern at the bottom of Figure 3 shows contact lines (inside of the gear tooth projection) that extend throughout the active working area of the flank. This is also typical for conjugacy between pinion and gear flanks; however, such a conjugate tooth contact leads to edge contact as result of manufacturing tolerances and deflections under load.

Crowning has to be applied either to the pinion or gear—or both—in order to prevent edge contact along the boundaries of the teeth. Figure 4 shows TCA sequences of the three

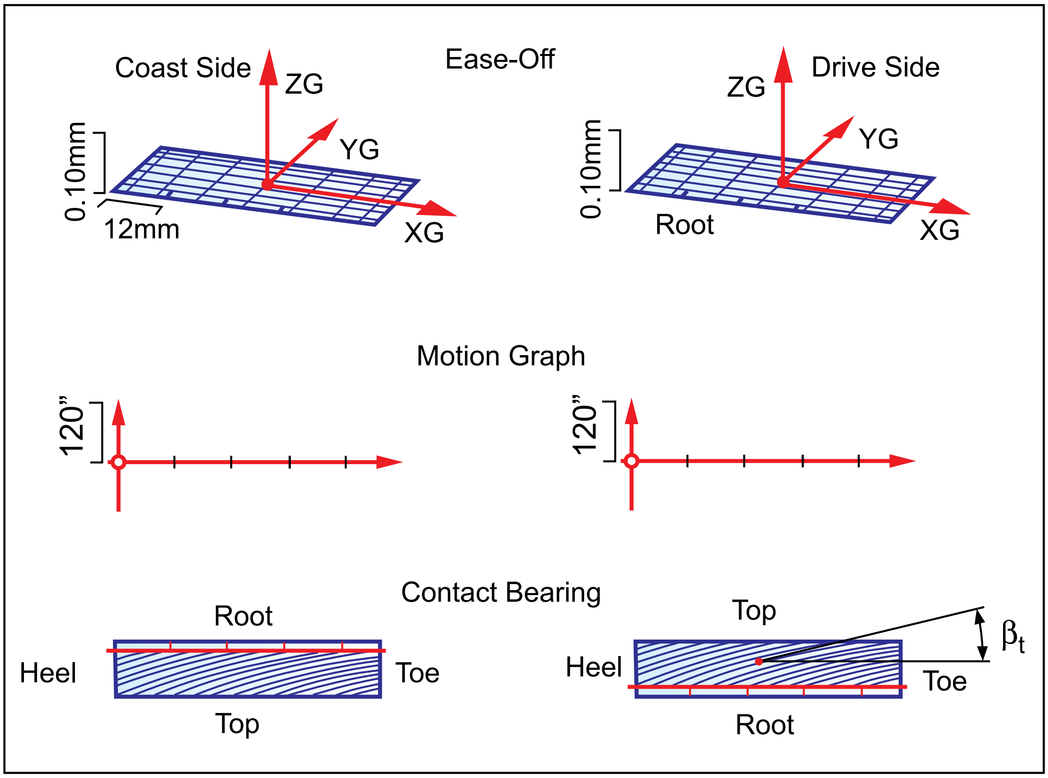


Figure 3—Tooth contact analysis of conjugate gear set.

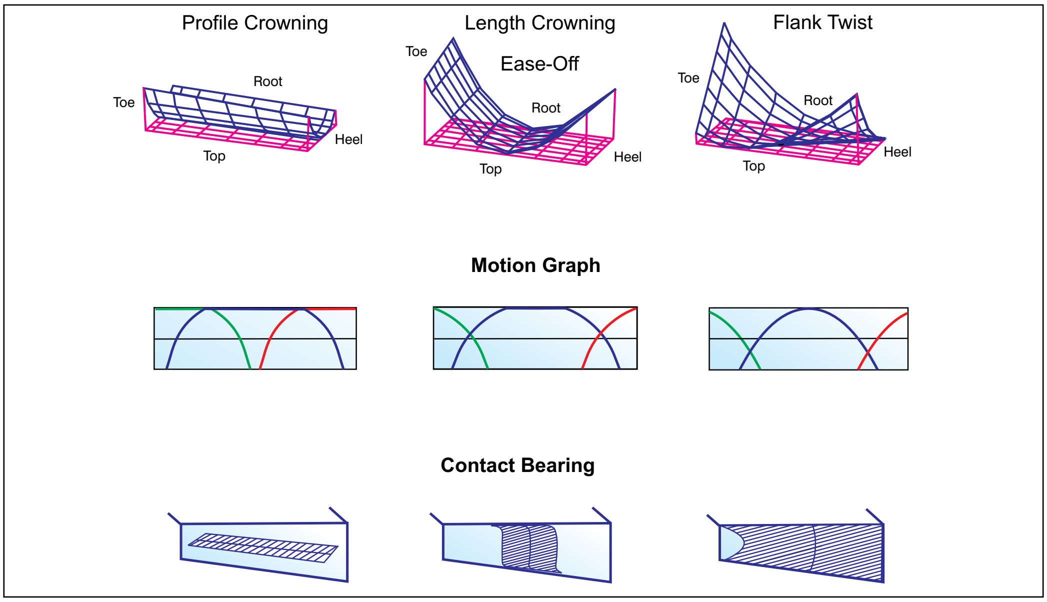


Figure 4—Tooth contact analysis with various types of crowning.

typical kinds of crowning. The top graphics show the ease-off topography. The surface above the presentation grid shows the consolidation of the pinion crowning portion and the gear crowning portion. The ease-offs in Figure 4 could be the result of pinion crowning only, or of the superimposition of a certain amount of both pinion and gear crowning.

Below each ease-off, the motion transmission graphs of the particular mating flank pair are shown. The graphs are drawn for the rotation and mesh of three consecutive pairs of teeth. While the ease-off requires reflecting a sufficient amount of crowning in order to prevent edge contact and allow for load-affected deflections, the crowning will in turn cause proportional amounts of maximal motion variation from zero.

At the bottom of Figure 4, the contact patterns are calculated for zero load and a virtual marking compound film of 6 µm thickness. This basically duplicates the tooth contact one would observe—i.e., rolling the real version of the analyzed gear set under light load on a roll tester while the gear member is coated with a marking compound layer of about 6 µm thickness. A smaller tooth contact area generally results from large magnitudes of ease-off and motion graph magnitudes, and vice versa. The parallel lines inside of the contact pattern are the contact lines for a number of discrete roll and contact positions between a pinion and a gear flank. The central line inside of the contact pattern is the path of contact, which is the sum of contact locations if the teeth are rolled with zero load. The left vertical sequence in Figure 4 is the analysis result of a pure profile crowning. The sequence in the center shows a pure length crowning and the right sequence is the result of a pure flank twist. Real bevel and hypoid gear sets consist generally of a mixture of these three crowning types.

Lubrication Gap Analysis

The basis of a lubrication gap analysis is the geometric and kinematic understanding of the interaction between the pinion and gear flank surfaces. Figure 5 (left side) shows a pinion flank rolling on a gear flank with a contact zone. The contact zone extends distance A along one pair of corresponding, potential contact lines between pinion and gear. While the gear set rotates in mesh, the contact zone will move from its current location—i.e., to the right. The relative surface curvatures between the two flanks are separated in two principal

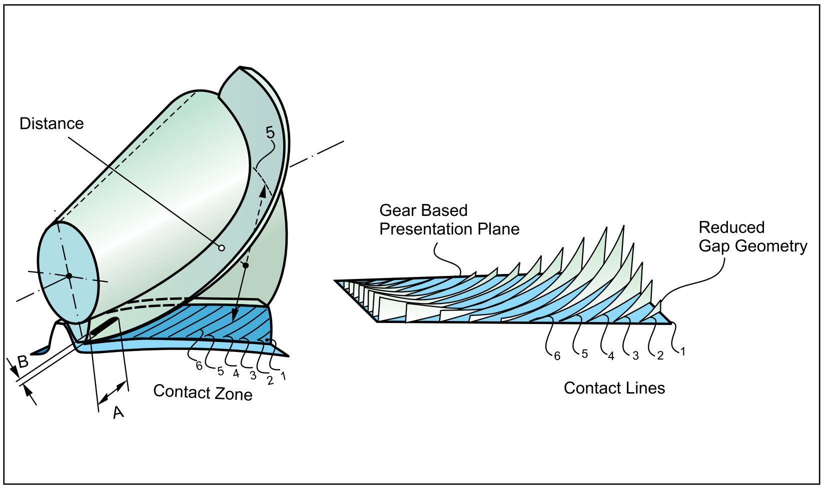


Figure 5—Two lubrication gap aspects.

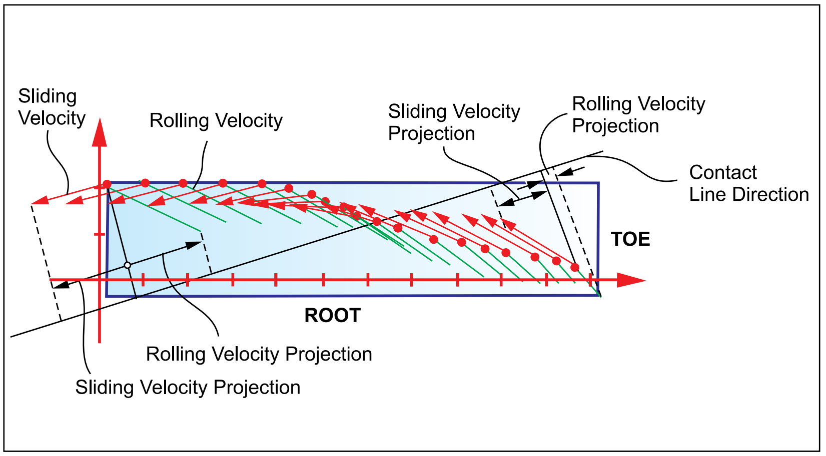


Figure 6—Sliding and rolling velocities of a hypoid gear set along the path of contact.

directions: one along the contact line and one along the path of contact, which is the direction from one contact line to the next. The curvature in the path-of-contact direction is some magnitudes larger than the curvature in contact-line direction, which is reflected by A>>B. However, depending on the angle of the contact lines and on the direction of the sliding and rolling velocities between both flanks—both directions, contact line direction and the direction perpendicular to that (the latter is not always identical with the path-of-contact direction)—have to be considered for a hydrodynamic investigation. The right-side graphic in Figure 5 shows the reduced curvatures of 20 discrete contact lines, each in their contact position, plotted above the gear projection plane (contact line scan).

Figure 6 shows the sliding- and rolling-velocity vectors of a typical hypoid gear set for each path-of-contact point for the 20 discussed roll positions; each vector is projected to the tangential plane at the point of origin of the

continued

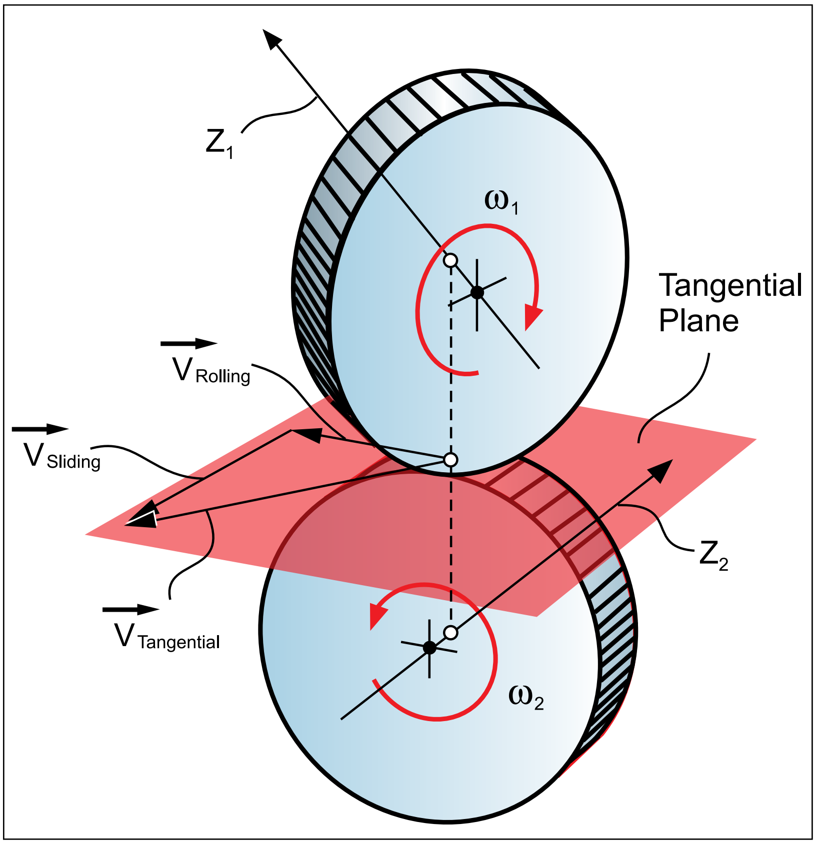


Figure 7—Definition of sliding and rolling velocity.

vector. The velocity vectors are drawn inside the gear tooth projection plane. The points of origin for both rolling- and sliding-velocity vectors are grouped along the path of contact, which is found as the connection of the minima of the individual lines in the contact line scan graphic (Fig. 5, right). An observer of one particular path-of-contact point on the gear flank surface would notice a momentarily contacting pinion point sliding away in the direction and with the speed represented by the sliding-velocity vector. The observer would also notice (particularly at the pitch point in straight bevel and spiral bevel gears, where no sliding and only rolling occurs) that the solid body connected to that point moved in a certain direction by rolling like a wheel rolls on pavement. The direction of this rolling and the movement accomplished via rolling (per time unit) are represented by the direction and magnitude of the rolling-velocity vector. Another way to explain the definition of rolling and sliding velocity in bevel and hypoid gears is shown in Figure 7. Disk 1 (top) rotates with ω_1 and is in contact with Disk 2 (bottom). The circumferential speed of Disk 1 is called the tangential velocity $V_{Tangential}$. The component of $V_{Tangential}$, which points in the axial direction of Disk 2, cannot rotate Disk 2—it only causes a sliding $V_{Sliding}$. The component that points in tangential direction of Disk 2 $V_{Rolling}$ and causes Disk 2 to rotate with ω_2 is called the rolling velocity.

It is worth noting that the rolling velocities have a relatively consistent direction, while the sliding velocities change their direction along the path of contact significantly. Figure 6 shows the average directions of the contact lines. The sliding and rolling velocities are projected in the contact-line direction (see two example projections at left and right, Fig. 6). An analog projection in the direction perpendicular to the contact lines (not identical to the path-of-contact direction) allows two separate observations of the dynamics along the contact lines and perpendicular to them. The gap geometry change from contact line to contact line (Fig. 5, right) can be considered as an additional aspect. A single observation, for example, of the main direction seems to be unacceptable since sliding and rolling velocity have different directions and change along the path of contact significantly.

The answer to the question—Why is the split of sliding and rolling velocities proposed in the contact line direction and in a second component in the direction perpendicular to it, rather than in the path-of-contact direction—may not be obvious. The path of contact is not a principal curvature direction. Sliding and rolling velocities and the geometry of the contact line scan will move the contact from one path-of-contact point to the next. Small crowning changes will not influence the contact lines but will have great influence on the path-of-contact direction. The path of contact is an indirect gear set property that depends on the following parameters:

- sliding velocity (hypoid offset)
- rolling velocity (spiral angle)
- contact line orientation (spiral angle)
- characteristic of crowning (ease-off, contact-line crowning)

This phenomenon, which can only be observed in bevel and hypoid gears, derives from the fact that along the major contact movement (direction perpendicular to contact lines) the curvature of the lubrication gap is basically constant, but the velocities change. Whereas, in the contact-line direction, both curvature and velocities change constantly (Figs. 5–6).

Examples

The observation of this complex condition

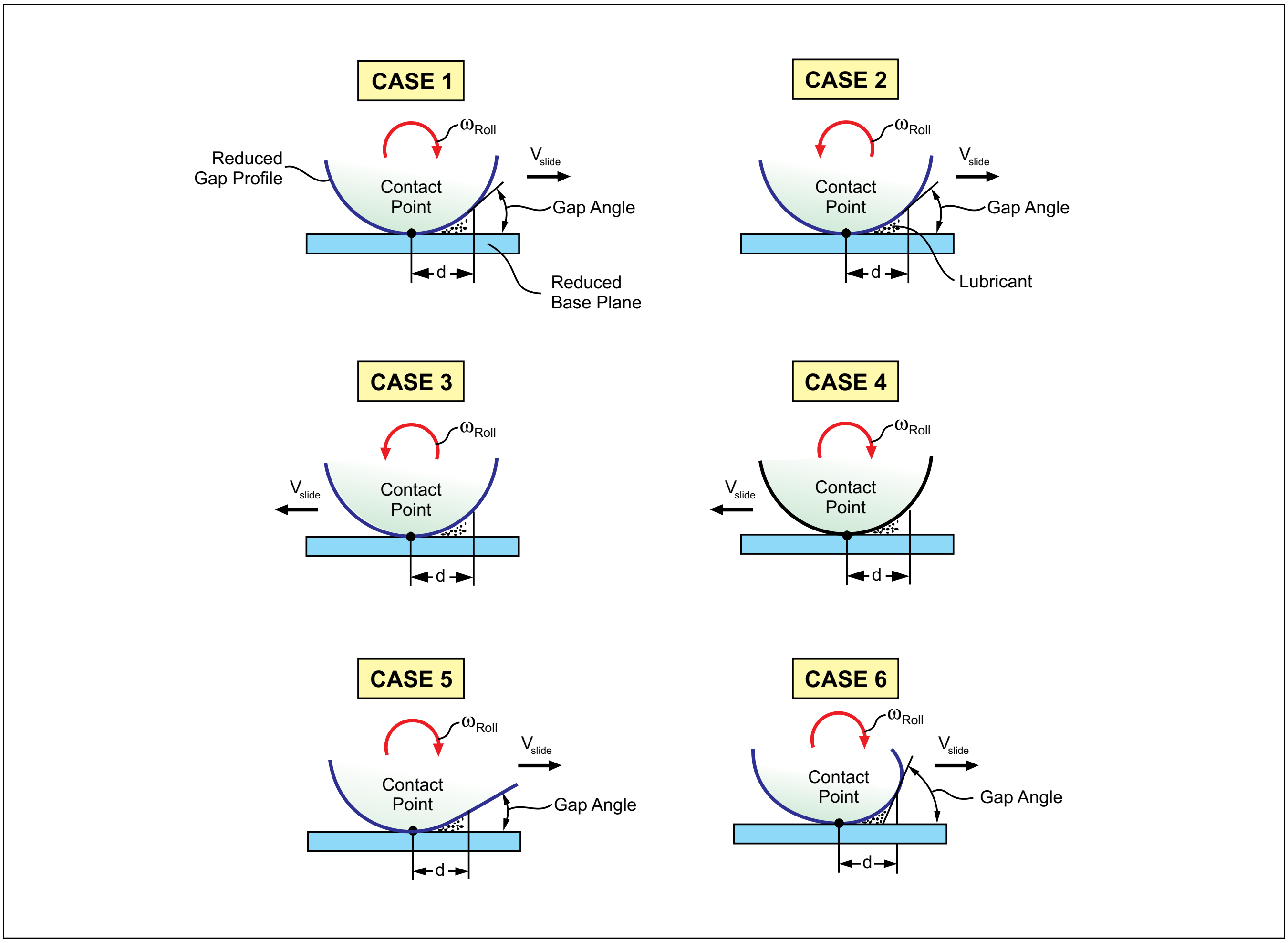


Figure 8—Six principal cases of lubrication gap kinematics.

leads to Figure 8, which shows six interesting cases of lubrication gap geometry and kinematics. Lubrication fluid is presented at right in each case drawing. Case 1 shows a clockwise rotation of a circular profile and a sliding to the right. This presents an enhancing condition for hydrodynamics. In Case 2 the rolling is reversed, thus reducing oil access to the lubrication gap. In Case 3 the sliding velocity and rotation are reversed, versus Case 1, thus presenting the most unfavorable kinematic lubrication condition. Case 4 has a reversed velocity direction versus Case 1 that presents a lubrication condition similar to Case 2. Cases 5 and 6 at bottom of Figure 8 are geometry variations that are applicable for the rolling and sliding directions indicated in Figure 6.

In Case 5 the curvature reduces while the profile rotates. This increases the lubricant pressure in front of the gap and will therefore enhance Case 1. In Case 6 a curvature increase is noticed while the rotation is progressing, which expands the lubrication gap. The latter will generate a vacuum that tends to pump the lubricant away from the contact zone. Case 6 will reduce the lubrication quality. A simplified rating of the lubrication quality is proposed:

Very Good:

a Case 5

b Case 1

c Case 6

d Case 2

e Case 4

Poor:

f Case 3

A qualitative judgment of the lubrication case of a bevel or hypoid gear set is possible by comparing the contact line gaps (and their change during the rolling process) as well as the velocities with the principal cases shown in Figure 8.

With awareness of the rolling and sliding velocities within the flank surface area, every contact line and every path-of-contact point

continued

$$\{F_n\} = (F_x, F_y, F_z) \quad (1)$$

Tangential force Fx calculated from torque (2)

$$F_x = -T / (A_m \cdot \sin\gamma)$$

Rotation of vector normal to flank (3)

$$\{F_n\} = (90° - \gamma)_X \cdot (\beta)_Z \cdot (\alpha)_Y \cdot (|F_n|, 0, 0)$$

Matrix multiplication of formula 3 and component solution

$$F_x = |F_n| \cdot \cos\beta \cdot \cos\alpha \quad (4)$$
$$F_y = |F_n| \cdot (\cos(90° - \gamma) \cdot \sin\beta \cdot \cos\alpha + \sin(90° - \gamma) \cdot \sin\alpha) \quad (5)$$
$$F_z = |F_n| \cdot (\sin(90° - \gamma) \cdot \sin\beta \cdot \cos\alpha - \cos(90° - \gamma) \cdot \sin\alpha) \quad (6)$$

Eliminate absolute value of F_n (7)

$$|F_n| = F_x / (\cos\beta \cdot \cos\alpha) = -T / (A_m \cdot \sin\gamma \cdot \cos\beta \cdot \cos\alpha)$$

Final solution of force components

$$F_x = -T / (A_m \cdot \sin\gamma) \quad (8)$$
$$F_y = -T \cdot (\sin\gamma \cdot \sin\beta \cdot \cos\alpha + \cos\gamma \cdot \sin\alpha) / (A_m \cdot \sin\gamma \cdot \cos\beta \cdot \cos\alpha) \quad (9)$$
$$F_z = -T \cdot (\cos\gamma \cdot \sin\beta \cdot \cos\alpha - \sin\gamma \cdot \sin\alpha) / (A_m \cdot \sin\gamma \cdot \cos\beta \cdot \cos\alpha) \quad (10)$$

where:

T	Torque of observed member
A_m	Mean cone distance
γ	Pitch angle
β	Spiral angle
α	Pressure angle
$\{F_n\}$	Normal force vector
$\|F_n\|$	Absolute value of normal force
F_x, F_y, F_z	Bearing load force components

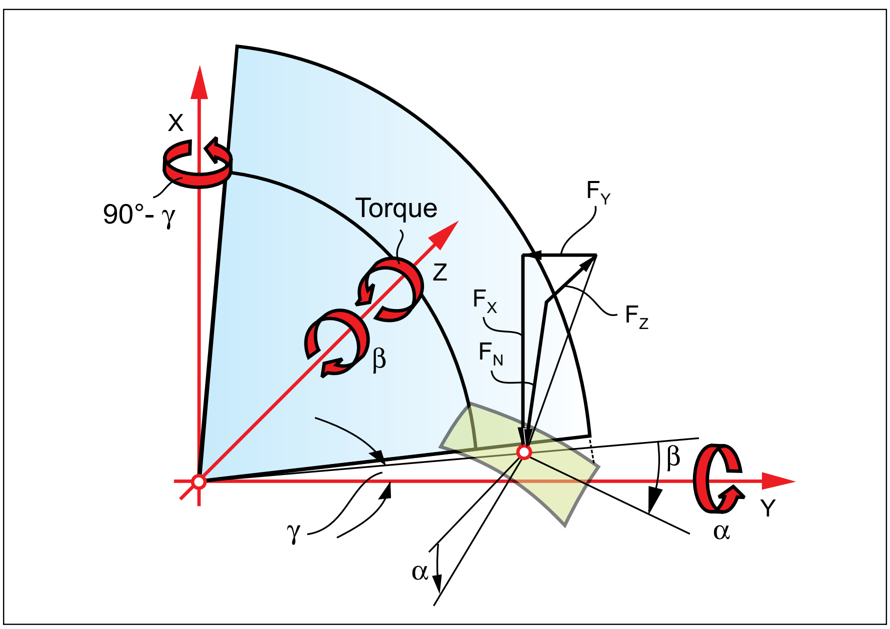


Figure 9—Bearing reaction load calculation.

can be assigned to one case in Figure 8. It is also possible to use the reduced curvatures (which are contained in the contact line graphs) in connection with surface roughness and normal force distribution to establish a Stribeck graph and find contact conditions (boundary condition, mixed contact and hydrodynamic contact) in different cases and in different flank areas.

Proposed Bearing Forces Calculation

A formula derivation to calculate bearing forces is shown below. The formulas are based on the assumption that one pair of teeth transmits the torque with one normal force vector in the mean point of the flank pair. Figure 9 shows a graphical representation of the following derivation:

• The observed flank is rotated with the mean point into the horizontal Y-Z plane. The force F_x is the tangential force that transmits the torque. The normal force vector is found by a vector rotation from an X-orientation and in three steps—pressure angle, spiral angle and pitch angle—shown in Equation 3. With knowledge of the tangential component, the solution of Equation 7 can be plugged into Equations 4, 5 and 6 in order to find a universal solution in Equations 8, 9 and 10 for the bearing loads of one particular member. In the case of a right-hand, spiral-angle β, the sign is positive. In the case of a left-hand, spiral-angle β, the sign is negative. If the torque develops a force F_x pointing in contrast to Figure 9 to the positive *X*-direction, then α and *T* must be applied with a negative sign.

The results of the simplified bearing force calculation are good approximations and reflect the real bearing loads for multiple-tooth meshing within an acceptable tolerance. A precise calculation is, for example, possible with Gleason bevel and hypoid gear software.

(*Next issue—Hypoid Gears*)

Crowning Techniques in Aerospace Actuation Gearing

Anngwo Wang and Lotfi El-Bayoumy

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Management Summary

One of the most effective methods in solving the edge loading problem due to excess misalignment and deflection in aerospace actuation gearing is to localize tooth-bearing contact by crowning the teeth. Irrespective of the applied load, if the misalignment and/or deflection are large enough to cause the contact area to reduce to zero, the stress becomes large enough to cause failure. The edge loading could cause the teeth to break or pit, but too much crowning may also cause the teeth to pit due to concentrated loading. In this paper, a proposed method to localize the contact bearing area and calculate the contact stress with crowning is presented and demonstrated on some real-life examples in aerospace actuation systems.

Introduction

The high-lift system of an aircraft composed of trailing and/or leading edge flaps increases the lift during takeoff, does flight controls during cruising and reduces the landing distance when the airplane touches down. This flight control system is usually composed of power control units, torque tubes, bevel gearboxes, offset gearboxes, leading-edge rotary actuators, trailing edge rotary actuators and leading-edge sector gears and pinions. The system also includes other protective components such as torque limiters, slip clutches, no-back devices and wing-tip brakes. Many of these components contain different types of gears that are usually highly loaded to increase the power-to-weight ratio.

Deflection and misalignment between a pair of meshing gears can become detrimental when the gears are edge loaded—generating noise and high bending and contact stresses. The deflection emanates from the high loading and the misalignment from wing bending or the deflection of the housing that supports the gears. Irrespective of the load, once the misalignment and/or deflection cause the contact area to vanish, the stress becomes large enough to cause problems.

AGMA 2001-B88 (Ref. 2), provides a misalignment factor for straight and helical gears, but it does not cover crowned gears. AGMA2003-B97 (Ref. 5) has a crowning factor of 1.5 for all bevel gears.

A way of localizing the gear contact pattern from line contact to point contact has been developed for reducing noise and vibration by Litvin (Ref. 1). Using a parabolic function of the rotational relationship between the cutter and the gear, one of the gears is crowned in both transverse and longitudinal directions so that the piece-wise transmission error can be transformed to a parabolic distribution.

The traditional way of crowning is by either plunging the cutter or changing the lead. The crowning is in the longitudinal direction and the contact is localized, but it will not be stabilized unless the amount of crowning is optimized.

The purpose of this paper is to find an optimized crown so that the contact pattern will not become too large and/or sensitive to fall outside of the tooth surface, or too small to cause an excessive contact stress.

Leading-edge rotary actuators. A cross section of a typical leading-edge rotary gear actuator is shown in Figure 1, and the schematic of the compound stage is shown in Figure 2. There are three meshes on each one of the planet gears. The center ring gear is usually the output and the end ring gears are fixed to the structure. The reaction forces from the ring gears on the compound planet gear bend the planet to a shape as shown in Figure 5. If the gears are not crowned, the planets are edge-loaded, thereby reducing the overall capacity of the actuator.

Trailing-edge rotary actuators. A

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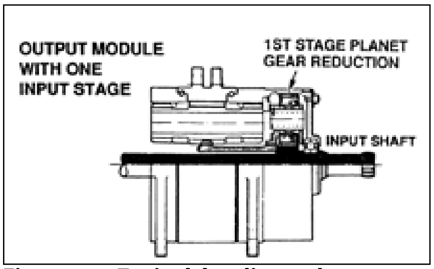

Figure 1—Typical leading-edge rotary actuator.

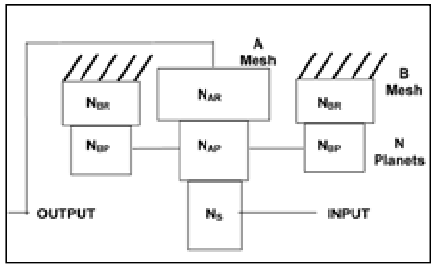

Figure 2—Schematic of the output stage of a typical leading-edge rotary actuator.

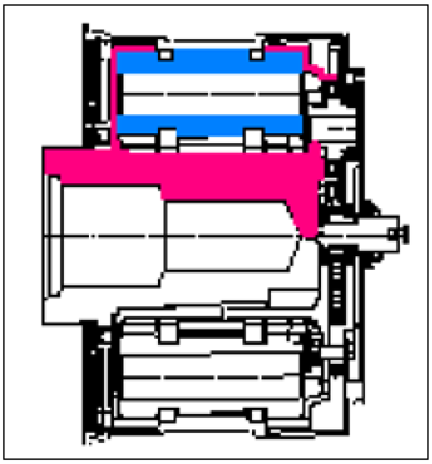

Figure 3—Typical trailing-edge rotary actuator.

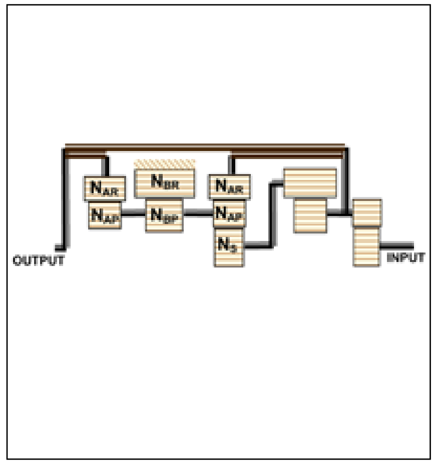

Figure 4—Schematics of the output stage of a typical trailing-edge rotary actuator.

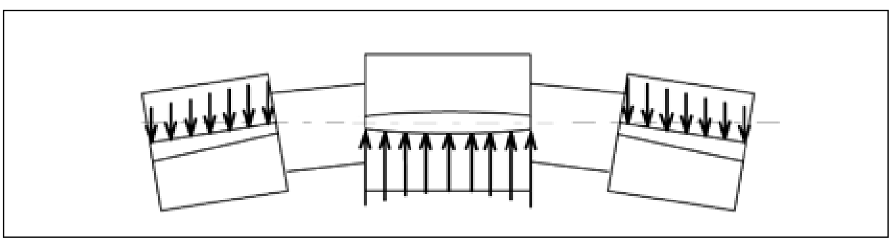

Figure 5—Typical compound planet crowning.

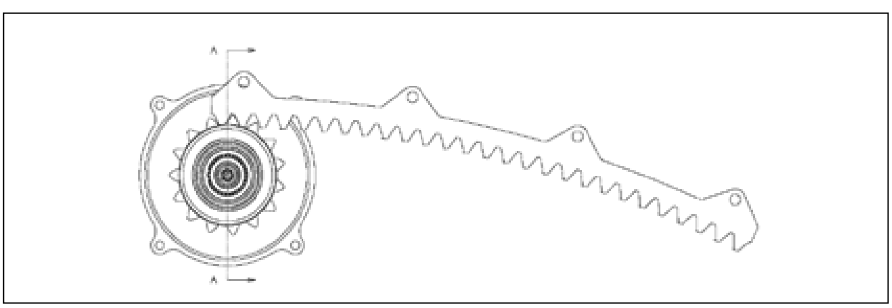

Figure 6—Typical leading-edge sector gear and pinion.

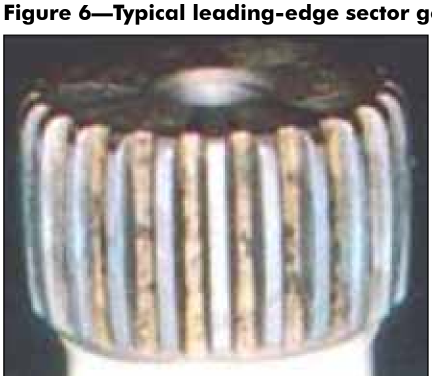

Figure 7—Typical crowned splines.

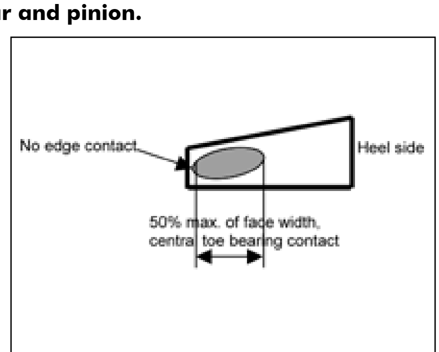

Figure 8—Desired contact pattern under light load.

cross section of a typical trailing-edge rotary gear actuator is shown in Figure 3, and the gear schematic is shown in Figure 4. The output consists of two load paths from two end ring gears. The sun gear driving the right end of the planet gear and stiffness difference between the right and left load paths causes the compound planet gear to tilt. Thus, the planet gear loads—due to meshing with the ring gears—have to be considered, and the misalignment from the two load paths needs to be included for selecting the optimum crown.

Leading-edge sector gears and pinions. A typical leading-edge sector gear and pinion is shown in Figure 6. The pinion has to be crowned to allow for wing bending if a spherical bearing mount is not possible. This gear set is exposed to the outside environment, and the grease or dry film lubrication may be compromised between maintenance servicing. The contact stress and crowning radius have to be optimized, so the risk of running dry is mitigated.

Torque tube splines. When misalignment is relatively small, a crowned spline can be used to transmit torque between two components. Figure 7 shows a typical crowned spline. Similar to the sector and pinion, the main purpose of the crowned spline is to localize the contact to avoid edge loading. It is usually a full crown. Because of the large misalignment, the contact area is considerably small. Usually, bending or contact stress is not an issue, but wear due to reciprocating rubbing on every revolution becomes significant. To evaluate wear life, one can follow Dudley's recommendation (Ref. 4) to calculate the contact stress.

Crowned bevel gears. A straight bevel gear with crowned teeth is called a Coniflex bevel gear. The curvature from the cutting process is to provide the needed misalignment capability.

Under light load, the contact pattern should be located at the central toe of the teeth (Fig. 8), and the length of the bearing contact should not exceed 50% of the total face width.

Under operating load, the contact pattern should be located at the central toe of the teeth (Fig. 9), and the length of the bearing contact should normally be 50–75% of the total face width.

There should be no edge loading under any circumstances. The V-H check is performed to validate that—under simulated misalignment—the contact ellipse should always be within the face width.

For the purpose of analysis, an equivalent spur gear can be used to simulate the bevel gear.

From all the above applications in a high-lift system, we can appreciate the importance of gear crowning. How to design, balance and position the contact region is the subject of the next section.

Optimization of Crowning

The contact stress in a spur involute gear set is usually calculated at the lowest point of single tooth contact (LPSTC) of the pinion. The transverse radii of curvature of the gear tooth profiles at this contact point are defined as in AGMA standards (Ref. 2):

$$\rho_1 = \sqrt{(R_{O1}^2 - R_{b1}^2)} - 2\pi \cdot R_{b1} / N_1 \quad (1)$$

$$\rho_2 = C_d \cdot \sin\phi_{op} \mp \rho_1 \quad (2)$$

where:

ρ_1 is the transverse radius of curvature of pinion at LPSTC; ρ_2 is the transverse radius of curvature of gear at highest point of single tooth contact (HPSTC); R_{O1} is the outside diameter of the pinion; R_{b1} is the base circle radius of the pinion; N_1 is the number of teeth of the pinion; C_d is the center distance of the gear set; ϕ_{op} is the operating pressure angle; and -/+ is for external and internal gear meshes, respectively.

The contact stress in a spur gear set with no crowning and no misalignment is defined in AGMA standards (Ref. 2):

$$S_c = C_p \sqrt{\frac{W_t}{d \cdot F \cdot I}} \quad (3)$$

where:

$$I = \frac{\cos\phi_{op}}{(\frac{1}{\rho_1} \pm \frac{1}{\rho_2}) \cdot d} \quad (4)$$

$$C_p = \sqrt{\frac{1}{\pi \cdot (\frac{1-\nu_1^2}{E_1} + \frac{1-\nu_2^2}{E_2})}} \quad (5)$$

where:

S_c is the contact stress; C_p is the elastic coefficient; W_t is the tangential load; d is the operating pitch diameter of pinion; F is the net face width; I is the geometry factor for pitting resistance; ν_1 and ν_2 are Poisson's ratio for pinion and gear respectively, and E_1 and E_2 are modulus of elasticity for pinion and gear respectively.

If a gear set is crowned, the crown is usually on the pinion. The contact stress calculated from Equation 3 considers only the contact stress without crowning. As AGMA does not have an equation for the contact stress with crowning, we propose using equations from Roark and Young (Ref. 3)—i.e.,

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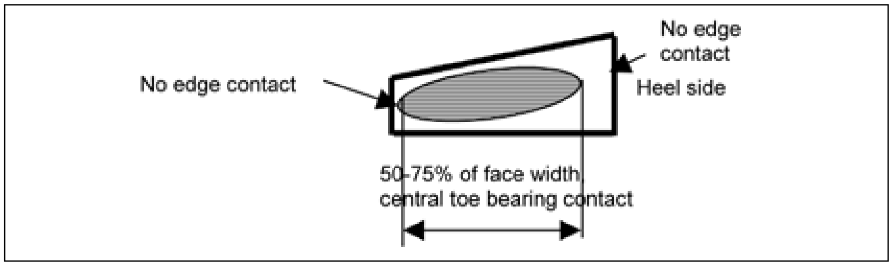

Figure 9—Desired contact pattern under operating load.

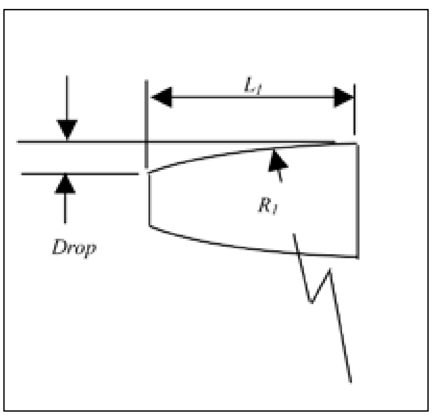

Figure 10—Gear crowning.

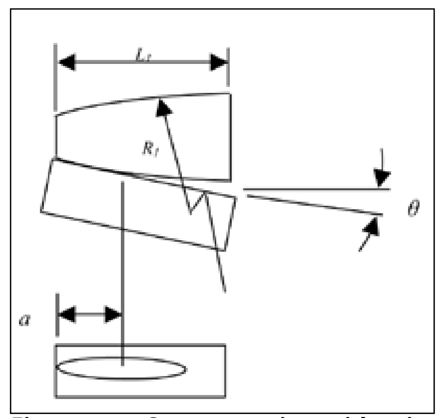

Figure 11—Gear crowning with misalignment and deflection.

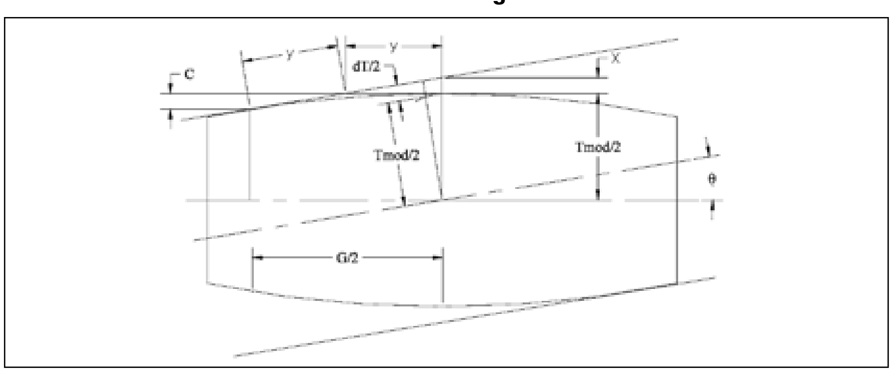

Figure 12—Derivation of crowning radius.

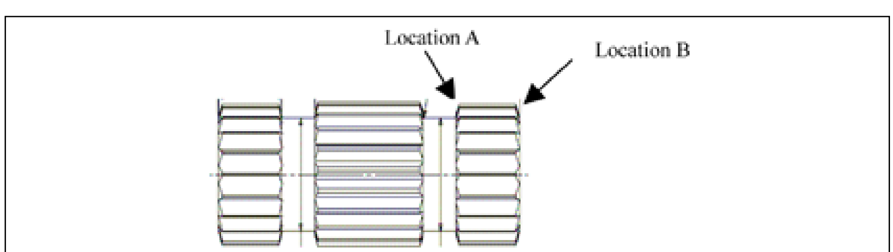

Figure 13—A triple planet gear.

the contact stress for the general case of two bodies in contact. The shape of the instantaneous contact area is an ellipse, and the contact stress is calculated by the following equation.

$$\sigma_c = \frac{1.5 \cdot P}{\pi \cdot a \cdot b} \qquad (6)$$

where:

$$P = \frac{W_t}{\cos\phi_{op}} \qquad (7)$$

$$a = \alpha \cdot (P \cdot K_D \cdot C_E)^{1/3} \qquad (8)$$

$$b = \beta \cdot (P \cdot K_D \cdot C_E)^{1/3} \qquad (9)$$

$$K_D = \frac{1.5}{(\frac{1}{\rho_1} + \frac{1}{\rho_2} + \frac{1}{R_1} + \frac{1}{R_2}) \cdot d} \qquad (10)$$

$$C_E = (\frac{1-\nu_1^2}{E_1} + \frac{1-\nu_2^2}{E_2}) \qquad (11)$$

where:

σ_c is contact stress for crowned gear pair; P is the normal load; a is the semi-length of the instantaneous contact ellipse in the face width direction; b is the semi-length of the instantaneous contact ellipse in the profile direction; a and b are geometrical coefficients (Ref. 3); R_1 is the crowning radius of the pinion; and R_2 would be infinite if the gear is not crowned.

Gear crowning is specified using the following equation, as shown in Fig. 10:

$$R_1^2 = (R_1 - Drop)^2 + L_1^2 \qquad (12)$$

where:

R_1 is crowning radius; *Drop* is the drop over the distance L_1, which is from the center of crown to the end of the tooth. The *drop* should include the deflection and misalignment.

The general rule for a good crown design should be that the contact pattern lies within the tooth face at the maximum misalignment condition.

$$R_1 \cdot \theta + a \le L_1 \qquad (13)$$

where:

θ is the angular displacement from the combination of misalignment and deflection. Depending on the amount of misalignment and deflection, with all the equations above, one can optimize the contact so that the contact stress is within the material allowable. Also, the contact ellipse is stabilized within the tooth face boundary without edge loading. Depending on the application, the optimization between the variables a, R_1, θ and L_1 can greatly influence wear life.

Some gears have more deflection than misalignment, as in the case of the compound planet gears shown in Figure 5, and the contact area is wide. Some gears are tilted by deflection, so the center of the crown is not at the center of the tooth face (called bias crown). And some gears have more misalignment than deflection, as in the case of crowned splines, and the contact ellipse is small compared to the face width. Here, the center of the crown is at the center of the tooth face (called full crown).

A crowned spline has one more limitation—the tooth thickness has to be modified from the standard because the minimum effective clearance is zero. The tooth thickness T_{mod} is dependent on R_1 and θ. From Figure 12, the following equations can be derived:

$$X = (T_{mod}/2 + dT/2)/\cos\theta \qquad (14)$$

$$y = X/\tan\theta \qquad (15)$$

$$G/2 = y \cdot (1+\cos\theta) \qquad (16)$$

$$C = (G/2) \cdot \tan\theta \qquad (17)$$

$$R_1^2 = (R_1 - C)^2 + (G/2)^2 \qquad (18)$$

where:

C is the *drop* in the normal plane; *G* is the total gage length; the gage from the center of the crown is *G/2*; and

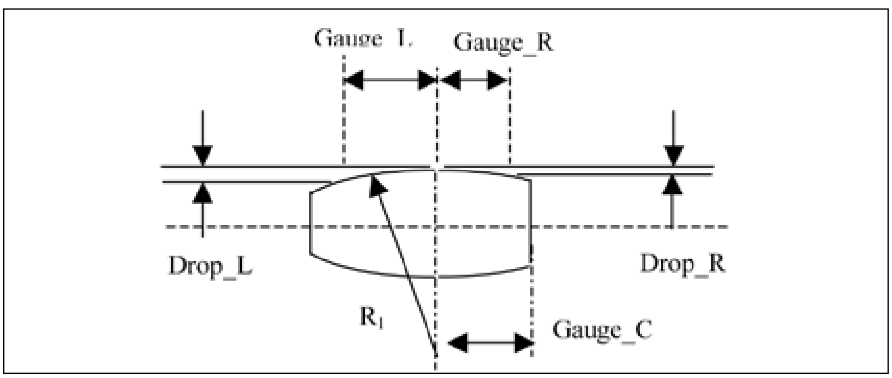

Figure 14—End planet gear crowning.

Figure 15—Damaged gear without crowning.

Figure 16—Good gear contact with crowning.

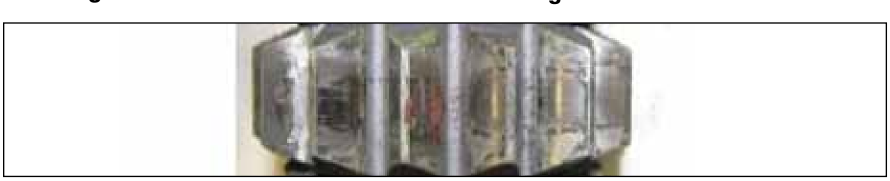

Figure 17—Contact pattern of crowned sector pinion.

dT is the clearance between the space width of the internal teeth and the tooth thickness of the external teeth.

From the above equations, the following relationship can be derived:

$$R_1 = \left[dT/2 + T_{mod}/2 \cdot (1-\cos\theta)\right] \cdot (1+\cos\theta)/\sin\theta^2 \qquad (19)$$

Numerical Examples

Example 1. A triple planet gear of a trailing-edge actuator is shown in Figure 13. The mating gears are all internal gears.

The tangential load at both ends is calculated as 3,600 lbf.

The relative deflection under this load is .0015 inch, and the misalignment due to backlash and runout from the ring gear and planet gear is .0023 inch total. The face width on the end gear is 1.44 inch. The misalignment is .0008 inch/inch slope. The relative slope under the load at point B in Figure 13 is .0011 inch/inch. The total slope is .0019 inch/inch on point A. At point B, the slope is .0015/1.44 less .0011, and is equal to –.00006 inch/inch. The total slope is .0008 –.00006 = .00074 inch/inch on point B. After solving simultaneous equations, the crowning radius is 143 inch, and the crowning center is .64 inch from location B. A bias crown is shown in Fig. 14. A contact stress value of 239 ksi is calculated. Compared to the baseline design of the crowning radius of 126 inch— crowning center is at the middle of the end tooth and the contact stress of 254 ksi—the contact stress is 6% better.

Example 2. An offset gear—with one bearing very close to the one end and another support at the other end—is shown in Figure 15. Because of excessive deflection, the gear is edge-loaded and pitted, as shown. The face width is .80 inch. The total slope including the deflection and misalignment is .0048 in/in. After solving the simultaneous equations, the crowning radius is 91 inch, and the crowning center is at the end of the tooth. A contact stress of 266 ksi is calculated under the maximum tangential load of 1,000 lbf. From Fig 16 we can see that crowning has eliminated the pitting problem, so that the full tooth is now sharing the load.

Example 3. A sector and pinion gear set in Figure 6 must accommodate the wing bending. Because of the environmental exposure, the contact stress must be low enough that running the gears without re-grease is possible. For a given misalignment, we would like to design a new crowning radius and face width, so the stress is low enough to eliminate the need for re-lubrication.

The baseline design is regularly lubricated, and maximum allowable misalignment is .0015 inch/inch. The face width is 1.1 inch, crowning radius 21.5 inch. The calculated contact stress is 312 ksi under the maximum operating tangential force of 3,800 lbf. After increasing the face width to 1.5 inch, the contact stress is reduced by only 8%. However, the increased face width comes with a weight penalty. One solution is to change to a material that has higher allowable contact. The pinion shown in Figure 17 was tested for a no re-grease application. It is clear that although the contact pattern is localized—as a result of the higher contact stress—the initial lubrication eventually degrades and micropitting and rusting will soon follow.

Conclusions

In this paper a proposed method to optimize the contact pattern and to calculate the contact stress with crowning is presented. Some real-life applications in aerospace actuation gearing with proposed crowning are demonstrated.

Deflection and misalignment in a gear set can be detrimental if the gears are edge loaded, generating noise and high bending and contact stresses. Deflection usually results from highly loaded gears, and misalignment from wing bending or deflection of the gear housing.

It is very important to have the right crowning, so the contact area is stabilized, and the possibility of edge loading—which leads to high contact and bending stresses—is reduced. These proposed methods have been successfully applied in finding the optimum crown, so the crown radius is not too large to cause the contact pattern to fall outside the tooth surface—or too small,which would result in excessive contact stress.

Although the method has been demonstrated here for spur gears, similar approaches can be applied to helical, bevel or other types of gears.

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Optimizing Gear Geometry for Minimum Transmission Error, Mesh Friction Losses and Scuffing Risk Through Computer-Aided Engineering

R.C. Frazer, B.A. Shaw, D. Palmer and M. Fish

Management Summary

Minimizing gear losses caused by churning, windage and mesh friction is important if plant operating costs and environmental impact are to be minimized. This paper concentrates on mesh friction losses and associated scuffing risk. It describes the preliminary results from using a validated, 3-D Finite Element Analysis (FEA) and Tooth Contact Analysis (TCA) program to optimize cylindrical gears for low friction losses without compromising transmission error (TE), noise and power density. Some case studies and generic procedures for minimizing losses are presented. Future development and further validation work is discussed.

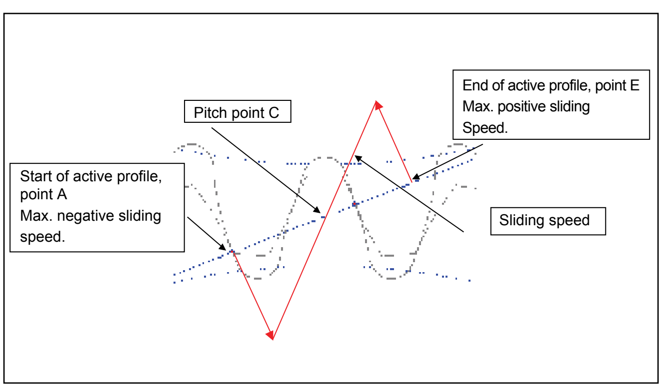

Figure 1—Variation in drive gear sliding speed with mesh phase (position).

Introduction

Cylindrical involute gears have many advantages over other gears. They are relatively easy to manufacture with standard tools; insensitive to center distance change; can accommodate modifications in microgeometry to account for elastic deflection and manufacturing errors; and have geometry that is mathematically straightforward and relatively easy to measure. Standards covering the rating and analysis of cylindrical gears—such as the ISO 6336 suite of standards and ANSI/AGMA 2101-D04—are well developed and applied worldwide.

Users of cylindrical gears demand continuous improvement such as increased power density, lower weight, reduced manufacturing costs, reduced noise, increased reliability and reduced operating costs. In recent years it has become more important to reduce environmental impact from plant operation.

Cylindrical involute gears are inherently very efficient—i.e., typically 98–99.5% per mesh. However, small improvements in efficiency will minimize overall system losses and reduce lubricant and cooling system requirements.

Gearbox losses occur from a number of sources:

- Churning losses—due to lubricant agitation—are geometry- and speed (pitch line velocity)-dependent. These can be minimized by using spray lubrication, dry sumps and internal gearbox baffles to minimize gear immersion as well as using smaller module and higher helix angle gears.
- Windage losses are geometry- and speed-dependent and can be minimized by modification to geometry (smaller module and higher helix angle) running in partial vacuums or light gases.
- Mesh friction losses, which are affected by speed, load, coefficient of friction and gear geometry.
- Bearing losses, which are affected by speed, load and gear geometry.
- Seal losses, which are seal type- and speed-dependent.

The work described in this paper concentrates on mesh friction losses. In a 2 MW installation, losses of between 10 to 40 kW occur with efficiencies of 98–99.5%. This power is lost as heat—which requires external cooling systems and control systems—adding to the cost of the plant. Lower gear friction improves operational efficiency and, if applied carefully, will reduce plant manufacturing costs and lubrication requirements.

Minimizing the mesh friction loss is of particular importance because it will also reduce the risk of scuffing failure and help to eradicate the need for lubricant additive packages that are costly and environmentally harmful. Scuffing risk is difficult to assess, and although there are two ISO Technical reports (Refs. 5–6) and the ANSI/AGMA standard 6011-I03/Annex B (Ref. 7) published on the subject, the safety factors that result from the analysis procedures often conflict, reducing confidence in the results and evaluation procedure. The accurate modeling of mesh friction in gears—including microgeometry correction, manufacturing and alignment errors and accounting for elastic deflection under load—is therefore important to minimize the mesh friction losses in cylindrical gear design and improve gear reliability.

The preliminary results from the development of a friction loss model are described in this paper. The work to model and minimize mesh friction losses was undertaken as part of a wide-ranging project funded by the European Union named X-GEAR. This targeted specifically wind turbine and automotive gear applications. However, the results from this work are generic and applicable to all cylindrical gear transmissions.

Background

Gear mesh friction. Figure 1 illustrates that as the tooth pair moves along the line of action, the combination of sliding and rolling changes throughout the mesh cycle. Pure rolling occurs at the pitch point (point C in Figure 1), but as contact moves away from the pitch point, sliding increases. Meshing gear pairs require a lubricating film to separate the gear surfaces, but if this film breaks down, a failure mode called scuffing occurs (Fig. 2). When the lubrication film breaks down, the gear tooth surfaces instantaneously weld together and are then pulled apart due to the combination of rolling and sliding that occurs during the mesh cycle. Gear lubricants have been developed over many years to prevent this with extreme pressure (EP) additives, generally sulfur-based, which bond to the gear surfaces and thus prevent metal-to-metal contact. However, the additive packages make gear oil unpleasant to handle and significantly increase the environmental impact of the lubricant when it is disposed.

Figure 2—Scuffed gear sample from Design Unit's 160-mm center test rig.

Gear scuffing is difficult to predict, but several standards (DIN3991, ISO/TR13989-1 and ISO/TR 13989-2 (Refs. 5–7) provide procedures to estimate a safety factor for scuffing. These procedures use the gear macrogeometry, the calculated load distribution factors from the gear accuracy and the estimated shaft deflections to estimate scuffing risk. The standards provide good general guidance but fail to consider the important effect gear microgeometry has on the local tooth surface loads and thus the localized scuffing risk. The microgeometry of a gear is the intentional departure from a standard gear form that can optimize its performance by improving load distribution and minimizing transmission error and noise by compensating for deformation and misalignments present in all loaded systems. It is important that this is considered as part of the modeling process.

Minimizing friction losses in gears is straightforward in principle, i.e.:

- Minimize sliding speed [m/s] by reducing the height of the gear teeth—either by using a smaller module or simply reducing the addendum and dedendum of the gear, sometimes known as a stub tooth gear form.
- Reduce the peak tooth loads by applying flank cor rections for calculated elastic deflections and improv ing the gear accuracy and alignment within the gear case.

continued

- Reduce self-induced dynamic loads by minimizing transmission error.
- Reduce the mesh friction coefficient by improving lubricant additives, surface finish and applying low-friction coatings.

In practice, consideration has to be given to balancing the requirements of low-friction-loss gears with key requirements of maintaining power density, reliability, low noise and low cost, and to minimize sensitivity to manufacturing and alignment errors.

Friction power loss. Friction power losses (P_L) in gears are dependent on the normal force (F_N), coefficient of friction (μ) and the sliding speed of the surfaces (ν_g) shown in Equation 1:

$$P_L = \mu N v_g \quad (1)$$

Each of these quantities varies through the mesh cycle, depending on the instantaneous position of the mesh point between A (start of active profile) and E (end of active profile) shown in Figure 1, but they also vary across the face width (b) as discussed below:

- The normal force (F_N) depends on the number of teeth in mesh (affected by transverse contact ratio and overlap ratio) and load distribution due to manufac turing errors and elastic deflection of the gear teeth, the gear shafts and housing. The actual load is required at each phase of the gear mesh along the path of contact (x) from (A–E) in Figure 1 to accurately estimate gear losses.
- The coefficient of friction (μ) will vary with sliding speed. It is likely that the coefficient of friction will be higher at the entry to the mesh and the static fric tion at the pitch point will be different.
- The sliding speed (ν_g) varies linearly with distance along the path of contact from A to E, with $\nu_g = 0$ at the pitch point C in Figure 2. This can be calculated directly.

Thus the equation derived for power loss (W) in real gears, with geometry errors, flank relief and elastic deflection effects is given by Equation 2:

$$P_L = \frac{1}{b\,P_{et}} \int_{o}^{z=b} \int_{A}^{E} \left[\mu(x)\, F(x)\, v_g(x)\right] d_x\, d_z \quad [\mathrm{W}] \quad (2)$$

where:

P_{et}	base pitch (transverse), mm
$\mu(x)$	coefficient of friction
$F(x)$	local mesh load, N
$\nu_g(x)$	sliding speed, mm/s
b	face width, mm

The accurate assessment of Equation 2 requires accurate knowledge of the instantaneous mesh load $F(x)$. This is beyond the scope of standard gear stress analysis procedures defined in ISO 6336 (gear stress analysis standard) as detailed mesh deflection values, gear geometry (including predicted errors and the gear designer's specified helix and profile correction), and dynamic loads are not accurately modeled in the standard.

Existing work. There has been much work in recent years to minimize mesh friction. The EU-funded research project "Oil-Free Powertrain" (IPS-2001-CT-98006), a project coordinated by the VDMA (German Engineering Federation) in Germany, completed a systematic review of gear losses with the ambitious target of producing a lubricant-free powertrain (Ref. 1). The effect of geometry parameters—i.e., module (tooth size), addendum modification, ratio, helix angle, pressure angle and face width on total gear losses was investigated. The results showed:

Module (M_n)—Reducing the module reduces sliding speed but increases root bending stress. This effect can be minimized by controlled shot peening or increasing the helix angle.

Pressure angle (α_n)—Increasing the pressure angle reduces the contact stress—but also reduces the transverse contact ratio—which can increase the mean tooth load and bearing loads.

Addendum (h_a)—Decreasing the addendum reduces the sliding speed but also reduces the contact ratio and increases tooth stiffness, resulting in an increased sensitivity to geometry errors.

Helix angle (β)—Increasing the helix angle increases the overlap ratio, increases the transverse pressure angle and reduces transverse contact ratio, but increases axial bearing loads.

Addendum modification factor (x)—Increasing the addendum modification factor will increase the operating pressure angle and increase sliding speed at the tip, unless the mating gear is also adjusted.

Topping factor (k)—Changing the outside diameter without changing the cutting tool is called topping the gear. It allows gear geometry to be changed without changing the manufacturing tool. Positive (+) topping reduces the outside diameter (d_a) of the gear.

Reviewing the data published by the Oil-Free Powertrain project shows that the strongest correlation between reducing power loss and geometry modifications is by either minimizing module or reducing the transverse contact ratio by using a stub tooth gear geometry. Both have the same effect of reducing sliding speed, but the stub tooth geometry does not suffer from the reduced bending strength that affects the smaller module size.

These changes reduce the load contact line length, increasing contact loads and therefore also increasing contact stress. Two methods to compensate for this are to either increase the face width—with a resulting increase in gear manufacturing costs (due to larger bearing spans, gear blanks, gear case and increased weight)—or to increase the pressure angle of the gears, which increases the relative radius of flank curvature and thus reduces the Hertzian contact stress. It should be understood that for a given material and manufacturing route, the load-carrying capacity of a gear is proportional to its volume. Thus a change in a one-geometry parameter requires a proportional change in a second- geometry parameter.

Many of these changes in geometry can have potentially conflicting effects on gear performance. Throughout this work to minimize losses, it is imperative that good gear design practice is followed and that TE is minimized to reduce dynamic loads and gear noise.

Implementation of the Loss Calculation

GATES. In the early 1990s, the Design Unit (at Newcastle University) identified a need to improve the modeling of cylindrical gears and developed a 3-D FEA and TCA program to optimize the gear macrogeometry (module, helix angle, pressure angle, etc.), and gear microgeometry (flank relief/profile, tip/root relief and helix correction and crowning). It is used to estimate mesh forces, bending stresses, contact stresses and loaded TE. The model, known as *DU-GATES* (*Gear Analysis for Transmission Error and Stress*) was initially validated by a series of tests using an instrumented power recirculating test rig (back-to-back configuration), that can be run at 6,000 rev/min and 8 MW (Refs. 3, 8–9).

Transmission error was verified by measuring dynamic bearing loads, and mesh stiffness by measuring load distribution across the face width with strain gauges. It has since been successfully used for optimizing gear designs in conjunction with ISO 6336 analysis methods on a wide range of applications including marine gear, automotive, aerospace and industrial transmissions over a 15-year period.

In 2007 the software was transferred to Dontyne Systems Ltd. and renamed *GATES*. The development of the model continued with significant improvement in usability, visualization of results and extension of its analysis range with the added capability to estimate mesh friction losses.

The model works in two stages:

- A 3-D FEA to establish the stiffness matrix of the gear flank. This requires the definition of the gear macrogeometry, bore or shaft size and torque direction and rotation directions. Provided the geometry is unchanged, it requires running only once and takes typically 5 to 15 minutes to run. Post-processing the FEA compliance data into a series of curves for compliance and stress is performed, thus defining the compliance of any point on the tooth surface. It allows up to 120 points per contact line to be used in the subsequent TCA analysis.
- A TCA that includes the arrangement, load conditions, gear geometry errors, mounting errors and detailed microgeometry. This takes typically one minute to run and is used to investigate relief strategy, sensitivity to alignment errors and gear manufacturing errors. It calculates contact loads, bending stress, contact stress (by analytical methods), mesh friction power loss, peak power loss, loaded TE, mesh stiffness variation, axial load shuttle for a defined load condition and speed. Typically, 32 phases of mesh are analyzed.

Table 1—160 mm center test rig gear specification

Parameter	160 mm center test gears	
	Z 1	Z 2
Teeth (z)	33	34
Module (M_n)	4.5	4.5
Pressure angle (α_n)	20°	20°
Helix angle (β)	18.3535°	18.3535°
Additional mod. coefficient (x)	0.0	0.0
Outside diameter (d_a)	166.61	171.39
Root diameter (d_f)	145.01	149.79
Tooth height (h/M_n)	2.4	2.4
Root fillet radius (ρ_{ao})	0.590	0.587
Facewidth (b)	44.0	44.0
Accuracy (ISO 1328)	5	5
Profile crown (C_α)	–	–
Helix crown (C_β)	–	–
Tip relief	–	–
Operating speed (rev/min)	3000	2911.8
Torque (Nm)	4000	4132

An important parameter that has not been discussed is the value selected for the coefficient of mesh friction. This value is speed- and lubricant-dependent and will vary with mesh position through the contact region. It is known that mesh friction will be higher at the start of mesh engagement, and that at the pitch diameter, the rolling or static friction coefficient will also be higher, but for the purposes of this initial analysis, it has been assumed to be constant through the mesh region. A coefficient of 0.05 has been used for all the initial analysis work, although this is higher than is measured in some studies (Ref. 2).

Scope of geometry modifications to minimize friction losses. Many gear designs that have the specific objective of reducing losses result in a geometry that is significantly different from conventional involute gear designs, and may not be suitable for existing stress analysis methods. It is important to realize that a low-loss design should deliver minimum noise and maximum power density as primary objectives, and thus low-loss is considered a secondary design objective. To adhere to appropriate design practice and commonly used standards such as ISO 6336, the scope of the geometry modi-

continued

fications in this project have been limited by:

- transverse contact ratios of $\varepsilon_\alpha > 1.0$
- non-stubbed tooth forms
- maintaining pressure angles to reduce excessively high mesh forces, shaft deflections and bearing loads

Example. The 160-mm power recirculation test rig will be used as part of the validation process with the helical gear geometry specified in Table 1. The gears are highly loaded in the rig with powers in excess of 1.3 MW.

To begin, a calculation package was used to determine the characteristics of the nominal design according to ISO 6336 (Authors' note: The version of ISO 6336:2006 used in the analysis includes Technical Corrigendum 1, issued June 1, 2008). Examination of the ISO 6336 stress analysis in Table 2 shows that the gears are highly stressed and that bending fatigue failure is probable (see bold-type data in Table 2). Increasing the module and reducing tooth numbers is the obvious solution to increase bending strength, but Höhn (Ref. 1) shows that increasing module will increase friction losses. Also, to maintain the integer overlap ratio, a higher helix angle is required—higher than commonly used by industry. Work at the Design Unit has shown that increasing bending fatigue strength by 40% is practical by shot peening, and thus, the gear bending strength should be acceptable (Ref. 4). This is significantly more than the 10% allowed with ISO 6336:2006.

A 1.03:1 ratio was selected to avoid uneven flank damage. With a nominal ratio close to 1:1, mesh sliding speeds

Table 2—ISO 6336 Stress Analysis

**************************************				pinion material	Eh		
* DONTYNE SYSTEMS *				wheel material	Eh		
* www.dontynesystems.com *				hardness	HV	700	700
**************************************				material quality			
* (University of Newcastle Upon Tyne *				roughns flnk/µm	Rz	6.0	6.0
* Design Unit Report Style Format) *				roughns root/µm	Rz	15.0	15.0
**************************************				viscosity @ 40C	nu	160	
* Dontyne Systems ISO 6336 Rating *				pitting permitted?		no	no
* V 4.10 Bld 10 14/04/2009 18:17:42 *				reversing duty?		no	no
* 33-34 *							
**************************************				applicatn factr	KA	1.000	
number of Teeth	z	33	34	required life/h		1200	
normal module	mn	4.500		load cycles	NL	2.2e+08	2.1e+08
transvrs module	mt	4.776		mesh power/kW	P	1256.64	
gear ratio	u	1.030		torque/Nm	T	4000.0	4121.2
centres	a	160.00		**tr tang force/N**	**Ft**	**50757.6**	
facewidth	b	44.00	44.00	speed/RPM	n	3000.0	2911.8
reference diam	d	157.61	162.39	**pitch line speed/m/s**		**24.8**	
base diameter	db	147.02	151.48	tip relief/µm	Ca	30.0	
tip diameter	da	166.61	171.39				
root diameter	df	145.01	149.79	helix modifictn	none		
tooth depth	h	10.800	10.800	fav contact pattn posn verifctn?		no	
internal diameter		0.00	0.00	wheel web thickness			
norm pres angle	alphan	20.0000		pinion offset	s	0.000	
transv pres ang	alphat	21.1217					
wkng tr pr ang	alphawt	21.1217					
ref helix angle	beta	19.5778					
base helix ang	betab	18.3535					
prof shift coef	x	-0.000	-0.000	hx dev elast/µm	fsh	0.0	
sum of "" coefs	Sigx	-0.000		quality grade	q	5	5
bsc rack dedend	hfP/mn	1.400	1.400	hx dev manuf/µm	fma	5.0	
bsc rk root rd	rofP/mn	0.390	0.390	init'l misal/µm	Fbetax	6.1	
residual protub	spr/mn	0.000	0.000	run-in misal/µm	Fbetay	5.2	
root chord lgth	sFn/mn	2.163	2.169	stiff(N/mm/µm)	cgamma	16.6	
bending mom arm	hFa/mn	1.093	1.095				
root radius	roF/mn	0.583	0.581				
tr contct ratio	epsalpha	1.545		overlap ratio	epsbeta	1.043	
-----FACTORS-----							
resonance ratio	N	0.529		dynamic fct	KVB	1.055	
-----TOOTH FLANK-----				-----TOOTH ROOT-----			
face load factr	KHbeta	1.030		face load factr	KFbeta	1.023	1.023
transv load fct	KHalpha	1.000		transv load fct	KFalpha	1.000	
zone factor	ZH	2.376		form factor	YF	1.410	1.405
elasticity fctr	ZE	190.272		stress conc fct	YS	1.890	1.897
single pair fct	ZB/ZD	1.000	1.000	notch parameter	qs	1.854	1.867
cont ratio fctr	Zepsilon	0.805		cont ratio fctr	Yepsilon	0.687	
helix ang factr	Zbeta	1.030		helix ang factr	Ybeta	0.837	
life factor	ZN	0.956	0.957	life factor	YN	0.918	0.918
lub inf fct	ZLZVZR	0.978	0.978	notch sensy fct	YdrelT	0.994	0.994
work-hardng fct	ZW	1.000		surface factor	YRrelT	0.976	0.976
size factor	ZX	1.000		size factor	YX	1.000	1.000
-------CONTACT STRESS (N/mm²)-------				-------BENDING STRESS (N/mm²)-------			
allw stress num	sgHlm	1500.0	1500.0	allw stress num	sigFE	922.0	922.0
permiss stress	sigHP	1402.2	1403.4	permiss stress	sigFP	820.6	821.2
"" (reference)	" ref	1466.5	1466.5	" (reference)	" ref	894.0	894.2
contact stress	sigH	1484.0	1484.0	root stress	sigF	617.5	617.0
safety factor	**SH**	**0.94**	**0.95**	**safety factor**	**SF**	**1.33**	**1.33**
min safety fctr	SHmin	1.00		min safety fctr	SFmin	1.40	

Angles are in ° and distances in mm unless otherwise stated.

1. The version of ISO 6336:2006 used in the analysis includes technical corrigendum 1 issued 1st June 2008

are balanced. With other ratios, sliding speed may be biased more at the entry side or exit side of the mesh. This effect can be minimized by changing the addendum modification factors (*x*) of the gears, but care should be taken to ensure that good design practice is maintained, the tooth crest width is acceptable (say > 0.30 m_n) and tooth bending strength and contact strength are maintained. Given these considerations, the macrogeometry was determined as suitable for high-performance gear testing using the following criteria:

1. The geometry is compatible with the scope of ISO 6336.
2. The geometry has an integer overlap ratio (ea) to minimize potential transmission errors and thus reduce dynamic loads.
3. The helix angle of 18.35º is within the range used by many industrial and automotive gears, so these are representative of 'real' gears.
4. Controlled shot peening is used to increase bending strength without increasing the module.
5. The sliding speeds are reasonably well balanced at entry and exit.
6. The test rig is very rigid and the gears well aligned, so alignment errors should be minimal under test load conditions (< 10 µm).
7. A hunting ratio was selected to ensure contact fatigue damage is evenly distributed around the gear.

The results from the initial *GATES* TCA are for gears under the subject load conditions without flank corrections. Figure 3 shows the predicted contact load (N/mm) over a single tooth with a plot of the length of roll of the driving gear with face width. The length of roll is from the start of active profile (SAP) of the driving gear at 12.62 mm at the root, to the end of active profile at +12.62 mm at the tooth tip. The two peaks are both close to 963.8 N/mm and occur at the entry and exit of the tooth into the mesh region (this is a helical gear). There are two dotted lines on the chart representing the theoretical start and end of active profile (contact region) of the gear pair. Contact is obviously occurring beyond this region and is due to elastic deflection of the teeth under load. This extended contact region (non-conjugate contact) occurs in the mesh region where the highest sliding speeds occur and thus the greatest potential for friction losses and scuffing failure. Modeling this region accurately is obviously of paramount importance for realistic friction losses and is the reason that the 3-D FEA and TCA method was selected to evaluate gear losses, instead of an analytical method based around an ISO 6336 procedure.

GATES estimates contact stress using classical analytical methods from the tooth load data and instantaneous radius of curvature, thus avoiding the need for a fine FE mesh to predict contact stress. Contact stress is illustrated in Figure 4 showing a maximum contact stress of 1,864.7 N/mm^2.

The combination of the tooth load data (Fig. 3) and sliding speed data (Fig. 5) are used to estimate the mesh friction

continued

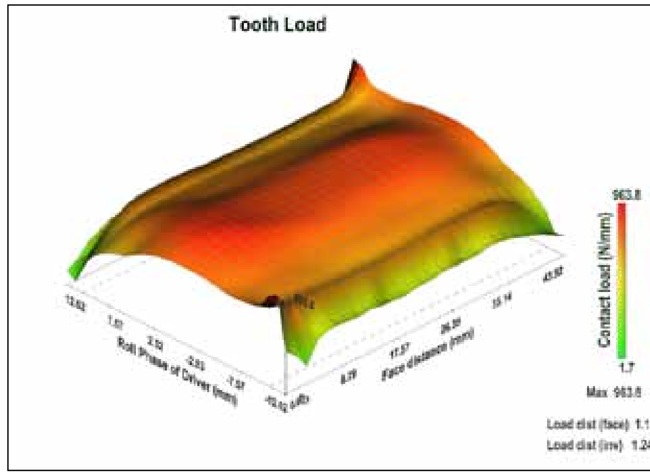

Figure 3—Tooth load: no flank relief.

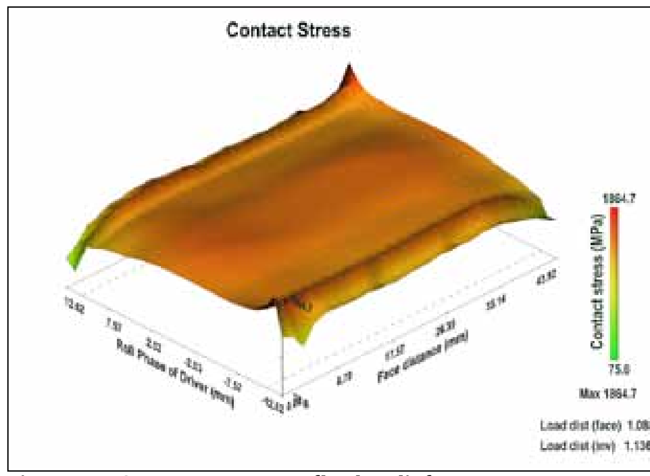

Figure 4—Contact stress: no flank relief.

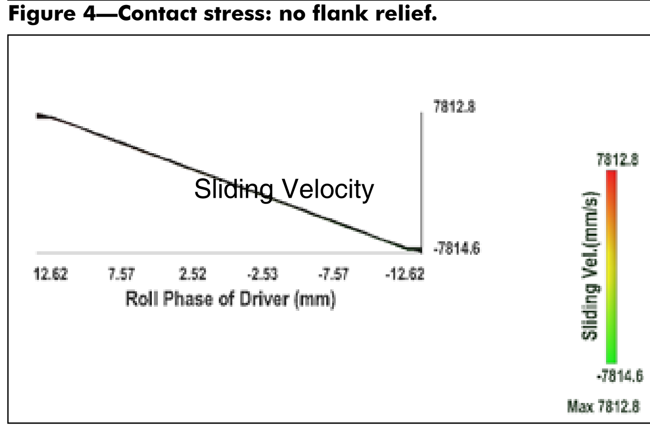

Figure 5—Mesh sliding speed, mm/sec.

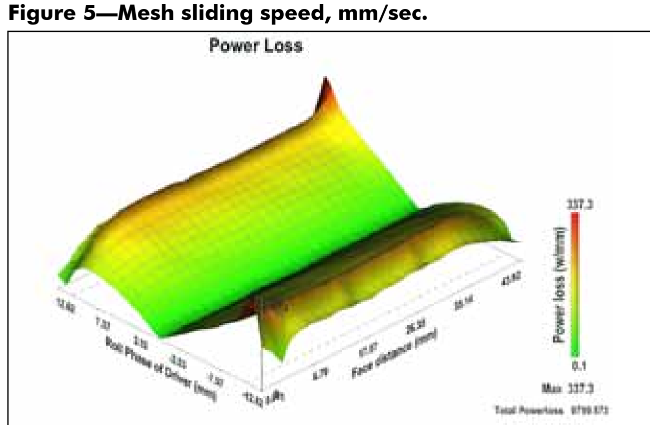

Figure 6—Mesh friction losses: no flank relief.

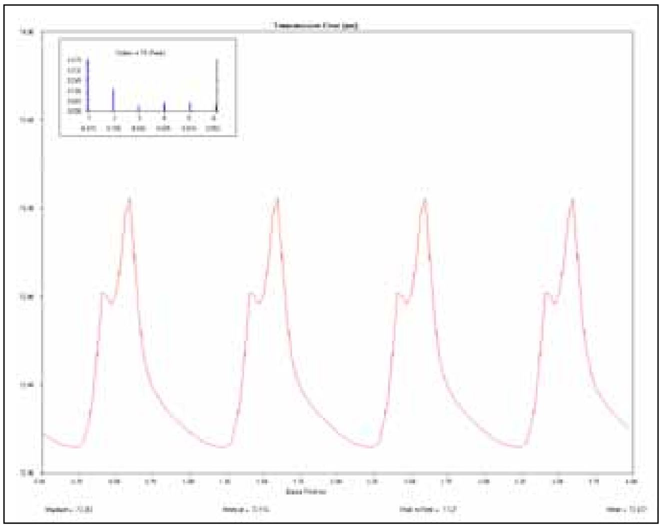

Figure 7—TE 1.27-mm pk-pk: no flank relief.

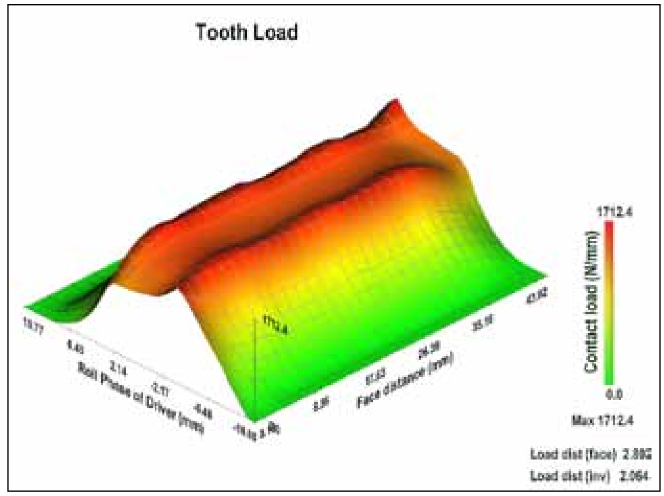

Figure 8—Contact load: 82-mm linear relief starting at the HPSTC contact stress.

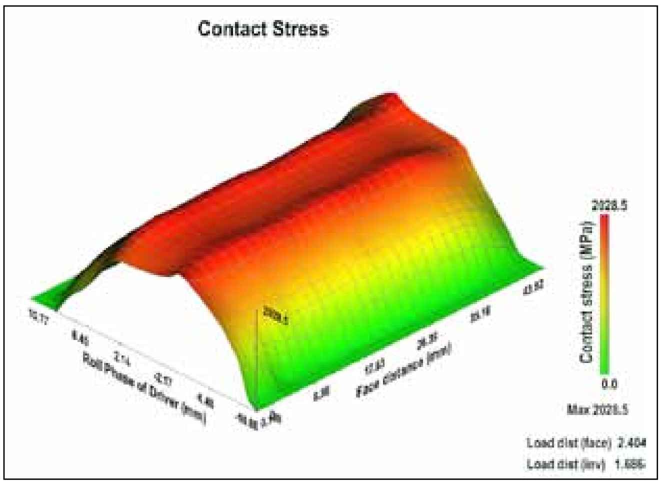

Figure 9—Contact stress: 82-mm linear relief starting at the HPSTC power loss.

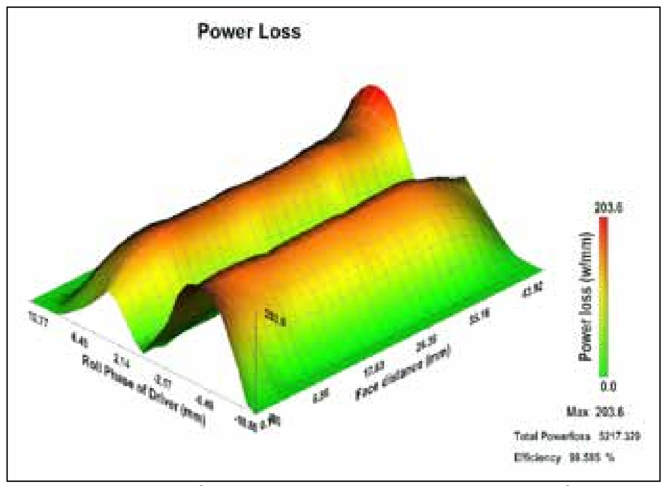

Figure 10—Mesh friction losses: 82-mm linear relief starting at the HPSTC.

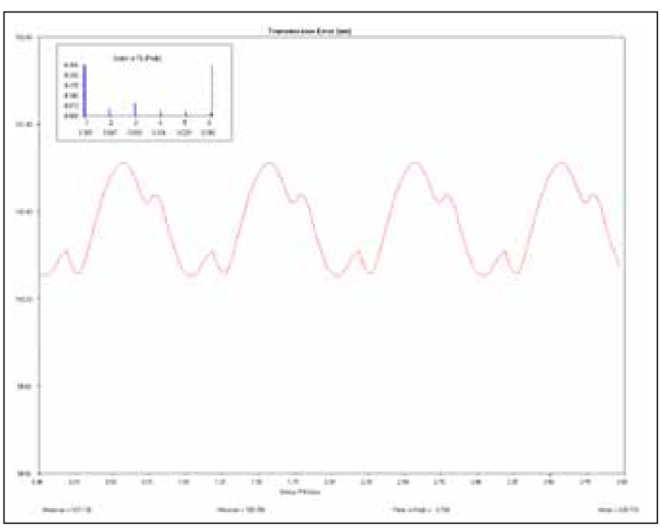

Figure 11—TE 0.784-mm pk-pk: 82-mm linear relief starting at the HPSTC.

losses (Fig. 6). It is important to note that the power loss calculation (Eq. 2) is modified to account for the extended area of contact (Fig. 3). The points A and E in Figure 1 and Equation 2 are extended due to this effective increase in the theoretical contact region.

The power loss of 9,799 W is the reference value for the proposed tests, equivalent to 99.220% mesh efficiency. A maximum predicted power loss of 337.3 W/mm indicates the maximum power loss region and thus where the most likely scuffing initiation point is likely to be.

Figure 7 shows the predicted loaded TE for the gears of 1.27 μm peak-to-peak value. This is low for gears without flank relief and is a result of the integer overlap ratio selected for the gear macrogeometry. Low TE will minimize the unknown effect of dynamic loads on the gears in the test program.

For this example, two tip relief strategies were tested with *GATES* that are applied in industry:

- Linear tip relief, starting from the HPSTC (highest point of single tooth contact)
- Parabolic tip relief starting from the pitch circle diameter

Table 3—Summary of 160mm Test Gears *GATES* Analysis Results					
Parameter	No relief	82 µm linear tip relief	82 µm parabolic tip relief	90 µm parabolic tip relief	100 µm parabolic tip relief
Maximum contact load, N	964	1712.4	1491.6	1532	1580.9
Maximum contact stress, N/mm^2	1864.7 (100%)	2028.5 (108.7%)	1885.7 (101.1%)	1911.1 (102.5%)	1941.4 (104.1%)
Power loss, W, (µ = 0.05)	9799 (100%)	5217 (53%)	5556 (56.7%)	5363 (54.7%)	5187 (52.9%)
Efficiency (µ = 0.05)	99.220%	99.585%	99.558%	99.573%	99.587%
Peak power loss, [W/mm]	337.3 (100%)	203.6 (60.3%)	201.3 (59.7%)	186.8 (55.3%)	191.3 (56.7%)
Transmission error, µm, (pk–pk)	1.27 (100%)	0.78 (69.2%)	0.95 (74.8%)	0.80 (62.9%)	0.83 (65.4%)

The amount of relief was estimated from the mean mesh deflection calculated from Equation 3:

$$F_{ro} = \frac{F_t}{b\,C_\gamma} \qquad (3)$$

where:

F_t tangential force, N

b face width, mm

C_γ combined mesh stiffness, N/mm/µm—use 14–18 as a guide value—ISO overestimates the stiffness, in our experience.

For the subject gears and load condition—and assuming that for a highly loaded gear (b = 44 mm and F_t = 50757.6 N), a mesh stiffness of 14 N/mm/mm is appropriate. Equation 3 predicts a mean mesh deflection of 82 µm. The mean mesh deflection value was used to define the tip relief amount and is always a good estimate for the sum of tip relief and crowning height combined. The resulting *GATES* analysis results for the linear relief strategy are illustrated in Figures 8–11and summarized in Table 3.

The results for 82 µm parabolic tip relief starting at the reference diameter are illustrated in Figures 12–15. Comparing the contact stress shape for the linear tip relief, Figure 9—with the parabolic relief in Figure 13—shows that peak stresses at the intersection of the linear tip relief with true involute form have vanished. This intersection point is often where micropitting failures are observed with its potential to initiate macropitting and flank-initiated bending fatigue failures. In general, the TE and losses are slightly higher with a parabolic relief strategy, although the overriding benefit of reduced contact stresses by 7% would dictate that a parabolic relief strategy is recommended.

The effect of increasing the amount of parabolic tip relief is shown in Table 3. Although the changes are small, increasing the tip relief to 90 µm clearly has some benefits and manufacturing variability will have little effect on gear performance. Additional work (Ref. 9) shows that peak contact stress with parabolic tip relief is less sensitive to profile slope and helix slope manufacturing errors.

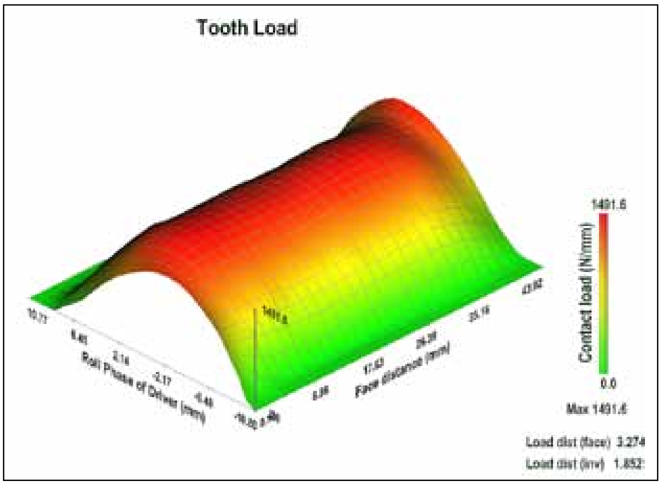

Figure 12—Tooth load: 82-µm parabolic relief starting at the reference diameter.

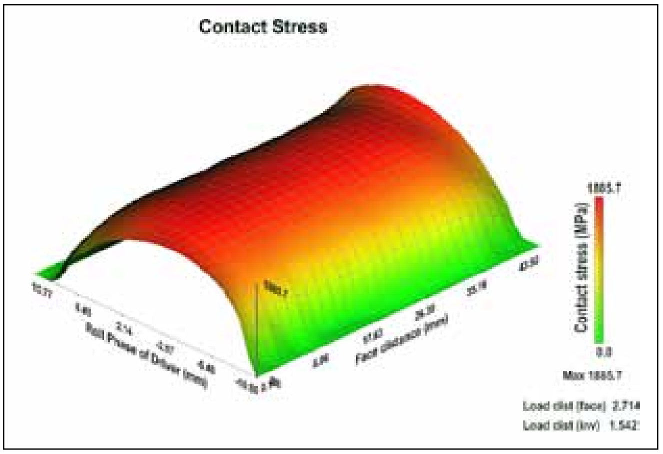

Figure 13—Contact stress: 82-µm parabolic relief starting at the reference diameter.

continued

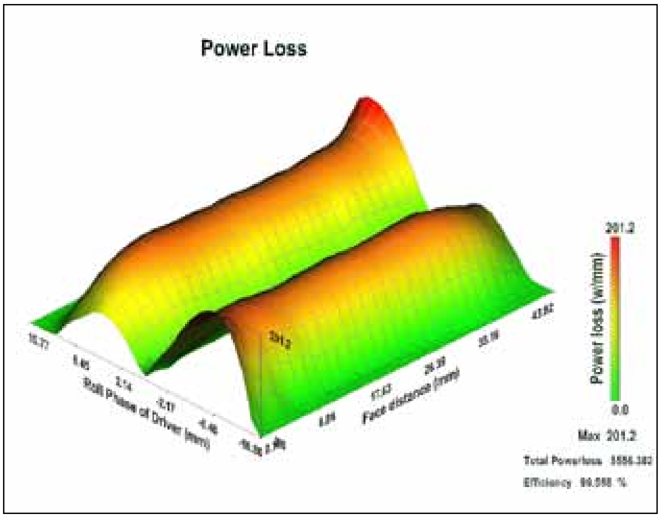

Figure 14—Mesh friction losses: 82-μm parabolic relief starting at the reference diameter.

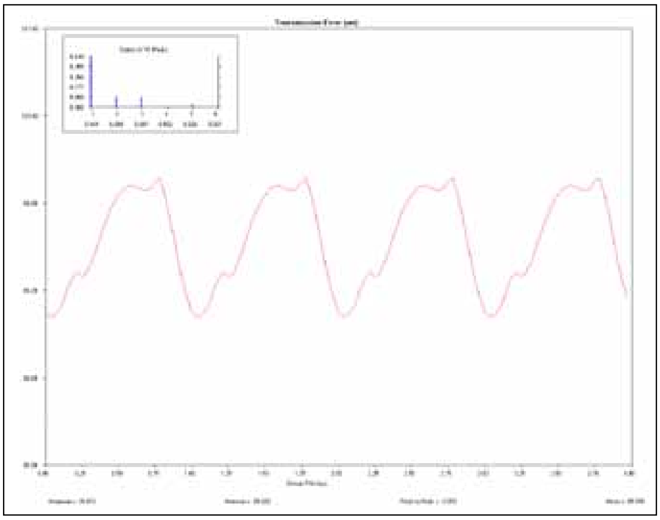

Figure 15—TE 0.95-mm pk-pk: 82-mm parabolic relief starting at the reference diameter.

A final benefit that is not illustrated in this example is that in most practical gears, helix crowning is required to minimize the increase in peak contact and bending stress due to gear alignment errors. The *GATES* analysis shows that minimizing the crown height applied to gears will minimize the increase in TE and contact stress (Ref. 10). The *GATES* TCA model includes alignment errors, profile slope errors and shaft and bearing compliance data to accurately assess these effects.

Applications

A number of "real gear applications" were investigated as part of the X-GEAR project. A few are summarized in an Appendix to this article, which can be found online at *http://www.geartechnology.com/issues/0810*.

Discussion

The work completed to date predicts that low-friction-loss gears can be designed without compromising performance while retaining standard gear geometry. Applying good design practice will result in gears with low friction loss and scuffing risk. Significant points to consider during the design are:

- Adequate contact stress and bending stress safety factor assessed in accordance with ISO 6336/AGMA 2101.
- Maximize permissible stresses using high-strength material and heat treatment.
- Maximize bending strength by increasing the root fillet radius.
- Minimize sliding speeds at the extremes of contact (start of active profile and end of active profile) to minimize scuffing risk and minimize losses by reducing module size.
- Shot peening should be considered to increase bending strength if supported by a cost/benefit analysis.
- Balance sliding speeds at the extremes of contact (start of active profile and end of active profile) to minimize losses with appropriate addendum modification factors (x).
- Maximize the length of contact line using helical gears with integer overlap ratio and thus minimize the change in length of contact line through different contact phases.
- Minimize noise and dynamic loads by minimizing TE using optimized macrogeometry and microgeometry.
- Optimize the tip relief strategy using the approximate Equation 3 and minimize discontinuities in the flank profile using parabolic tip relief. Apply appropriate helix correction to compensate for gear, shaft and gear case deflections and apply the minimum amount of crowning to correct for random manufacturing and alignment errors.
- Use current stress analysis software to the latest standards (ISO 6336/AGMA 2101), and where possible, use 3-D FEA optimization software to investigate the effect of random manufacturing errors on gear performance.
- It is recommended that gears be optimized using load data gathered from the measurement of in-service loads with appropriate strain gaging instrumentation. The load data should include transient loads and duty cycle from a representative operational duty. ISO 6336-6 should be used to evaluate the gear loads using a Miners sum cumulative damage analysis.

Conclusion

Using existing design tools such as ISO 6336 procedures in conjunction with good design practice discussed herewith should result in gears with lower mesh friction losses, lower scuffing risk and lower contact stress. Mesh friction losses can be minimized without compromising the performance of gear load carrying capacity and noise with standard tool geometry.

The paper has shown how a CAE tool has been employed to optimize performance characteristics beyond the scope of the international standards. Even marginal improvements of 0.2–0.5% represent a significant economic benefit in large-scale engineering. Using an experimentally validated design tool such as *GATES* allows individual gear sets to be optimized with confidence with particular reference to investigating the robustness of the design subject to random manufacturing and different operating conditions before manufacture and testing.

Future plans include the further validation of the model by testing at the Design Unit with back-to-back test rigs as part of the X-GEAR project. The refinement of the *GATES* model at the critical mesh regions at the start and end of active profile is also planned.

Acknowledgment

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Dr. Michael Fish *Dr. Fish is a graduate of mathematics and applied mechanics from Heriot-Watt University, Edinburgh, and went on to carry out his Ph.D. studies under Prof. Bob Munro at The University of Huddersfield investigating "Transmission Errors in Precision Worm Gears." After graduating in 1998 he went on to work for Holroyd Machine Tools and Rotors based in Milnrow, U.K., where he worked on several R&D projects aimed at producing gears more efficiently. He then worked in Switzerland for several years, first at Reishauer AG in modeling and machine tool systems, and then at KISSsoft AG developing software tools for the gear industry. A co-founder of Dontyne Systems in 2006, he is responsible for the general management of the company but is also involved in the development and support of software products.*

Dr. Robert Frazer *completed an apprenticeship with GEC in power generation before studying for a degree in mechanical engineering at Newcastle University. He spent 3 years working in the gear manufacturing industry before returning to Newcastle, joining the Design Unit in 1988. He is head of the U.K. National Gear Metrology Laboratory, responsible for gear design and analysis within the Design Unit and is actively involved with delivering the British Gear Association (BGA) training seminar program. He is the U.K. representative on the ISO gear accuracy committee (ISO TC 60 WG2) and a member of the U.K. shadow committee supporting the work of ISO TC60 WG6 on gear performance.*

Dr. David Palmer *Dr. Palmer was a graduate of engineering from Leeds University and went on to carry out his PhD studies at The University of Huddersfield analyzing "The Effects of Profile Relief on Narrow Face Width Parallel Axis Gears." After graduating in 1998 he went on to work for Romax Technologies based in Nottingham, U.K. During this time he worked on many engineering projects with many of the top names in the transmissions industry and was often used to teach and train customers in gear theory and design techniques. Dr. Palmer was a co-founder of Dontyne Systems in 2006. He is a director of Dontyne Systems, responsible for the development of software products for gear design, analysis and manufacture. He is also responsible for product training and support. He contributes to the development of international standards via U.K. working group for ISO6336.*

Building Repeat Business

WHAT BUYERS REALLY WANT FROM GEAR MANUFACTURERS

Matthew Jaster, Associate Editor

If you're reading this, you've survived the doom and gloom of an economic downturn and business is starting to pick up. The glass-is-half-full types will put 2007–2008 behind them and focus on the future; the less optimistic are undoubtedly preparing for another financial collapse by November 2010. Whether your views of the future are favorable or not, there are signs—paper trails and economic experts suggesting U.S. manufacturing is improving.

At the heart of this battle for financial stability are your gear customers. They've stuck by you through thick and thin (hopefully), continue to place orders (cautiously) and are always recommending your manufacturing services and products (cross your fingers). Typically, gear buyers focus on quality and service above all else, but there are other factors involved before a purchase takes place.

While it's important to read about the latest technology trends, product releases and technical information, wouldn't it be nice to hear what your customers look for from gear manufacturers? In this article, gear buyers have been given an opportunity to discuss quality, value, customer service and how gear manufacturers can improve business practices.

(*Ed's note: The participants involved in this article asked for anonymity given the subject matter. Discussions took place between two gearbox manufacturers, a medical components supplier, an engineering firm in the energy market, an automotive parts supplier and a specialty shop in off-road racing.*)

Quality Remains King

Warren Buffet, investment guru and philanthropist, summed it up when saying, "Price is what you pay; value is what you get." Whether you're purchasing automobiles, heavy industrial equipment or a bulk order of gears, the same rules apply. The gear industry remains an area of manufacturing where quality reigns supreme and complex components need to perform consistently and without failure. In the gear industry, companies tend to pay for what they get.

"Where is the value in a $1,000 gear set that fails in a race event that costs you a quarter of a million dollars to compete in?" asks the director of an off-road racing specialty shop. "There is very little demand in our industry for cheaper parts, so when we shop for gears, we want the best quality and value we can get our hands on."

This specialty shop, founded in 2005, provides power transmission components for off-road racing. The director shopped around several gear companies before agreeing to work with a few candidates, including one major gear manufacturer in the United States. "The companies we have long-term relationships with understand what we need and are willing to go out on a limb with us when we're pushing the edge harder and further. These are the companies we stick with, and we are very loyal."

One gear manufacturer was chosen for its ability to go above and beyond when it came to its attention to detail and quality standards. The specialty shop director says that reoccurring lubrication issues at one point had stumped his engineering team, but the gear company's engineers immediately took it upon themselves to work on resolving the problem.

"We started testing some different lubrication to address the technical issues we were having. Our partner took initiative and spent a great deal of time helping us solve the problem. You rarely see this kind of commitment in our industry. People had never been this helpful before. It says a lot about the integrity of the organization, and it's one of many reasons they remain one of our largest suppliers of gears."

A mechanical application engineer for a global gearbox manufacturer can't stress enough the importance of quality when purchasing gears. "Quality, minimum defects and good value are the most important factors," he says. "If the quality is not adequate, it's a deal breaker."

The engineer believes more emphasis on these details will lead to better products in the future, and he

continued

stresses the importance of further R&D on the tools and components used in the gear industry. "Quality stands out when you're shopping for gears, even more so than price in most cases. While there are plenty of options available to gear buyers, the decision is going to come down to quality, value and the service you receive before and after the purchase."

For prototype procurement, a gear buyer from an engineering firm in the energy market suggests timing and costs are important factors, but quality is the most critical purchasing decision. "This is not the same criteria used when purchasing production gears. Quality in prototype is one of the main factors due to the fact we are proving out concepts, so we need quality gears made to our specifications. This enables us to test properly and obtain results that will be used for future development of each project. In the prototype process, we develop relationships with a few gear houses and use them as our main vendors as long as quality, timing and value costing remain the measuring stick on each project."

A gear customer in the medical sector summed up quality in three simple measures. "It comes from a technical standpoint, a staffing standpoint and the advancements you come to find on the manufacturing floor. Hands down, you'll have a difficult time trying to get what you want from a gear manufacturer that is not established, highly specialized and up-to-date on the latest technology benefits. Our company has worked with a family-owned manufacturer because quality, delivery and customer service make a huge difference when it comes to purchasing gears. In a technical application, these are the three factors to consider."

An automotive supplier ranks quality, price and lead time as the items she looks for when preparing to make a purchase. "Our gears have specific tolerances that must be met for our end product to perform correctly. A good value does me no good if the gear is not to spec."

Timing is Everything

For gear buyers, specifically in the prototype arena, timing is another key to repeat business. If a gear company

The specialized gears used in the automotive industry can cost millions if failure occurs prematurely.

can meet quick timing requirements and measure and confirm that they have made the gears to print, it makes it easier to make purchasing decisions. The gear buyer in the energy market believes in-house inspection equipment has changed the game on the prototype side of the business. “If our vendors have the in-house capabilities to inspect gears accurately and get them out to us on time, we will continue to work with them. It’s that simple.”

Customer service plays a large role in delivery as well. The medical manufacturing rep has received countless phone calls from customer service agents in the gear industry. “They just state the same thing over and over again. ‘We’ll have it in another three weeks,’ ‘Give us three more weeks,’ ‘It’s going to be about three more weeks.’ Sure, they were polite enough to keep us informed on where the order stood, but this wasn’t exactly the kind of customer service we were looking for.”

The director of the off-road racing specialty shop believes delivery issues can clearly be avoided by working directly with manufacturers in the United States. “We don’t do business in Asia. We have made gear sets in the U.K. and still work with a company there, but most of our gears are made right here in the United States. It just makes sense to stay local and build relationships.”

The same rules apply to the automotive supplier that builds relationships with key suppliers and sticks with them. The gear purchases at this organization have been 100 percent domestic for more than 10 years.

When the gearbox manufacturing rep began dealing with timing constraints, his company began a transitional period to avoid purchasing gears altogether. Suddenly, the company was producing gears in-house. “Delivery problems can be avoided by eliminating the amount of companies involved in a particular project. I don’t have the exact number, but my guess is probably 40 percent of our gears are manufactured domestically, in-house.”

A gear buyer from a U.S. gearbox and speed reducer company notes that delivery will continue to be an issue

continued

until management is held accountable for their actions. "The customers will tell you what they need and when they expect it from a manufacturer, but nothing will change unless they're forced to. Our company would look for other suppliers if more were available that handled high-end applications and made lead time a priority. We just don't see a lot of options right now."

This growing concern for delivery time is a problem that won't go away in the near future. All the companies involved in the article agreed that they hear increased lead time pitches from sales representatives all the time and have yet to see any significant results. Many companies have cut back on peripheral customers in order to keep the regulars happy.

"It's strange that many manufacturers have scaled back their work and yet the delivery times aren't improving, I understand that material availability is still a problem, but you hear one thing and then you see something completely different. It's an area some will want to consider improving upon."

Off-road racing depends on high-quality gear sets that don't come cheaply. Specialty shops will pay top dollar to get the best equipment into their vehicles.

Racing events can cost a quarter of a million dollars to enter, and the components must be able to handle a variety of engineering challenges.

Value and Customer Service

What other factors will prevent potential customers from purchasing gears? Quality and delivery time seem to be standard fare in gear manufacturing, but other factors come into play before a company begins writing a check. "We also have to consider value, given the nature of manufacturing right now," says the energy market rep. "This industry sorely needs a larger quantity of gear houses that can manufacture quickly while maintaining

quality requirements and value pricing. There are simply not enough options right now, especially for prototype gears. With the engineering advancements in alternative energy projects, there's going to be a greater need for quality components and I'm not sure the current market will be able to keep up with the demand. We'd like to have more options available to us so value increases."

The automotive supplier's spending habits have changed since the economic downturn. "I no longer place blanket PO's based on forecast or past trends. I usually have to have firm customer PO's for items before placing part orders."

A disconnect between the Asian and American markets is causing some animosity in the global gear market, according to the U.S. gearbox and speed reducer representative. "Some companies overseas purposely went out of their way not to provide product upgrades or in-plant services to meet customers' application needs here in the United States. They also never intended to support or authorize any component packaging (motor/gearbox/electrical drives, etc.) at any level. Some consider the U.S. a lost market, intentionally setting them up to fail."

He also discusses some large name mergers that have not exactly won favors in the industry.

"Several mergers that have taken place recently have really killed the gear industry. The companies involved have lost a lot of their engineering and

continued

packaging capabilities in the process. Other companies are dragging their feet on new technology; struggling to learn the industry and obtain a representative line of products to cover all the industrial markets. Another problem is the engineering staff that many companies employ. They don't work well with local service companies to bring the much needed local support in putting packages, equipment/system upgrade and retrofits together."

The finger pointing starts and ends with management according to the gearbox rep. "Management suffers from the arrogance and even ignorance that continues to drive engineering/service support and the business/management levels that attempt to service the needs of the customer. There is plenty of talk of change in company standards and product offerings, but it never seems to lead to any real initiative. Because of this, we rely on the same companies time and time again."

Familiarity tends to make gear buyers more comfortable. All of those interviewed for the article tend to stick with the same manufacturers for each project. If a gear company can practice what it preaches in terms of quality and value, they may be able to snap up some additional business in the future. "It's a specialized market, so you really have to see something significant that will make you want to change vendors," says the gearbox rep.

Most customers are completely satisfied with the gear companies they currently work with and see no need to change hands in the future. "A few years back, I took some information to IMTS regarding gear failure that needed to be addressed at our organization. I couldn't believe the amount of associates from gear companies that didn't want to bother looking at the material. Here I was, looking for potential new business and they weren't interested," says the off-road racing specialty shop director. "Thankfully, we began working with a company that was willing to answer all our questions and provide the kind of service we were looking for. We've never looked back."

The medical manufacturing representative thinks gear buyers already have a pretty good idea who the market leaders are and will continue to be in the future.

"We need highly specialized gears for our medical applications. There are only a handful of names that come up over and over again when you talk to gear customers. These are the same names that were on top ten years ago. They offer the best service support, the best technology, the best quality. I'd be surprised to find any gear manufacturer on the market that can do better."

Those involved in the alternative energy industry continue to aggressively seek technology and efficiency benefits from gearbox manufacturers. It starts with the gear sets.

PM Community

GATHERS FOR ANNUAL EVENT

The automotive engine Award of Distinction went to these V6 engine crankshaft sprockets.

The metal powder industry gathered in force this past June for PowderMet2010, the 2010 International Conference on Powder Metallurgy and Particulate Materials. The economic forecast was very positive for PM, as reported by Michael E. Lutheran, president of the Metal Powder Industries Federation (MPIF). Several gear and power transmission parts were honored in the PM Design Excellence Awards while a special nod went to the variable valve timing (VVT) technology for its role improving efficiency in the auto industry, and the industry released a sustainability report to highlight PM part forming as a green technology.

A strong rebound in the fourth quarter of 2009 continued to the first quarter of 2010 with iron powder shipments up 64 percent from the same period in 2009. First quarter 2010 copper and copper-base powder shipments rose 36 percent.

The light-vehicle market is the most prevalent force supporting PM industry growth and is expected to consume an estimated 230,000 short tons of PM parts in 2010, according to Lutheran. "There is more good news about the automotive market," he said. "The new six-speed transmissions introduced by GM and Ford have a high PM content, in the 30-pound range. Several of Ward's 2010 Best Engine choices have high PM contents as well. Ford's 3.5L EcoBoost Turbocharged V-6 engine has 81 PM parts weighing a total of 21 pounds. The engine contains PM valve guides and valve seat inserts, connecting rods, oil pump, sensor ring, cam caps, VVT assemblies, camshaft sprocket and crankshaft sprocket and hub."

Metal Injection Molding and hot isostatic pressing (HIP) are newer areas of the industry that are expected to perform well in the future. The VVT was recognized at PowderMet2010 as a PM Industry Landmark technology for its use of PM parts to help automakers meet environmental and fuel efficiency standards by advancing or retarding the timing of the intake or exhaust valves. Most current VVT systems contain three PM parts: a vane rotor, sprocket and thrust plate.

"Let us view 2010 as a transition year leading us to a new era of opportunity in the global marketplace," Lutheran said. "The industry has been

continued

In the hand tools/recreation category, this motorcycle drive sprocket won an Award of Distinction.

In the hardware/appliances category, this transfixed gear and sector was given an Award of Distinction.

challenged and shaken, yet the future is still positive. Again, never underestimate the creative resiliency of this industry to overcome and rise again to new heights. Competitive technologies that do, do so at their peril."

The PM Design Excellence Awards' winning parts are examples of PM's precision, performance, complexity, economy and innovative design advantages. They compete against manufacturing processes that include hobbing cast iron, die casting, weldments, machining and investment casting. Grand Prize Awards and Awards of Distinction were doled out.

Capstan Atlantic won an Award of Distinction for a high-density transfixed pinion gear and sector used in a high-volume printing application. The pinion gear meets the AGMA Q9 precision level, is selectively roll-densified and crowned for bending-fatigue resistance and rolling contact fatigue resistance.

PMG Füssen GmbH won the Award of Distinction in the automotive engine category for a PM steel crankshaft sprocket used in a V-6 engine made for iwis motorsysteme GmbH in Germany. It features an inner ring diameter that is pressed and machined after sintering for high-precision tolerances, secondary operations and significant cost saving.

Burgess/Norton Manufacturing Co. won an Award of Distinction in the hand tools/recreation category for a final belt-drive sprocket, which transmits torque from the transmission to the rear wheel on a motorcycle. It replaced a hobbed cast iron sprocket.

Other news from PowderMet2010 is the release of "Powder Metallurgy—Intrinsically Sustainable," a report that details the contributions PM makes to sustainable manufacturing. And APMI International, the professional society for the PM industry, named Herbert Danninger, a professor at the Vienna University of Technology in Austria; and Myron I. Jaffe, a consultant for Brewer Hill Designs LLC in Mill River, MA; to the 2010 Class of Fellows.

According to James Dale, vice president of member and industry relations at MPIF, "Our members are very involved with gears."

Sept 13–15—Gear Failure Analysis Seminar. Big Sky Resort, Big Sky, MT. AGMA's Gear Failure Analysis Seminar examines various types of gear failure, including macropitting, micropitting, scuffing, tooth wear and breakage. The possible causes of these failures are presented along with suggestions on how to avoid them. Lectures are paired with slide presentations, hands-on workshops with failed gears and Q&A sessions designed to provide comprehensive understanding of reasons gears fail. Attendees are encouraged to bring their personal failed gears or photographs of them to discuss. The seminar aims to help solve everyday problems faced by gear engineers, researchers, maintenance technicians, lubricant experts or managers. For more information, visit *www.agma.org/events-training/detail/gear-failure-analysis-seminar/*.

September 21–23. Atlantic Manufacturing Technology Show. Exhibition Park, Halifax, Novia Scotia. Atlantic Manufacturing Technology Show (AMTS) brings manufacturers together to connect on new technology and new products. The Atlantic Canada region is home to more than 2,600 manufacturing companies employing nearly 24,000 workers. AMTS will bring together diverse industries such as aerospace, defense, heavy equipment, mining, energy, wood products, machinery and metal fabrication. For more information, visit *www.sme.org/amts*.

September 28–30—Gear Manufacturing and Inspection Training. Concordville Hotel and Conference Center, Concordville, PA. AGMA and Raymond Drago present this training session on the methods, practices, application and interpretation for the design engineer. Attendees gain a broad understanding of the methods used to manufacture and inspect gears and more. The seminar takes it one step further, by teaching how the resultant information can be applied and interpreted in the design process. The premise of the seminar is that it is critical for the design engineer to understand the manufacturing and inspection processes that will be employed so that the intent of the design can be successfully translated into practice. Cost for AGMA members is $1,395 per individual, $1,195 for groups from the same company; $1,895 for nonmembers, $1,695 for groups from the same company. For more information, visit *www.agma.org/events-training/detail/gear-manufacturing-inspection1/*.

October 4–8—Basic Training for Gear Manufacturing. Richard J. Daley College, Building 300, 7500 S. Pulaski Rd., Chicago. Through classroom and hands-on training from AGMA, attendees learn to set up machines for maximum efficiency, inspect gears accurately and understand basic gearing. The course covers gearing and nomenclature, principles of inspection, gear manufacturing methods and hobbing and shaping. The course is intended for those with at least six months of experience in setup or machine operation, though most everyone can benefit. Past students have included executives, sales representatives and quality control managers. For more information, e-mail Jenny Blackford at *blackford@agma.org* or visit *www.agma.org/events-training/detail/basic-training-for-gear-manufacturing2/*.

October 5–7—North American Offshore Wind Conference and Exhibition. Atlantic City, NJ. The North American Offshore Wind Energy Conference and Exhibition will provide opportunities for networking, learning and collaborating. The event includes an exhibit floor, posters, technical sessions, business and policy sessions, as well as an offshore supply chain track. The supply chain track will examine the needs, opportunities, barriers and challenges to manufacturing, transporting and constructing off-shore wind turbines. For more information, visit *www.offshorewindexpo.org*.

October 20–21—Manufacturing Innovations-Aerospace/Defense. Gaylord Palms, Orlando, FL. Manufacturing Innovations-Aerospace/Defense is exclusively designed for aerospace and defense manufacturers and suppliers, addressing an expanding market with specific needs for innovation, precision, accelerated production and improved quality. The event will be co-located with the Aerospace Measurement, Inspection and Analysis Conference. For more information, visit *www.sme.org/aerospacedefense*.

Great Lakes Industry

AWARDED MICHIGAN CLEAN ENERGY GRANT

A $2.5 million Clean Energy Advanced Manufacturing (CEAM) award was granted to Great Lakes Industry Gear LLC, a subsidiary of Jackson, MI-based Great Lakes Industry Inc. (GLI). The award is from the Michigan Department of Energy, Labor and Economic Growth (DELEG) and is comprised of a $2 million grant and a $500,000 low-cost loan to support GLI's planned expansion into wind turbine gear manufacturing.

Nine small manufacturers were awarded $15 million in grants and $5 million in loans from the state of Michigan through the CEAM program, which is funded by the American Recovery and Reinvestment Act of 2009. The program is designed to help Michigan businesses diversify into high-growth, clean-energy industries.

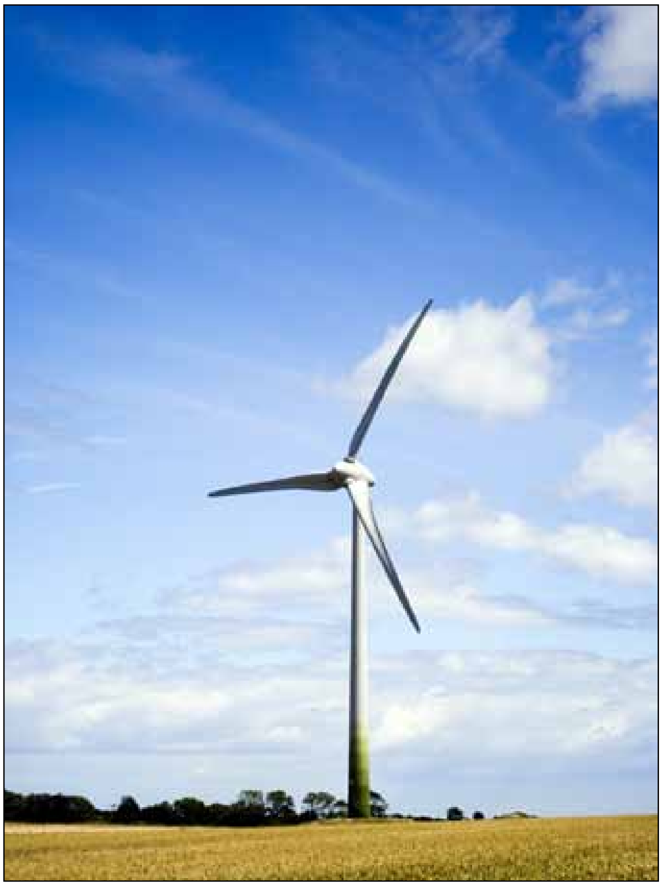
GLI was selected from among 40 applicants representing more than $105 million in proposed projects.

"So Great Lakes Industry is going to convert its existing gear manufacturing operations to meet the growing demand for precision gearboxes needed in large wind turbines. At the moment, there are no known Michigan companies producing these large format gears, and there are only 10 such companies in the entire United States," says Michigan Governor Jennifer Granholm, in her weekly radio address where she announced these CEAM grants.

"This means that more than 50 percent of these gears have to be imported. So by the state and federal governments partnering with Great Lakes Industry, we can grow a Michigan company, diversify our economy, create jobs and provide a domestic source for wind turbine gearboxes."

Great Lakes Industries manufactures carburized and hardened axle shafts, large diameter ring gears, induction heat treated spur gears, heat treated drive shafts, starter jack shafts, gear and rack sets, custom gear sets, pressed assemblies, welded roller chain sprocket assemblies, shaft assemblies and many other power transmission components.

"GLI has established itself as a world-class manufacturer of gears for the mining, off-road, construction and agricultural equipment markets since 1979," says Lawrence Schultz, president of GLI Gear. "The ability to expand over the next several years into commercial production of



utility-grade wind turbine gears presents the opportunity for significant growth for GLI, but also the creation of several hundred direct and ancillary manufacturing jobs for Jackson and Michigan. We still have a long way to go to secure the necessary customer commitments and secure financing, but the financial support and endorsement of DELEG is an important milestone from which we intend to establish a position of market leadership in the manufacture of large precision gears for the rapidly growing, utility-grade wind turbine industry."

Wenzel/Xspect

APPOINTS GM, SALES MANAGER

Andy Woodward has been named general manager of North American operations for Wenzel/Xspect Solutions, a subsidiary of Wenzel Group GmbH, as announced by Frank

Andy Woodward

Wenzel, managing director of Wenzel GmbH.

Woodward comes to Wenzel/Xspect from the United Kingdom, where he has been managing director for Wenzel's operations for the past eight years. He spent fifteen years with Hexagon Metrology Inc. in various engineering and general management positions at Hexagon's DEA and Brown and Sharpe operations in the United Kingdom.

Woodward holds a bachelor's degree from the University of Birmingham. He and his family are relocating to the Detroit metropolitan area. He says: "I intend to continue to build on the solid business model for metrology equipment and services that Xspect Solutions has created over the past six years. By combining Xspect's broad customer base and marketing network with Wenzel's Gear Tec gear measuring machine technology and Wenzel's expanding 3-D scanning products, we should be able to make additional market penetration in related product and industry areas here in North America."

Giles Gaskell

Giles Gaskell was announced as the North American sales manger for 3-D imaging products for Wenzel/Xspect Solutions, subsidiary of Wenzel Group GmbH, by Andy Woodward, North American general manager for the company.

Woodward comments: "Wenzel continues to broaden its product base through the addition of unique new 3-D imaging technologies to complement Wenzel's CMM metrology products. As a result, we are focusing new sales and marketing resources to help develop markets for these new products in North America. Giles Gaskell will be directing those efforts and brings a wealth of technical and business development experience in the areas of non-contact scanning for reverse engineering and 3-D imaging technology. He has worked with many of Europe's most prestigious design, engineering and manufacturing companies on reverse engineering and non-contact inspection projects."

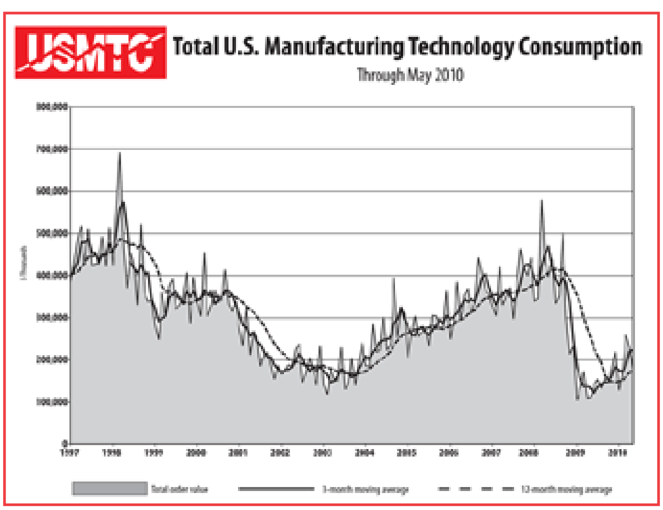
Gaskell previously worked for GKS-Laser Design Inc.,

continued

where he was the business development manager. Prior to that, he was director of business development for NVision Inc., a manufacturer of non-contact measurement and 3-D imaging hardware and software. He founded 3-D Scanners Ltd., a U.K.-based manufacturer that introduced the first hand-held laser scanners to the U.K. market.

A mechanical engineering graduate from Aston University in Birmingham, England, Gaskell is a member of the Society of Manufacturing Engineers and the Institution of Mechanical Engineers. He and his family reside in Linden, MI.

Manufacturing Technology Consumption up 52.9 Percent



U.S. manufacturing technology consumption (USMTC) in May totaled $178.34 million, according to the American Machine Tool Distributors' Association (AMTDA) and The Association for Manufacturing Technology (AMT). This total is based on actual data from companies participating in the USMTC program, and it is down 22.9 percent from April but up 58.6 percent from the total of $112.42 million reported for May 2009. The year-to-date total of $966.63 million is up 52.9 percent compared with 2009.

"While we would like to see first quarter growth rates continue, we are not surprised by the typical second quarter ebb and flow in capital spending," says Peter Borden, AMTDA president. "We have seen an additional month of substantial orders, which helps to confirm that a sustainable recovery is taking place despite the buzz of those forecasting a W-shaped rebound. Industry forecasts for the year have been revised slightly upward by many sources, and if Congress passes the bonus depreciation allowance, this could accelerate growth even further."

USMTC is also reported on a regional basis for five geographic breakdowns: Northeast, Southern, Midwest, Central and Western. The full report can be viewed at the AMT's website, *www.amtonline.org*.

Koepfer and Carl Zeiss

FORM BUSINESS PARTNERSHIP

From left to right: Greg Lee, president of Carl Zeiss IMT, Dennis Gimpert, president of Koepfer America, Andrew Sisler, vice president of sales for Carl Zeiss IMT, Cory Sanderson, vice president of sales and marketing for Koepfer America, joined for a business partner agreement between the two companies in the United States and Canada.

Carl Zeiss IMT is expanding its reach into all areas of gear metrology in its business partner agreement with Koepfer America for the United States and Canada. The agreement provides improved technical and marketing support related to all areas of CMM gear metrology offered by Carl Zeiss.

Carl Zeiss offers machines to measure both parallel axis and bevel gears from the smallest gears used in microtechnologies up to gears four meters in diameter using the *Gear Pro* software package. Prismatic features can be measured in seamless integration with the *Calypso* metrology software package.

Koepfer America has sold parallel axis gear manufacturing equipment, service and support since 1989. Koepfer is involved with AGMA, The Association for Manufacturing Technology (AMT), the Society of Manufacturing Engineers and other technical groups.

Chuck Miller

JOINS SOLAR ATMOSPHERES OF SOUTHERN CALIFORNIA

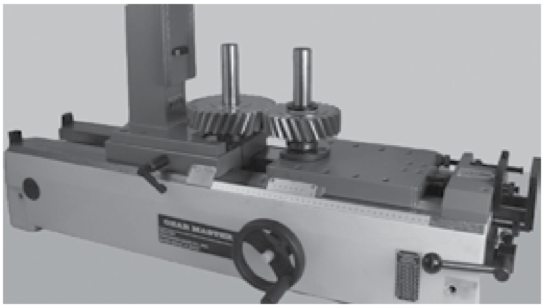
Solar Atmospheres of California (SACA) is one step closer to the establishment of its state-of-the-art vacuum heat treating facility in Southern California with the hiring of Charles (Chuck) Miller as manager of maintenance and facilities engineer.

Miller comes to Solar after years of supervisory experience in the heat treating industry. Miller's areas of expertise are vacuum furnace maintenance, pyrometry, instrumentation, hot zone fabrication and repair, among many other areas of proficiency. His prior employment duties included regional maintenance engineer for Bodycote Thermal Processing and prior to that, maintenance supervisor for Hitech Metallurgical, both located in the Southern California region.

Derek Dennis, SACA president states: "We are very fortunate to have somebody with Chuck's in-depth knowledge and experience on the SACA team. I'm looking forward to working with Chuck in facility engineering and start up, along with the continuing day-to-day operations of the heat treating plant."

Miller's first assignment will be the installation of Solar's support equipment and installation of Solar's first three furnaces to include the west coast's largest commercial vacuum furnace, at 24', with a double car bottom loading system. All furnaces are engineered and manufactured by

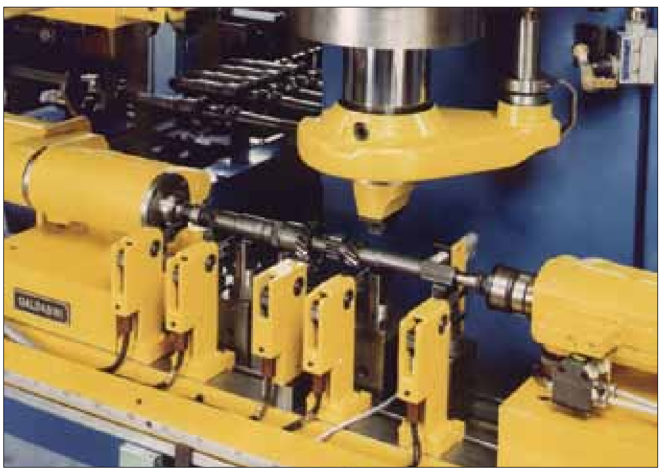
continued



Solar Atmospheres' sister company, Solar Manufacturing of Souderton, PA.

Star SU

REPRESENTING GALDABINI



A cooperation agreement has been reached between Galdabini and Star SU for sale and after-sales service of manual and automatic straightening machines. The agreement is the result of Galdabini's desire to reach the North American market with local support to strengthen the long-term partnership with its customers.

Galdabini manufactures straightening machines from its factories in Switzerland and Italy. Opening local representative offices in Beijing and Singapore has been part of its effort to direct attention to new developing markets.

Galdabini is the long-term partner for advanced straightening solutions for various products in the automotive, electro-mechanical, steel and forging, military, oil and mining, aerospace, marine and train industries. Products that can be processed on Galdabini equipment include gear, cam, crank, starter, axle and propeller shafts; synchronizing rings and gear selector forks; steering racks, pinions, ball screws and drill bits. Other products are bars and profiles, such as linear guides, elevator guides, square racks, rails and special profiles; forged and bright round, square and rectangular bars and gun barrels.

Gear Technology

APPOINTS MANAGEMENT, INVESTS IN MACHINERY

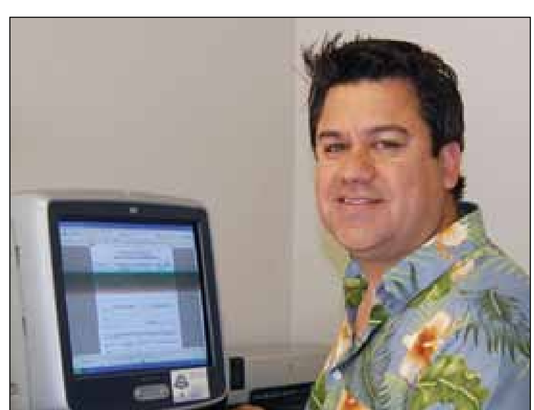
Joe Campa

Two senior level managers were promoted by Gear Technology. Joe Campa, formerly quality assurance manager, is now director of engineering. Jerry Flores was promoted from quality assurance representative to quality manager.

Campa is a ten-year veteran of Gear Technology. He was previously employed by Boeing Space and Communications Group as a procurement specialist. He has held quality management positions with Kosmo Gears and Newman Machine Works. In this new position, Campa is responsible for Gear Technology's integrated engineering department.

Flores' new management responsibilities include implementing and maintaining the company's ISO9001:2008/AS9100 AMS quality standards, inspection, employee training, safety, internal and external audits, performance monitoring and lean manufacturing.

"We are pleased to recognize the dedication and performance of these two long-term employees who have demonstrated their commitment to the company's business goals and customer service value standards," says Tom Marino,



Jerry Flores

A newly rebuilt Fellows CNC Gear Shaper is one recent investment Gear Technology made.

president of Gear Technology.

Marino has also recently made some new investments in machinery, including a newly rebuilt Fellows CNC Gear Shaper in an effort to break into green energy.

"This advanced gear shaper will allow us to cut gears up to 20 inches in diameter, so we can expand our customer base with companies in the clean and wind energy industries," says Tom Cruse, director of operations at Gear Technology. "We will now be able to fabricate larger gears and full gearbox designs and assemblies."

The other major acquisition was a Zeiss Prismo Navigator Coordinate Measuring Machine, featuring *GearPro* software, providing complete gear measuring and analysis. "It's a versatile system that can handle a large range of gear configurations, including spiral bevel gears, Gleason straight bevels, internal and external spur gears, worm gears, helical gears and internal and external splines up to 25.50 inches in diameter," Flores says.

The Zeiss Prismo Navigator CMM was acquired by Gear Technology.

The Prismo Navigator is equipped with the Zeiss Vast Gold Probe Head, *Calypso* measuring software and integrated with a rotary table. "With this new Zeiss Prismo Navigator Coordinate Measuring Machine, Gear Technology is making a significant investment in advanced gear manufacturing technology," Flores says. "It's the latest addition in our ongoing commitment to offer our customers the best quality, value and service in the industry."

U.S. Gear

CONTRACTS UNITED PROCESS CONTROLS

New furnace controls and data acquisition from United Process Controls have been ordered by U.S. Gear, a division of AxleTech International, a General Dynamics Company. The order includes a surface combustion pusher furnace outfitting with CQI-9 compliant furnace controls based on Protherm 600 controller, FurnaceDoctor infra-red multi-point gas analyzer and Waukee Flo-Tronic electronic flow meters.

The *Protherm 9800* software application will integrate the control systems of the pusher and other batch furnaces and streamline heat treating operations at the company's Chicago plant. The software performs data acquisition, recipe management, monitoring and analysis.

This upgrade investment will bring an older piece of equipment into CQI-9 compliance, so there is greater accuracy in the heat treat cycles, as well as providing the company with comprehensive process documentation.

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THE WORDS AND WISDOM OF SHELDON "GEAR RATIO" BROWN

"I have always loved riding bicycles, especially for the feeling of freedom and self-sufficiency that they give."

—Sheldon Brown

"My 'panache' is a plastic eagle which probably began life at the top of a small flag pole. It is a road find, held onto my old Bell Image by a plastic zip tie."—Sheldon Brown.

Bicyclophiles (OK—not a real word, but you get the idea) around the globe may very well know the name, but chances are good that most *Gear Technology* readers have never heard of Sheldon Brown, AKA—"Gear Ratio," "Gain Ratio," "Mouldy Oldie," "Theory," "Quixote," "Fixit" and some the Addendum team probably missed.

As the names demonstrate, Brown was indeed a Renaissance man to kindred, bicycle-bound saddle tramps everywhere. We say "was" because, sadly, Sheldon passed away in 2008.

But what a life he had.

A perusal of his website (which is being refreshed and updated as this goes to press) reveals the seemingly endless curiosity and wisdom of the man who claims the likes of Robert Heinlein, Martin Luther King and Bertrand Russell as great influences during his "formative years." A self-taught bicycle mechanic—his principal claim to fame, aside from his family—Brown's mechanical genius didn't stop there, according to John Allen, the site's bicycle technical guru and co-author of several editions of "Sutherland's Handbook for Bicycle Mechanics."

"He also worked for several years in a camera repair shop. He got the job by reassembling a difficult camera that the owner handed him with the expectation that he wouldn't be able to repair it. This went along with his strong interest in photography. Almost all the photos on the website are his own, including the many that illustrate bicycle parts and mechanical procedures. He was an obsessive tinkerer," adds Allen.

Also available on the site are Brown's essays, journals, observations and everything else bicycle-related, including all-things gearing. There you'll find issues addressed such as gears and drivetrains, derailer adjustment, tandem synch trains, gear measurement, an online gear calculator and even fixed-gear bikes (remember those!?).

An enterprise like this had to start somewhere, and that somewhere was—of course—a bicycle shop.

"Sheldon started work at Harris Cyclery (in West Newton, MA) in the mid 90s—1996, I think," says Brown's widow, Harriet Fell, a computer science professor. "He had already written many articles for *Bicycling* magazine and had also written some instructional pamphlets for (another shop). He started the website to advertise Harris Cyclery and found that it was a great way to advertise himself."

And the genesis of Sheldon's love for bicycles? "Sheldon met bicycles as a kid," she says. "His older sister used to pedal him around on her handlebars when he was two and she was eight. He went on a cycle touring trip to Maine with his Boy Scout leader." And thus our bike boy was born.

The road got very bumpy for Sheldon in his latter years, spent battling multiple sclerosis. And while the MS is not what finally took him, how cruelly ironic is that? But how did the bikemeister respond?

With a site page entitled, "The Bright Side of MS." There he refers to his disease as "not so much a 'tragedy' but as a Really Major Inconvenience."

So do yourself a favor—biker or not—visit *sheldonbrown.com*. There you will indeed find all you need to know to keep your ride moving reliably. But there's a lot more.

You'll see.