July 2010

GEAR TECHNOLOGY

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The Journal of Gear Manufacturing

Quality & Inspection

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- Gear Checking with CMM Flexibility

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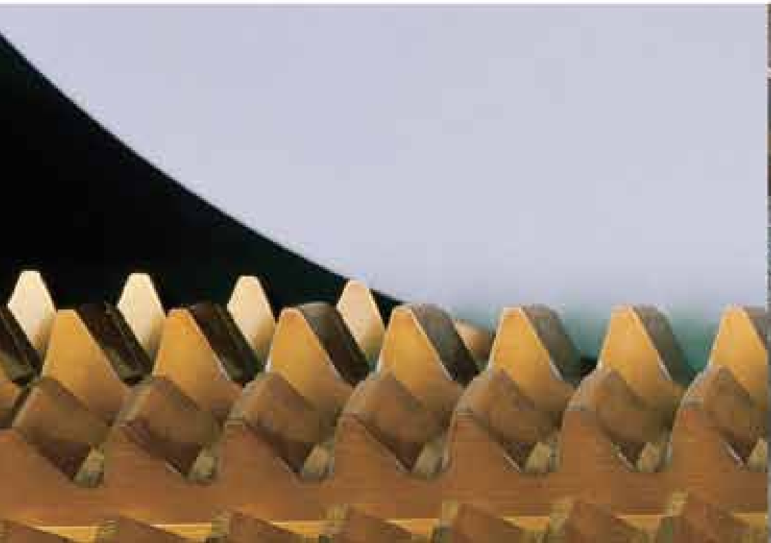

GEAR TECHNOLOGY

July 2010

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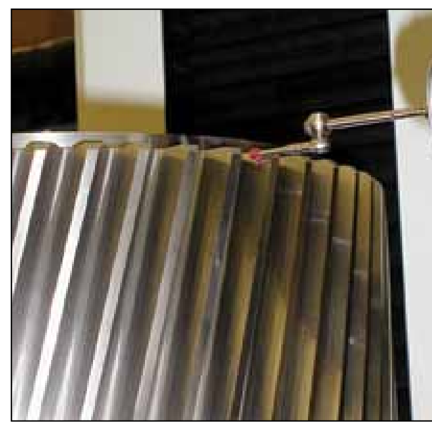

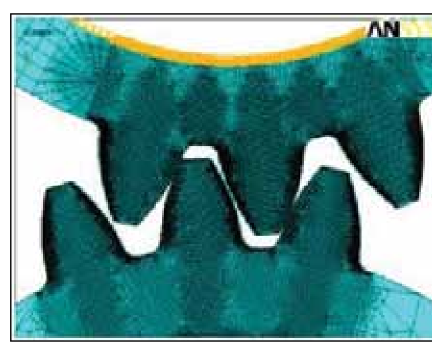

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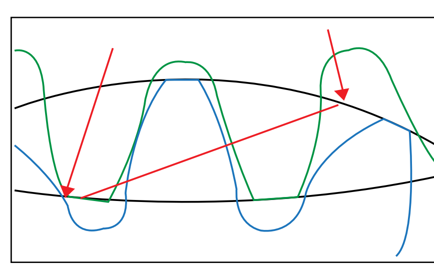

Vol. 27, No. 5 GEAR TECHNOLOGY, The Journal of Gear Manufacturing (ISSN 0743-6858) is published monthly, except in February, April, October and December by Randall Publications LLC, P.O. Box 1426, Elk Grove Village, IL 60007, (847) 437-6604. Cover price $7.00 U.S. Periodical postage paid at Arlington Heights, IL, and at additional mailing office (USPS No. 749-290). Randall Publications makes every effort to ensure that the processes described in GEAR TECHNOLOGY conform to sound engineering practice. Neither the authors nor the publisher can be held responsible for injuries sustained while following the procedures described. Postmaster: Send address changes to GEAR TECHNOLOGY, The Journal of Gear Manufacturing, P.O. Box 1426, Elk Grove Village, IL, 60007.

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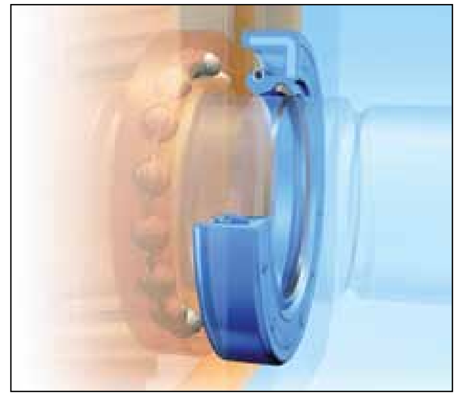

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GEAR TECHNOLOGY

VOL. 27, NO. 5

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BPA WORLDWIDE


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FREE at LAST

Those of you who are regular readers of this column know that a little more than a year ago, I began a transition from Phase I to Phase II of my life. That transition involved me dealing with substantial legal, personal and business issues, and it also involved significant changes in my roles and responsibilities, both as a publisher, which now accounts for the majority of my professional life, and as a used machine tool dealer, which accounts for the rest.

The transition has also meant finding a new physical home for our office. Over the past year, we've been working as bedouins, with some of us in a temporary office, others working remotely via the Internet.

The transition to Phase II is now complete: The tether has been cut, and the chain has been broken. All of the legal and operational issues have been resolved. By the time you read this, we'll be moving into our beautiful new offices at 1840 Jarvis Avenue, Elk Grove Village, IL 60007. Now that all of that is over, I can fully concentrate on both of my roles. I'm free at last.

Despite the intense and hectic transformation over the past year, during which I and my staff experienced unbelievable strain on our time and concentration, and despite the fact that our industry has gone through the scariest economic time of my business career, we have achieved remarkable accomplishments at Randall Publications LLC. All of our products—*Gear Technology*, *the Journal of Gear Manufacturing*; *Power Transmission Engineering* magazine and the websites *www.geartechnology.com* and *www.powertransmission.com*—have grown and improved.

One area we've improved is the growth of our circulation. We focus on quality first, quantity second. Others may try to fool potential advertisers with bigger numbers or fancy window dressing. Anybody can rent a list of names and tell you they're reaching your customers. But no other publication makes an effort to actually reach them the way *Gear Technology* does.

For example, we require our qualified subscribers to be re-qualified every two years. No name on our qualified list is older than 24 months, and as of now, fully 80 percent of our qualified circulation has been qualified within the past year(*). Other magazines rely heavily on three-year names to make it appear that they have greater numbers. Even at a time when the manufacturing industries have significantly shrunk, we've increased our qualified circulation by more than 15 percent since the end of last year. I want to thank all our readers for being so helpful and cooperative and assisting us to accomplish this. I'm sure that if we were not providing the information you want and require, we would never be able to maintain such a clean and accurate mailing list.

Another area we've improved is our content. Over the last 26 years, you have expected Gear Technology to be the "Gear Industry's Information Source," and we take that role very seriously. Through this transformation in our company and in the marketplace itself, I have kept the editorial people separate from sales and never allowed them to prostitute our products and services by getting them involved in sales or trade-offs of publicity releases for advertisers or in any way to impact their judgment of what is the best information available for the industry, advertisers notwithstanding. This separation will continue.

Our goal is to provide the most relevant, accurate, useful and timely information available. That's why we employ four full-time editors in addition to myself. That's also why we rely on independent technical editors—industry experts with decades of experience—to help us identify the best technical articles available. Others rely on advertorials that look like real articles, or they publish technical articles of little or no interest.

To help us give you the best industrial magazine available, we've worked hard over the last several months to reaffirm our cooperation and relationship with a wide variety of industrial organizations and associations. Most notably, we've developed a new cooperative program with the AGMA and have already started a series of "AGMA Voices" columns, which will explain, in depth, all of the activities

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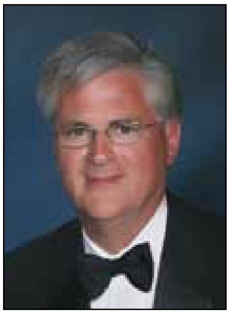

AGMA Foundation—A Dream Fulfilled

Arlin Perry, president, Comer Industries

The AGMA Annual Meeting in Tucson in March, 2010, marked the end of my term as chairman of the AGMA Foundation. This chairmanship was one of my most pleasurable and fulfilling roles at AGMA. It allowed me to oversee an organization that was conceived in the early '90s—while I served on the Technical Division Executive Committee—by some of AGMA's finest visionaries.

The foundation was a brainstorm of people like the late Don McVittie, Dan Thurman of Caterpillar, Bill Bradley of AGMA and Wendy Allen of AGMA to name a few. The original charter of the organization was to raise funds to support AGMA's role as Secretariat of ISO TC60. Companies like Caterpillar, Gleason and Falk had an interest in promoting global standards while having foundations of their own that were looking for worthy projects to finance. After filing the necessary documents with the IRS, the AGMA Foundation was approved as a 501(c)(3) in 1994.

The newly formed foundation had a vision, mission and multi-year grants from some major corporations. The funding of the ISO TC60 work was secure, and the board quickly recognized that the role should be expanded to include education and research. A fundraising campaign began and ground rules were set for an endowment fund with a goal of $500,000. Since 1994, the foundation has raised more than $2.5 million, and the endowment fund has risen to $304,000 after many successful annual campaigns with generous contributions coming from a broad spectrum of AGMA member companies and individuals.

The foundation has a clear set of objectives:

- Identify gaps in gear education and training that need curriculum or training tool development.
- Identify institutions with the core competencies to create solutions for the needs.
- Match solution providers with the identified needs and create funding sources for the resulting project.
- Identify AGMA standards that need a better or deeper scientific foundation.

To promote gear education and training, a project is under way to create a web-based, detailed gear design class where students can be trained in sixteen one-hour segments at their leisure, as opposed to traveling to a seminar location. Besides being a cost-effective alternative, engineers do not have to sacrifice as much time from their busy schedules.

Another noteworthy project is the funding of a resource book on the subject of gear vibration and noise. This topic is becoming critical as companies focus on a safe working environment for their employees.

In 2010, The AGMA Foundation will make its first scholarship grant to a graduate engineer doing gear education and research. This scholarship was made possible by donations in honor of Don McVittie, a long-time supporter of AGMA/ISO, who passed away in 2008. His family, friends and colleagues wanted to do something meaningful to honor the man who devoted his long and rewarding career to the gear industry.

Fundraising is critical to any foundation. The AGMA Foundation raises money through project-specific grants, the annual campaign, which netted $73,000 last year, and the annual meeting events. At this year's annual meeting, the first ever casino night was a great success. Combined with the golf event and live auction, over $30,000 was raised.

On behalf of the trustees and recipients of the foundation-funded projects, I want to personally thank you for your support. The foundation has made a difference for the industry as it was conceptualized by the founders.

For more information about the foundation, please visit *www.agmafoundation.org*.

Improved Inspection Software Helps Provide Optimum Gear Cutting Results

KLINGELNBERG MEASURING CENTERS ELIMINATE TRIAL-AND-ERROR WITH MODERN ANALYSIS TOOLS

Figure 1—The P26 Gear Measuring Center from Klingelnberg now offers advanced analysis software.

Improved software for assessing gear deviations is creating a new generation of more efficient gear cutting systems. Gear metrology and subsequent evaluation of test data play a crucial role in the gear manufacturing process. This is especially true if gear quality specifications are not met, or if a component fails to achieve the desired running behavior despite being within tolerances. Whereas modern gear measuring centers (Fig. 1) now achieve very high performances and possess a wide range of measurement and evaluation functions, analysis of gear variations and definition of suitable countermeasures still rely mainly on empirical know-how.

Relying on Empirical Data

Although a broad spectrum of remedial aids is stored in the machine control, gear know-how and the experience of qualified operators are often essential. This is particularly the case if the selected quality criteria or parameters (e.g. according to DIN 3962) do not sufficiently reflect the required component design. This frequently leads to systematic trial-and-error procedures, which may involve a whole series of iteration steps that often fail to obtain an optimum solution (Fig. 2). Klingelnberg has developed an analytical tool that supports detailed analysis of the diagrams (e.g. profile line and tooth trace, pitch and radial runout) to assist even the experienced specialist.

The aim of the new software is to support systematic solution-finding and to identify and quantify non-apparent influences. It provides four basic functions, which are described in more detail below.

Improvement through Comparison

When a gear is tested, the shape of the teeth is identified by means of profile and tooth trace measurements, usually on four teeth, and the position of all teeth is determined by pitch and radial runout measurements. With the aid of machine support and in some cases empirical know-how, the numerical quality values calculated from the variations are then converted into remedial steps. This procedure is usually reliable and simple. If it fails to produce the desired result, consideration of the variation curves themselves will be required.

In particular, the new software optimally supports the comparison of different test results. Figure 3 shows an example of profile measurements on two workpieces that have been profile ground on different machines. The profiles exhibit similar curves, and the calculated parameters are also the same. Only when they are shown together does it become apparent that the upper machine generates a much greater scatter of the profile form. Such a scatter could be due to a worn grinding spindle, for example. By contrast, the reproducibility of the profile on the lower grinding machine is very high. Its remaining waviness could be improved by optimizing the dressing process.

The potential offered by comparative curve displays is clear from this example. There are other application potentials in many other areas, such as the investigation of hardening distortions, tool wear, noise problems and production fluctuations, including capability testing of processes, machines and measuring devices.

Focusing on Tooth Thickness

Functionally, the tooth thickness of a gear describes the clearance in the installed state or the allowance for post processing. Geometrically, it represents a measurement that varies over the diameter. It can be measured directly by a gear inspection system or coordinate measuring machine, or indirectly in shop operation on the basis of the base tangent length or the two-ball dimension.

On gear measuring machines, the profile and tooth trace variations for various teeth are measured and presented as form variations in relation to the desired form, without the curves being related to one another in terms of their position. The pitch variations are also unrelated to the tooth thickness of the individual tooth.

With the aid of Klingelnberg's new analysis software, it is now possible to display all variation curves in the correct positions in relation to one another. The profile and tooth trace curves (Fig. 4) are now displaced horizontally in line with the existing pitch variations and are offset to the desired line by the amount of the base tangent length variations.

The pitch variations are likewise shifted vertically from the desired line by the amount of the base tangent length variations. The relationship of the form variations to the nominal

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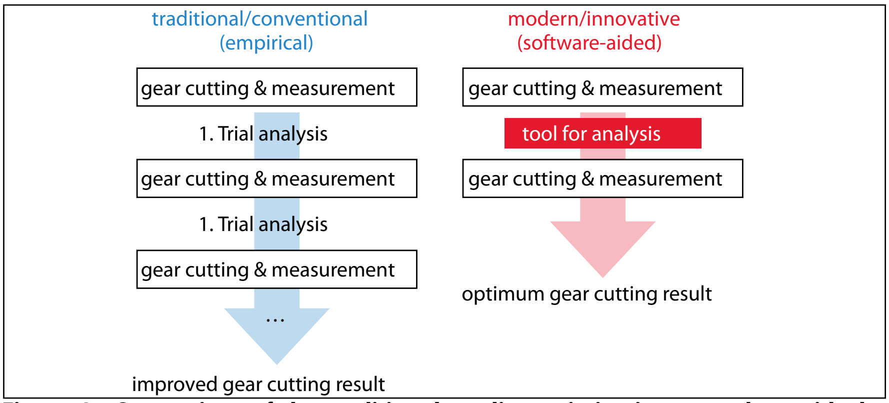

Figure 2—Comparison of the traditional quality optimization procedure with the procedure available using modern software.

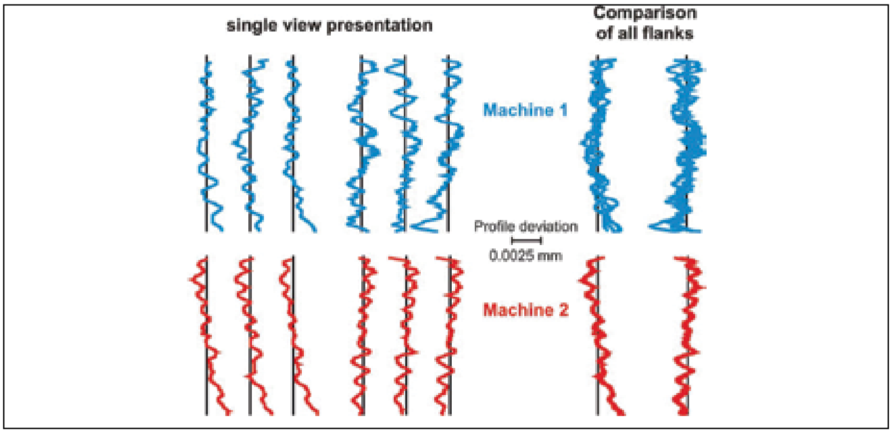

Figure 3—Klingelnberg analysis software allows side-by-side comparison of profile inspection traces.

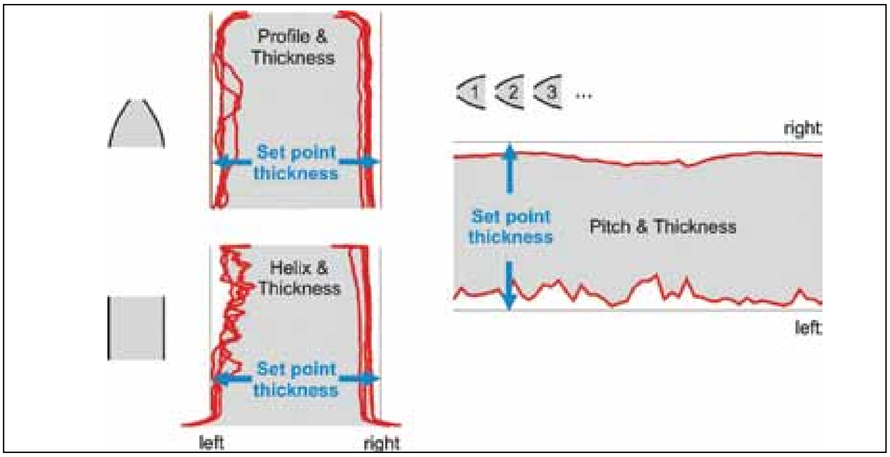

Figure 4—All variation curves are displayed in the correct positions relative to one another.

dimension can therefore be seen at a glance.

The material side is shown in grey for easier visualization. It is evident from the example that the gear is undersized in almost all areas.

Determining the Cause of Variations

Gears have a highly complex geometry, which must be manufactured with great accuracy. Disturbances that occur in the production process frequently affect several quality attributes at the same time, though in very different forms and sizes. Deducing the causes of a quality problem from the measured variations requires a great deal of experience, especially if the influences are superimposed. Here, the new analysis software acts in a supporting role, simulating the causes of variations very simply through their influence on the measured curves and qualitatively assigning existing variations in the measured results to their causes. The cause may usually be ascribed to clamping errors during the production process or during measurement.

Positional deviations occur when the center of the gear does not coincide with the desired axis of rotation in the installed state. Geometrically, variations in position are described as gear eccentricity or wobble, as shown in Figure 5. In the measured results, this leads to a variation in the profile and tooth trace direction and to sinusoidal variations in radial runout and pitch (Fig. 5, left).

On the one hand, the analysis software enables the user to visualize the effects of positional variations on gear quality. On the other hand, the clamping errors resulting from positional variations can be quantified and the measured values ironed out to rectify the respective defect rates (Fig. 5, right). In this optimum position, the remaining gear errors are clearly evident and can be analyzed and interpreted much more effectively.

Waviness Analysis for Low-Noise Gears

Another feature of the analysis software is waviness analysis. A frequency spectrum is calculated and displayed for each profile and tooth trace on the basis of measured variations (Fig. 6). The dominant frequency is plotted in the variation curve and expressed as a parameter in terms of amplitude and wave number. For purposes of further analysis, the variation curve is then rectified and the procedure repeated as necessary for further frequencies. The calculated frequencies can be plotted individually or as a mass curve, allowing comparison of compensating curves with real variation curves.

Figure 7 illustrates a first application of this new analysis option. Following installation of a new batch of ground gears, unacceptable noise behavior was noted in the gearbox. A comparison of measured values between the new batch and reference parts indicated the same frequencies in the profile, but higher amplitudes

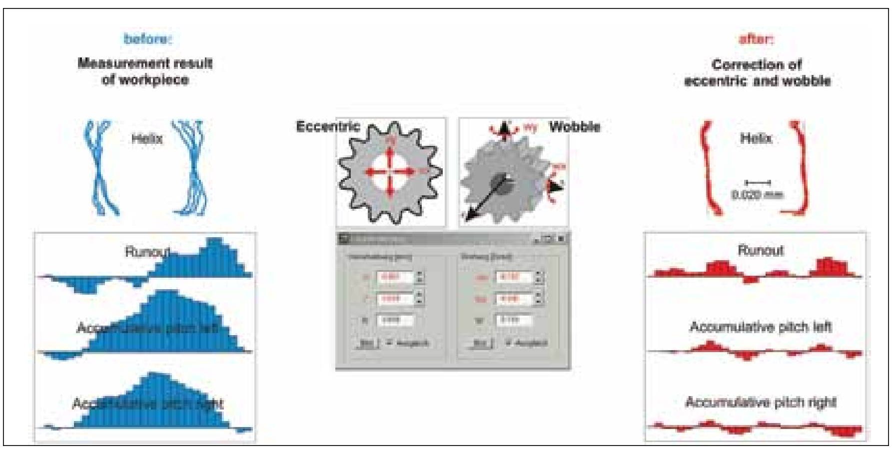

Figure 5—Software provides visualization of errors.

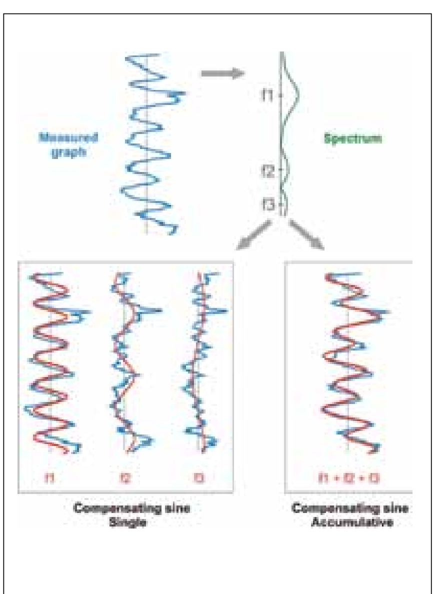

Figure 6—Waviness analysis allows a frequency spectrum to be calculated and displayed for each profile and tooth trace on the basis of measured variations.

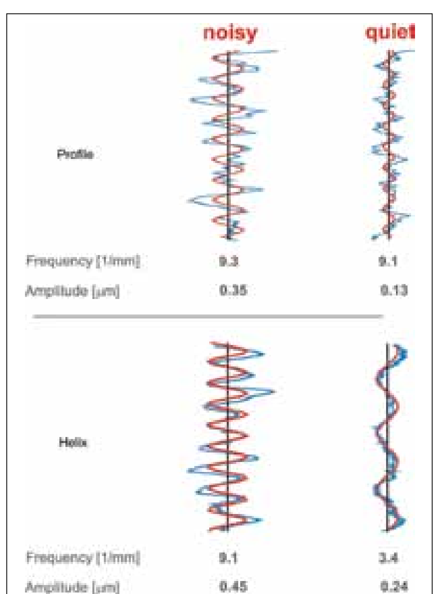

Figure 7—Example waviness analysis comparison between a noisy and quiet gear.

(approx. 0.2 µm), which could be attributed to altered dressing conditions for the grinding wheel. The tooth trace exhibits a change in frequency and amplitude caused by an increase in the feed rate during grinding.

Valuable Support

Modern gear metrology not only has to test gears as fast and reliably as possible, but must also support production in identifying the cause of errors. Klingelnberg's new variation analysis software is intended to bring users a step closer to this goal for a wide variety of problems and causes. Although the software cannot replace the necessary basic understanding of gear geometry and production experience, it can substantially support and simplify the process of troubleshooting.

For more information:

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D-42499 Hückeswagen
Germany
www.klingelnberg.com

Lube-Seal Solution

OPTIMIZES WIND APPLICATIONS

The Freudenberg Group embraces a natural synergy with the Lube&Seal package, jointly from Simrit and Klüber Lubrication, which combines the features of lubrication and sealing to benefit the greater system in wind turbine applications. The product integrates sealing lip systems and lubricants to create a more reliable tribological system.

"This is the first time we look at the lubrication and seals as an entire system instead of as individual components," says Tim Lomax, Simrit marketing communications director. "If, as in the past, each is regarded as completely independent of the other, one may be maximized at the expense of the other. For example, additives may be blended with a grease to give it certain lubrication properties with no regard as to how those additives affect the seal material. Certain additives

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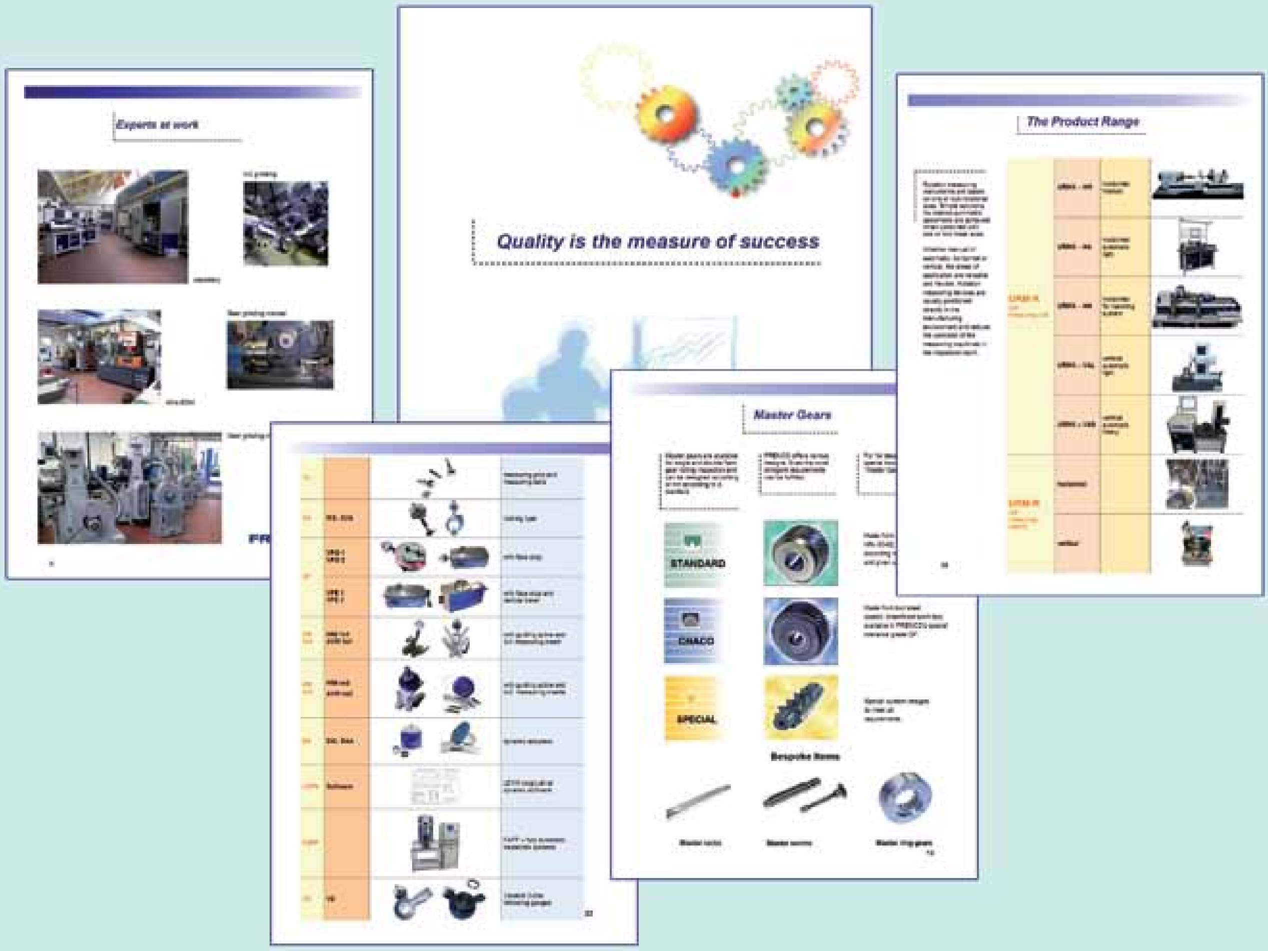
Process inspection of gears and splines



With more than 30 years of experience the german company FRENCO is an expert in the specialised field of industrial metrology for gears and splines.
The individual tasks of inspecting gears and splines vary considerably.

It is often a very easy process, but can also be a highly complex task from a mechanical or software point of view.
On this basis FRENCO is offering specialised tailor-made solutions for all spline and gear situations.

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are more aggressive toward rubber compounds, and by looking at the system as a whole, we can match the seal material and lubrication to maximize the life of each, reduce maintenance costs and eliminate costly downtime."

The Lube&Seal system helps minimize breakdowns in wind turbines due to leaks while preventing wear and reducing damage that can result from thermal instability or other environmental elements of concern to wind turbine manufacturers, such as ozone, salty air and mineral oils. This is well-suited for wind applications because manufacturers and operators look to extend maintenance cycles.

"Repairs on wind turbines can be costly, difficult and dangerous," says Jesse Dilk, industry group manager–wind, Klüber Lubrication North America L.P. "Therefore, it is vital to use high-quality components at every opportunity. Bearings, seals and lubricants are essential design elements when analyzing mechanical systems. Optimization of these elements leads to a more efficient, reliable machine design."

By looking at the lubrication in an application, the Lube&Seal system matches sealing materials to operate with that specific lubricant. Klüber's lubrication is designed to minimize the number of different lubes needed in wind turbines, which results in a simpler system. Simrit's low-friction seals provide reliable sealing with minimal energy loss. As an example of this, according to Lomax, "We've introduced [an] extremely low-friction labyrinth seal for turbine gearboxes, which combines PTFE and rubber elements for long-life and low-drag sealing."

The Lube&Seal package undergoes extensive testing and certification procedures to ensure chemical compatibility, low friction, temperature resistance, corrosion protection, contamination reduction and extended service life. The technology reduces wear and deterioration of

continued

key mechanical components.

Simrit and Klüber were a natural fit for this product collaboration. "Since Simrit and Klüber are both part of the Freudenberg and NOK Group of companies, we are uniquely positioned to look at both sealing and lubrication within the same group," Lomax says.

"The collaboration began in Europe when we began to study the effects of lubrication on sealing. It has since expanded to collaboration at the customer level to bring this knowledge out into the field where it can be used on a daily basis."

The Lube&Seal system debuted at Windpower 2010 in Dallas. "We are excited about our partnership with Klüber as it allows us to design, develop and manufacture a complete sealing system using the best possible materials and lubricants," says Dave Monaco, president of Simrit. "As a result, we can provide our customers with an all-in-one solution of the highest quality and durability, which is critically important in the wind power industry."

For more information:
Simrit Americas
Phone: (866) 274-6748
Fax: (734) 354-5500
information@simrit.us
www.simrit.com

KISSsoft

RELEASES NEWEST VERSION OF ISO/CD TR 15144

In the hitherto existing draft ISO/CD TR 6336-7, the information for the definition of the permissible specific lubricant film thickness λGFP was missing. Therefore, reference values considering λGFP had to be derived from literature. But the information in this context was often contradictory. The newest draft of the ISO/CD TR 15144, replacing the planned part of the ISO 6336, allows now the determination of the permissible specific lubricant film thickness λGFP, if the load level for micropitting of the oil is known. With the implementation of this standard addition in *KISSsoft*, the safety against micropitting is calculated.

For more information :
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Johnsburg, IL 60051
info@kisssoft.com
www.kisssoft.com

Vertical Grinder

RE-ENGINEERED FOR WELTER GEAR

The Welter Gear Division of Germany recently took delivery of a PFG re-engineered Doerries vertical grinder that offers some unique features that enhance the machine's use to Welter.

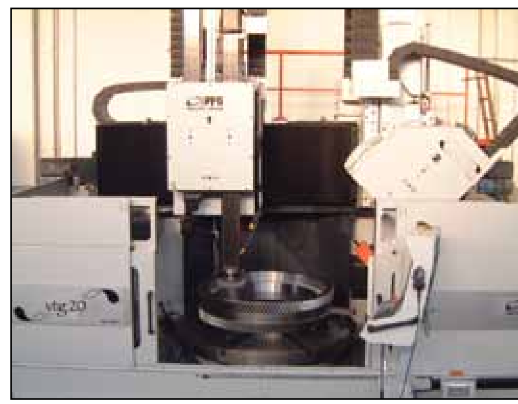
The grinder is equipped with two cross rail saddles; the left one supports a light, finish turning ram and a separate, straight vertical grinding head; and the right saddle provides a grinding spindle mounting support that will allow the grinding spindle to be mounted on two separate surfaces, 90 degrees opposed. Also, the entire right-side saddle can swivel ± 45, allowing surface grinding operations of ID and OD tapers, as well as angled surfaces on the top of a bearing ring, for example.

Welter has capabilities for spiral and straight bevel gears conforming to the Klingelnberg, Gleason and Kurvex cutting systems, as well as cylindrical gears up to 3,000 mm diameter. The re-engineered machine allows Welter Gear to machine finish and grind larger gear and

continued

bearing workpieces without re-fixturing or moving to another machine. This increases finished accuracies, reduces tolerances and improves fits. The PFG vertical grinder eliminates wasted set-up times while improving accuracy.

PFG is a privately owned builder of vertical machining centers and gantry mills located in Northern Italy, near Vicenza. PFG also re-engineers precision specialty machines that include grinders and turning machines. PFG is represented in the United States by Nanier Machine Tools of Ohio.



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60-Inch Diameter Gear Vacuum Carburized

Solar Atmospheres successfully vacuum carburized a large gear required for a defense application that had previously not been successfully processed using atmospheric-type equipment.

The achievement is directly related to modifications made to Solar's large 10 Bar Quenching Furnaces, so they can handle larger and more extensive loads. By adding new instrumentation, carburizing nozzles and improving the backfill system, this furnace—with a work zone measuring 48 inches wide by 72 inches long by 38 inches high and load capacity of 10,000 pounds—is capable of performing carburizing cycles on large parts and loads not previously thought possible in vacuum.

This successful application was a large gear of 9310 steel material with dimensions of 60 inches diameter by 13 inches high and weighed 1,900 pounds. The part was low pressure vacuum carburized to achieve an effective case depth of 0.070 inches, followed by a temper, a minus 225 degrees Fahrenheit freeze and a second temper operation. Quenching was accomplished using a mixture of nitrogen and helium gases. Flatness was within 0.100 inches and roundness within 0.050 inches.

Solar anticipates these types of results further expanding the applications for low pressure vacuum carburizing.

For more information:
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1969 Clearview Road
Souderton, PA 18964
Phone: (215) 721-1502
Fax: (215) 723-6460
www.solaratm.com

High-Speed Inserts

INCORPORATE THROUGH-COOLANT

Several products released by Ingersoll Cutting Tools expand machine tool cutting capabilities.

The Power-Feed+Mini high feed cutter features high-speed geometry with a double-sided, four-edge insert engineered specifically for high-

continued

speed machining to deliver economy, strength and performance.

The inserts infuse Power-Feed+ technology into a smaller insert to provide high-feed capabilities with higher insert densities in smaller diameter end mills. The cutter bodies incorporate through-coolant and are constructed of premium alloy steel materials. They are appropriate for high-speed roughing at lighter depths of cut.

The CVD coated series T-Tinox grades increase productivity, for stainless steel turning. The copper-colored T-Tinox coating resists material build-

up on the cutting edge, and a smooth, stable cutting edge results from Ingersoll's T-Turn+ technology.

The T-Tinox series consists of three grades. The TT9215 provides high wear and chipping resistance appropriate for high speed and continuous cutting in stainless. TT9225 provides a balance of wear and fracture resistance for general purpose stainless steel applications. The TT9235 provides fracture resistance and toughness for interrupted stainless steel cutting at low speeds.

The 3n1-Rounds series 45D...RP solid carbide roughing endmills feature high-feed geometry with variable pitch and chip slitters. This series covers a range of applications including slotting, pocketing, helical interpolation and contouring.

Four- and five-flute versions are available with a 38-degree helix and large corner radii to enable high-feed application. The serrated cutting edge features flat peaks for improved surface finish. Diameters range from 0.250 inches to 0.750 inches and are supplied in IN2005 grade.

Ingersoll also introduced integral collet tooling to connect to the Hi-PosMicro indexable end mills and Chip-Surfer solid carbide tipped tooling lines. Worn tooling can be replaced in seconds with 0.0005 inches axial and radial repeatability. Economy and higher feed rates of the indexable Hi-PosMicro end mill tips allow for high throughput at less cost. The Chip-Surfer tips can be applied to a wide range of materials. Cutter diameters range from 0.250 inches to 2.00 inches. Medium- and high-density versions expand application options.

For more information:
Ingersoll Cutting Tools
(815) 387-6600
www.ingersoll-imc.com

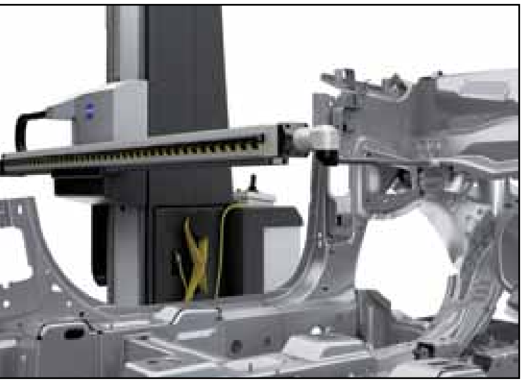
Zeiss Machines

MEASURE AUTO, ROUND PARTS

The Carmet II from Carl Zeiss was developed specifically for suppliers and manufacturers in the automotive industry. The horizontal-arm measuring machine is available in four sizes up to a measuring range of 7 meters by 1.6 meters by 2.5 meters (x, y and z axes respectively). It comes standard with the RDS stepping articulating probe holder featuring computer aided accuracy (CAA). It uses the foam insulation technology that was introduced recently with the Accura machine.

Setting new standards regard-

continued



ing robustness, ergonomic design and performance, Carmet II features an attractive price/performance ratio and low lifecycle costs. Carmet II has a smaller footprint than similar measuring machines, which is the result of the onboard controller on the machine. Sensitive machine components are enclosed in a special, high-tech material providing the machine with high temperature stability. A shortened maintenance time increases the machine availability with maintenance-relevant parts easily accessible.

The robust guideway system features pre-stressed friction drives that unite a high level of safety and quietness. The machine's design facilitates access to the measuring location and simply loads the complex components commonly found in car body measuring. Touch-trigger sensors achieve shorter calibration times, increasing productivity. Difficult-to-reach areas, like the wheel arch of the car body, can be assessed with different touch-trigger sensors and extensions up to 350 mm.

Carl Zeiss also introduced the O-Inspect multi-sensor measuring machine available with a rotary table that inspects small and complex parts used in the electronics and plastics industries, medical and automotive technology, as well as precision engineering applications.

The rotary table developed specifically for this machine can be mounted and removed by the measuring machine operator. It can be positioned both horizontally and vertically for added benefit. The rotary table enhances the effectiveness of the measurement of round parts that no longer have to be re-clamped for the optical measurement. Mechanical influences are minimized as the measuring axes of the CMM are only subject to minimal movement with the rotary table.

The O-Inspect essentially combines the functions of a profile projector, measuring machine, microscope and contour measuring machine. Multiple sensors on the O-Inspect allow alternation between optical and contact measurements in one run. The optical measurements are performed with the 2-D camera sensor with the image processing function contained in the Discovery zoom lens. Contact measurements are the domain of the Vast XXT scanning probe. The CAD-based *Calypso* measuring software comes standard.

For more information:
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Maple Grove, MN 55369
Phone (800) 327-9735
imt@zeiss.com
www.zeiss.com/imt

Induction Hardening and Tempering System

FOR DRIVELINE COMPONENTS

Inductoheat, Inc., an induction heating equipment manufacturer, recently delivered an induction hardening and tempering system to a leading supplier of driveline components. This machine was designed specifically for hardening and tempering hub spindles and ball races.

The equipment is comprised of a STATISCAN IV unit for induction hardening and a STATISCAN II unit for induction tempering. The part goes through an eight-station cycle using the following material handling features; four pneumatic linear transfer 180 degree grippers, two pneumatic accept/reject arms and a continuous feed conveyor.

Each of the eight stations adheres to

continued

the following responsibilities: Station 1, parts are automatically loaded; Station 2, pneumatic part locator and check; Station 3, induction hardening O.D. of hub shaft; Station 4, I.D. auxiliary quench cooling; Station 5, pneumatic exist and acceptable parts are transferred onto the tempering system conveyor; Station 6, parts travel through a channel coil for tempering; Station 7, conveyor quench cooling; and Station 8, automatic part unload for accepted parts or exit conveyor for rejected parts.

There are two induction power supplies for this compact system. The hardening inverter is a UNIPOWER UP12 power supply, which provides 200 kW at 10 kHz, and a STATIPOWER SP16 power supply offering 50 kW at 10 kHz for the tempering portion. Allen-Bradley PLC controls with touch-screen HMI interface, and process monitoring offers superior process control and monitoring capabilities assuring the highest quality and repeatability, according to the company. For system cooling and part quenching, an integrated closed-loop water recirculation system is included.

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www.inductoheat.com

Robotic Blast Machine

INCORPORATES TRANSFER CART

Guyson Corporation has introduced a robotic blasting system that incorporates a component-manipulating six-axis robot and a shuttle transfer cart to fully automate processing of tray-loads of components. The new Model RB-TRR-900 is designed for precise surface preparation, shot peening and cosmetic finishing operations.

The robotic blast machine is provided with a single suction-blast gun or pressure-blast nozzle that is rigidly bracketed in a fixed position inside the 42 x 42 x 42-inch blast chamber. Guide rails form a track extension into an antechamber on one side of the blast cabinet. Rolling on the track, the transfer cart bearing a tray full of components is moved in and out of the blast enclosure by a precision linear actuator, and a pneumatically actuated vertical sliding door closes to isolate the load/unload station from the blasting zone. A FANUC M-10iA robot with a custom-engineered pneumatic gripper serves as a component handler in the automated blasting system, grasping and removing a part from the tray, presenting the component to the blast, then replacing the finished work piece. A tailored skirt seals the cabinet wall and protects the robot from the potentially abrasive environment of the blast chamber.

FANUC Robotics offers larger and smaller 6-axis robots that can be integrated in the RB-TRR-900, should a different payload or reach be required. To blast a production lot of parts, a tray of oriented components, typically 6 to 24 in number, is placed on the transfer cart, the sliding load door is closed and a part identification number is entered or selected at the touch-screen control panel. Alternatively, component recognition features are available, including a bar code reader, to positively identify the work and prompt the recall of the correct motion program and blasting process recipe, with automatically controlled parameters such as blast pressure, media flow rate and the duration of the blast and blow-off cycles. While the robotic blast system methodically and identically repeats the surface treatment on each of the components in the batch, the human operator is freed for an extended period to perform other work.

According to the blast equipment manufacturer and authorized FANUC integrator, the robotic component manipulator constantly and accurately maintains the specified blast angle, nozzle offset and surface speed, even

continued

when following the contours of complex-shaped aerospace or medical parts, which makes it possible to produce extremely consistent surface conditions and eliminate non-conformities in finish quality.

Prospective users of automated and robotic blasting systems are invited to submit sample components for free laboratory testing and application engineering evaluation at the machine builder's factory in northeastern New York.

For more information:
Guyson Corporation U.S.A.
13 Grande Boulevard
W.J. Grande Industrial Park
Saratoga Springs, NY 12866
Phone: (800) 228-7894
www.guyson.com

Coolant Delivery

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The Perfect Jet Collet from Big Kaiser Precision Tooling Inc. is designed to optimize coolant supply in high-speed operations for better coolant delivery and the option to seal the collet for coolant-through tools.

The Perfect Jet Collet is designed for use with Big Kaiser's Hi-Power Milling Chucks and Mega Double Power Chucks. The collet seals the chuck face and directs the coolant down the tool shank to the cutting edge instead of centrifugal force disrupting the coolant supplied through the tool holder, resulting in coolant spraying wide.

For more information:
Big Kaiser
2600 Huntington Blvd
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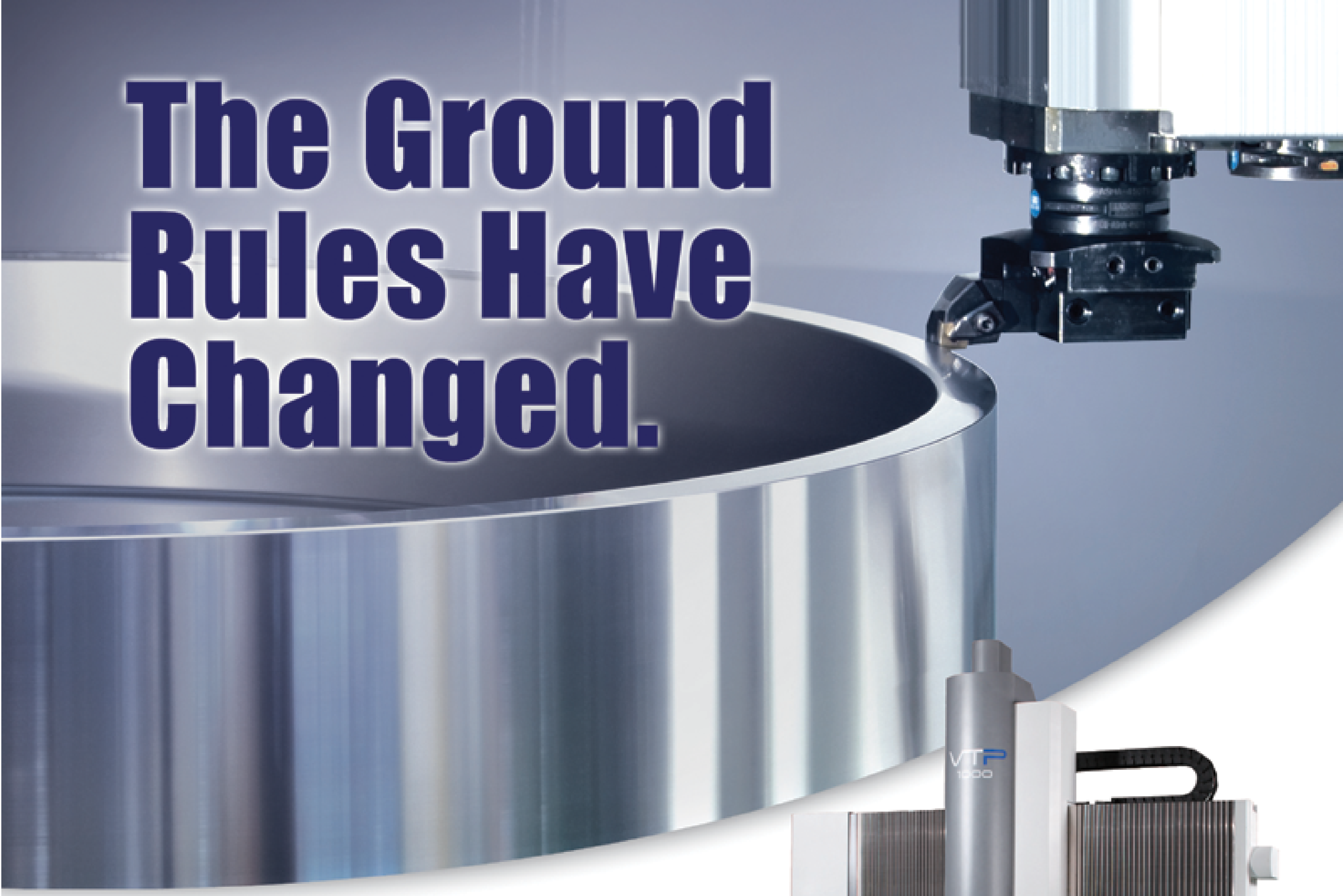
Phone: (847) 228-7660
Fax: (847) 228-0881
bigkaiser@bigkaiser.com
www.bigkaiser.com



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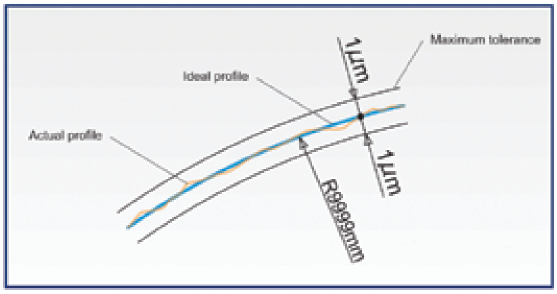

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Fully automated setup of the GMM inspection systems at Milwaukee Gear allows for greater productivity and repeatability than older-model machines.

Large Gears, Better Inspection

INVESTMENT IN GLEASON GMM SERIES INSPECTION EQUIPMENT HELPS DRIVE MILWAUKEE GEAR'S EXPANSION INTO PROFITABLE NEW MARKETS AROUND THE WORLD—ALL HUNGRY FOR LARGER, HIGH-PRECISION CUSTOM GEARS AND GEAR DRIVES.

Milwaukee Gear's diverse product portfolio includes gears for applications ranging from compressors to cooling towers, paper to plastics machines, wind turbines to coal mining equipment, offshore oil rigs to cranes and hoists—wherever particularly high-quality, often completely custom gears are required.

But Milwaukee Gear president/CEO Richard Fullington says that customers today, regardless of the industry, are all buying essentially the same product when they come to Milwaukee Gear: reliability.

Sales in *reliability* must be very good, judging from the robust level of activity on the production floors of Milwaukee Gear's 180,000-square-foot job shop, now running two shifts a day, five days a week. Milwaukee Gear's strategy in recent years of investing heavily in turnkey production capabilities for larger gears—including large-gear hobbing, grinding and heat treating equipment—is now paying off, as the company lands more and more work from "hot" sectors like wind power and mining and from markets as far away as China and India.

Investment in inspection. Now, Milwaukee Gear is "doubling down" on the big gears business again, this time with the installation of two new Gleason GMM Series Analytical Gear Inspection Systems, which Milwaukee Gear quality manager Joseph Leone says will enable the company to keep pace with both its expanding capacity and the increasingly challenging gear designs of its diverse customer base.

"Today's gear designers are stretching the limits of gear tooth geometries like never before," says Leone, who has spent the last 31 years helping put the "reliability" into Milwaukee Gear's products. "Extensively modified tooth forms, parabolic tip relief characteristics, finer micro finish tooth surface—whatever it takes to squeeze more horsepower, longer life, quieter operation out of the gear—it can and is being done. And all the while the quality bar continues to be raised, to where even AGMA 14 is typical rather than exceptional."

Leone says that, when push came to shove, the vintage 1980s 1.5-meter inspection system that was long the workhorse of his QC lab simply was not capable of meeting the accuracy and, most importantly, the repeatability requirements of many of these new-generation gears, despite the best efforts of inspectors with dozens of years of experience.

"Setting up the old system for a new part was a slow, tedious process, setting scales manually through a sight glass for lead inspection, then setting a scale for profile inspection, then pitch and so on," Leone says. "Measuring tooth thickness and tooth spacing was also painfully slow, with the probe being manually positioned for every tooth as the machine's rotary table was indexed. Ultimately, the process was not only extremely time-consuming, but also did not give us the ability to meet our repeatability requirements part to part. We needed an efficient, fully automated and highly accurate and repeatable solution. And one that even a less experienced operator could quickly get up to speed on."

Today, Milwaukee Gear's climate-controlled QC lab looks very different than it did just 12 months ago, with the older inspection workhorse put out to pasture and two new Gleason GMM Analytical Inspection Systems now standing in its place.

Leone says it was apparent "right out of the box" that Milwaukee Gear had made the right decision to purchase the Gleason 1000GMM (1 meter workpiece diameter capacity), and then a second, larger 1500GMM (1.5 meter capacity), contingent on the first machine's performance. In just a few months of operation, the inspection systems are exceeding expectations in every critical category. For example:

Repeatability. Acceptance of the 1000GMM hinged on a runoff using a precision master gear, with an allowable pitch variation from nominal of no more than ± 0.000030"—or 30 millionths of an inch. The average variation in pitch error during the month-long runoff period was 0.000016", and an average of 0.000013" from six readings taken every day, a fraction of what was required and well within the tolerances of even aircraft-quality gears.

Part of what allows such repeatability is the GMM's robust design, with a solid granite base, Meehanite cast-iron slide assemblies and

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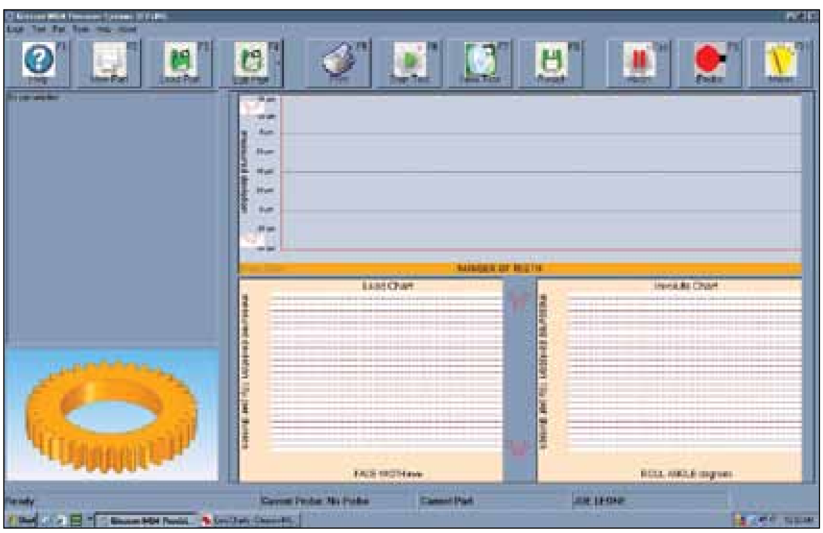
Part setup on the new machines is much faster and easier than on the 1980s-era predecessors.

The QC lab at Milwaukee Gear was recently retooled with two large-diameter GMM inspection systems from Gleason.



The Gleason *GAMA* software allows new part programs to be created in just minutes.

heavy-duty rotary table giving them exceptional stiffness and rigidity to accommodate gears weighing as much as 2,200 kg for the 1000GMM and 4,500 kg for the 1500GMM.

Productivity. Where it might have taken an hour to set up and perform all the measurements required by a typical 1-meter, 60-tooth external gear on the older inspection system, Leone estimates that time has been cut in half by the new GMMs. "For our operation, this is particularly important—not so much on inspection of finished parts because volumes are low but in support of new part setups on our big hobber and in the form grinding cell. At Milwaukee Gear, it's really the QC lab that first determines whether a part is ready for processing, whether soft cutting or hard finishing. With the GMMs, the QC lab can keep pace with production."

Where the older inspection system relied heavily on the expertise of the operator and considerable manual operation, Leone says that the GMMs instead use *GAMA* (*Gleason Automated Measurement and Analysis*) operating software to simplify programming and completely automate the inspection process. For both Milwaukee Gear's most experienced inspectors and a new generation of less experienced operators, *GAMA* is designed to make life easier. Here's how:

1) A typical screen has "quick buttons" across the top giving the operator immediate access to the most common system operations. All important gear and specific test information is shown down the left side of the screen, with tabs and forms making it easy for the operator to quickly and accurately establish gear parameters. The majority of the screen is used to chart the inspection results of, say, lead and involute tests, which appear in real time as the tests are performed. There is also a status bar at the bottom of the screen detailing the stage of the operation, who is operating the system, part number and so on.

2) Operators start the process either by loading and activating existing part programs with the click of a mouse, or by creating a completely new part program that can be done in just minutes with a few easy steps. The operator simply selects from a list of typical machine configurations, enters a part number and clicks a "create" button. A series of tabs then appears across the top of the screen. The operator clicks on these tabs one by one, filling out the necessary fields with pertinent gear data, special tests required for highly modified gear profiles and geometry, the type of analysis required (*GAMA* supports all global industrial standards such as DIN, AGMA, ISO, JIS, etc.), and so on. The operator also can select a variety of options for how a permanent record of the inspection is stored, whether in PDF format, SVG (scalable vector graphics), or even HTML for easy e-mailing.

GAMA is a true Windows VB.NET application, making it fully compatible with Milwaukee Gear's LAN network, so that Milwaukee Gear can easily interface inspection results with its gear design and production resources for corrective actions downstream.

"In addition, GMM's remote diagnostics capability has been very useful, particularly in the early stages of the installation, to get support from Gleason relative to programming and operational questions," adds Leone. "Gleason can actually take control of the GMMs from their location, help troubleshoot them…whatever we need."

Significant productivity gains also result from the GMM's use of a series of Renishaw SP80H 3-D scanning probes, with various stylus sizes and configurations—and all interchangeable from an automatic probe changer. As compared to the old inspection system and the process of painstakingly positioning the probe manually tooth by tooth, the Renishaw probe saves a lot of setup time. It acquires much more data faster by traveling along the surface of the part in all three dimensions—up, down, side to side and in and out—all fully automated.

…And, of course, reliability. Milwaukee Gear CEO Richard Fullington sells reliability—and he also believes in buying it. "Our relationship with both Gleason and M&M Precision Systems (a company purchased by Gleason in 2005) dates back several decades, and Gleason large gear hobbing and profile grinding equipment is at the heart of our expansion into new markets worldwide," he says. "Our level of confidence and trust in Gleason technology and [its] ability to service and support it, was of course instrumental in our decision to go forward with the GMMs. The results speak for themselves."

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User-Friendly Gear Measurement

GOOD TIMING LEADS TO PARTNERSHIP BETWEEN PROCESS EQUIPMENT AND SCHAFER GEAR

Matthew Jaster, Associate Editor

Schafer Gear Works, Inc., headquartered in South Bend, IN, is a producer of high-precision, custom-engineered gears and machined parts. The company saw a fortunate expansion of new business at the end of 2009 and needed to expand its gear capacity. Around the same time, the Process Equipment Company (PECo), located in Tipp City, OH, was dispatching representatives to discuss the advantages of its gear measurement systems.

"We needed to make a quick decision based on our increase in business, and PECo had a machine that was ready to go" says Doug Fozo, quality manager at Schafer Gear. "The timing was perfect, and we had confidence in PECo and what they had to offer us."

Schafer Gear soon purchased PECo's ND300 gear measurement system. The ND300 offered a user-friendly, intuitive software platform that made Jim Shinall, quality technician at Schafer Gear, very excited. "We had been using an outdated Höfler gear checker that was very difficult to find support for," Shinall says. "The ND300 gives us immediate network assistance from PECo representatives. They can walk me through any problem we might have directly online. It also stores every part on the server, so

continued

PECo's data acquisition and Renishaw 3-D probe technology enables the machine to generate measurements on various surfaces (All photos courtesy of PECo).

The ND300 from PECo fit perfectly with the gear measuring needs at Schafer Gear thanks to its service and support benefits.

The ND300 comes with a three-year warranty, telephone service response and remote software support.

I can recall anything I need to. The network capabilities are a huge advantage for us."

PECo's proprietary data acquisition algorithms and Renishaw 3-D probe technology produce true 3-D measurements in an error-compensated work envelope. This enables the machine to generate comprehensive measurements on various surface orientations. Thanks to off-the-shelf probing technology, the probes are less costly to replace, allow for quick-change tooling and are easy to find if a replacement is needed. The ND300 can measure down to 120 DP or 0.21 module and gives customers the ability to measure and analyze components that customers previously just had to assume were correct or had to test functionally on roll testing equipment.

Using a combination of linear displacement and volumetric algorithms, the ND300 maintains accuracy throughout the measuring zone, making it possible to inspect several features of a part and accurately relate them to one another. PECo's unique proprietary spatial mapping algorithms enhance the accuracy of the system, providing inspection throughout the entire measuring volume.

Schafer Gear put the ND300 to work immediately on internal and external gears, helical, spur, bevel, worm and cluster gears, as well as standard profile splines and flat root splines. "The machine has been running 10 hours a day since installation," Shinall says. "It supports our production floor and has been a great help in handling our new business."

The Microsoft Windows platform on the ND300 is easy to use, designed for custom software development and can interface with the latest computer hardware and operating systems. Shinall finds that the charts and data are "easy to read and accessible." The remote programming package allows for work to be done from an office away from the production floor.

Additionally, the ND300 offers features that can eliminate runout. It also has multiple standards that are built directly into the system. After a couple of clicks, Shinall can pull up any information he needs for a specific job. "The system reads between the lines, so to speak; it lets us do things our old gear checkers could not accomplish. There's also a feature that will let you put a gear on the machine, and it will tell you what it is. We don't always get a print, so the reverse engineering capabilities are another advantage."

Stan Blenke, executive vice president at Schafer Gear, believes the purchase of a new gear measuring machine is vital for several reasons in this economy. "First of all, it allows us to keep up with machine tool technology. Second, it increases productivity through improved efficiency, reduction of waste and eliminates bottlenecks. This helps us retain existing customers and generate new business. It also helps retain employees by allowing them to work with the latest technology in the industry."

Blenke says that Schafer Gear continues to see many large corporations consolidating clients, outsourcing and changing suppliers to reduce costs. The company wants to maintain its presence in the gear market by reducing production costs and enhancing product flow without compromising its quality standards.

The ND300 was brought in to support Schafer's expanding business ventures and give the company an opportunity for more business in the future. "There's a trend toward more gear grinding at Schafer, and we plan to expand our capabilities in this area," Blenke says.

If the opportunity presents itself for further investment in gear measuring equipment, Shinall believes Schafer will continue to work with PECo.

"The service support that PECo provides is outstanding. The support team calls us frequently and asks how things are going with the machine. They call us to ask about any problems before we call them. It's really a fresh approach to business."

Brian Slone, general manager equipment division at PECo, takes pride in the company's rapid response rate. "Our system was designed from the very beginning with support in mind. All of our components are modular for easy, quick replacement if needed and our software was designed to take advantage of Internet-based support and upgrade requests. All of our machines, from the first one installed a decade ago to the machine shipped recently to Italy, are Internet ready for remote access support."

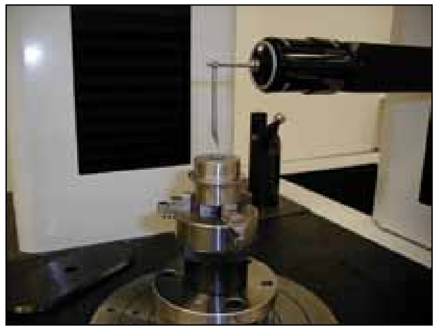
PECo offers a three-year warranty on its measurement system as well as telephone service response and the remote software support. On-site service is available if a technician is needed to come out and work directly on the machine.

"Over the past decade, our machines have averaged a Mean Time Between Failure of over four years," Slone says. "The ND300 is consistently dependable and our reputation for going the extra mile on technical support is just one of its many features."

The purchase of gear measurement equipment involves the technology benefits and all the bells and whistles included. In the case of Schafer Gear, a decision was made with these factors in mind, but PECo's customer service, technical support and immediate avail-

continued

With next day service and proficient software update installation, Schafer Gear will continue to look at PECo gear measuring products in the future.



ability played a larger role in the company's final decision.

"PECo installs updates and provides next-day service. We've reported no mechanical issues since start-up," Fozo says. "PECo would have an advantage over anyone else if and when we need another gear measurement machine on the production floor."

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Load Sharing Analysis of High-Contact-Ratio Spur Gears in Military Tracked Vehicle Applications

M. Rameshkumar, P. Sivakumar, S. Sundaresh and K. Gopinath

Nomenclature

a	addendum of gear tooth
b	face width
CR	contact ratio
F_t	tangential force
G_r	gear ratio
h	height of the parabola at the critical section
J	geometry factor
k_f	stress correction factor
m	module
r	minimum radius of curvature of root fillet
t	tooth thickness at the critical section
Y	tooth form factor
Y_a	addendum factor
Y_L	y coordinates of the vertex of the parabola
Z_1	number of teeth of pinion
α	pressure angle
φ_L	load angle
φ	pressure angle (same as α)
r_1, r_2	operating pitch radius of pinion and gear

Management Summary

Military tracked vehicles demand a very compact transmission to meet mobility requirements. A compact transmission with low operating noise and vibration is desirable in military tracked vehicles to reduce weight and improve power-to-weight ratio. It is also necessary to increase the rating of existing transmissions in military tracked vehicles, like prime movers, to accommodate the additional weight required for ballistic protection. Hence, it was decided to apply a high-contact-ratio (HCR) spur gearing concept that will reduce noise and vibration and enhance load carrying capacity for a 35-ton, tracked vehicle final drive. In HCR gearing, the load is shared by a minimum two pairs of teeth, as in helical gears. It was decided to analyze the load sharing of the normal-contact-ratio (NCR) gearing used in the sun/planet mesh of the existing final drive; and, to analyze the load sharing of the HCR gearing that will be used to replace the NCR gears without any change in the existing final drive assembly except sun, planet and annulus gears. This paper deals with analysis of the load sharing percentage between teeth in mesh for different load conditions throughout the profile for both sun and planet gears of NCR/HCR gearing—using finite element analysis (FEA). Also, the paper reveals the variation of bending stress, contact stress and deflection along the profile of both NCR and HCR gearing.

continued

Introduction

Contact ratio is defined as the average number of tooth pairs in contact under static conditions, and without errors and tooth profile modifications. A majority of the current gearboxes for tracked vehicle applications have contact ratios ranging from 1.3 to 1.6; the number of tooth engagements is either one or two. The term high-contact-ratio (HCR) applies to gearing that has at least two tooth pairs in contact at all times—i.e., a contact ratio of two or more. As the percentage change in mesh stiffness for HCR meshes is lower than the percentage change in mesh stiffness for normal-contact-ratio (NCR) meshes, one can expect high-quality HCR gear meshes to have lower mesh-induced vibration and noise than NCR gear meshes. A high-powered, compact transmission (Ref. 1) is essential to enhance the mobility of military tracked vehicles. This requirement is partially met by improvements applied to NCR gearing. A literature survey indicated that HCR gearing was designed (Ref. 2) and successfully used in helicopter transmissions (Ref. 3) to improve further the power-to-weight ratio of the transmission. In HCR gears, since a greater number of teeth share the load (Ref. 4), the concept appears to be simple and has wide, potential applicability. It has not to date been applied to military tracked vehicle transmissions.

A detailed study of the existing final drive planetary gear assembly (Fig. 1) of a 35-ton military tracked vehicle was carried out to apply the HCR concept. The final drive is an independent unit that has been isolated for separate testing to apply the concept of HCR. This paper provides an approach to arrive at the HCR gears for the final drive of a tracked vehicle—i.e., a detailed analysis of the load sharing percentage of teeth in mesh throughout the profile for both sun and planet gears of NCR/HCR gearing using finite element analysis (FEA). Bending stress, contact stress and deflection of gear teeth were also calculated.

An attempt has also been made to prove the new concept of HCR gearing using *ANSYS* software (Ref. 5).

Evolution of Design for HCR Final Drive

The mechanical schematic of the entire transmission is shown in Figure 1. NCR gearing was originally used through the transmission and final drive. The HCR gearing concept is applied to the final drive of the 800 hp automatic transmission.

The final drive is located outside the main transmission and is fixed to the vehicle hull. It serves as an additional reduction unit in multiplying the driving and braking torque for the tracks. The final drive (Fig. 2) consists of three gear elements, namely: sun gear (23 teeth), planet gear (22 teeth) and annulus gear (69 teeth) of module 4 mm with a contact ratio of 1.343. The transmission left-hand (LH) and right-hand (RH) outputs are connected via toothed, sliding couplings to the sun gears of the LH and RH final drives, respectively. The annulus gears of the two final drives are fixed, and they provide the reaction torque. The output power from the LH and RH final drives is taken from the planet carriers, which are connected to the LH and RH sprockets driving the tracks.

In order to increase the load carrying capacity of the existing NCR final drive—keeping the same weight and volume envelope—introducing HCR gearing was proposed.

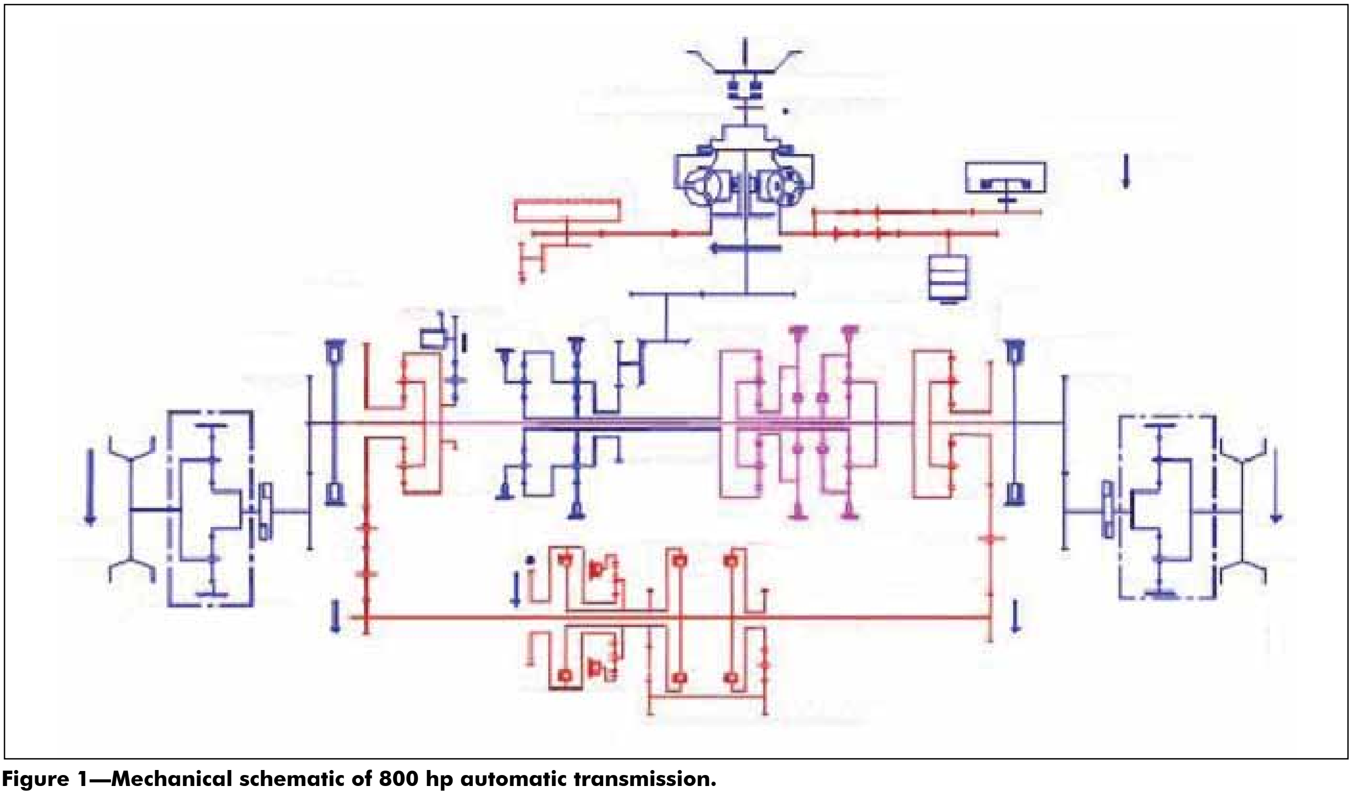


Figure 1—Mechanical schematic of 800 hp automatic transmission.

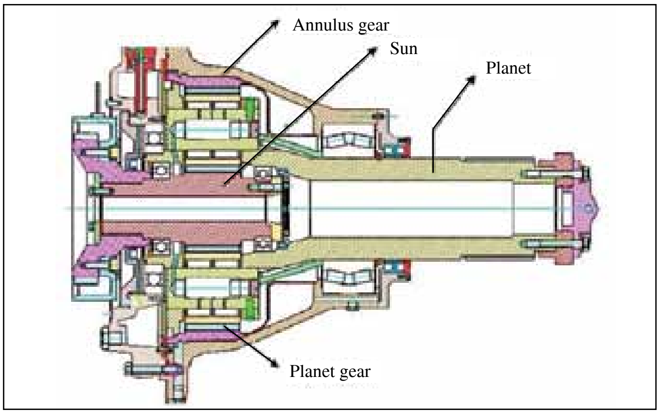


Figure 2—Cross section of final drive.

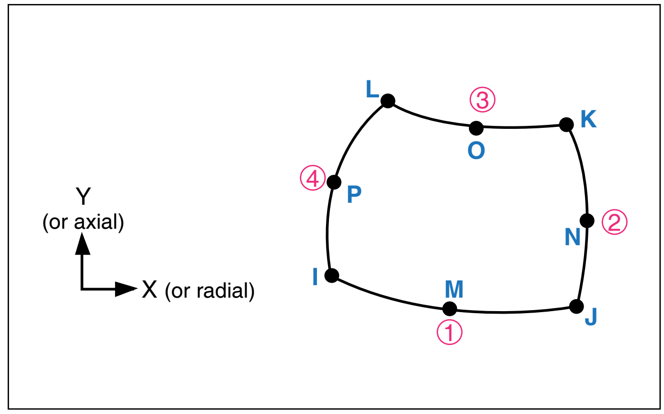
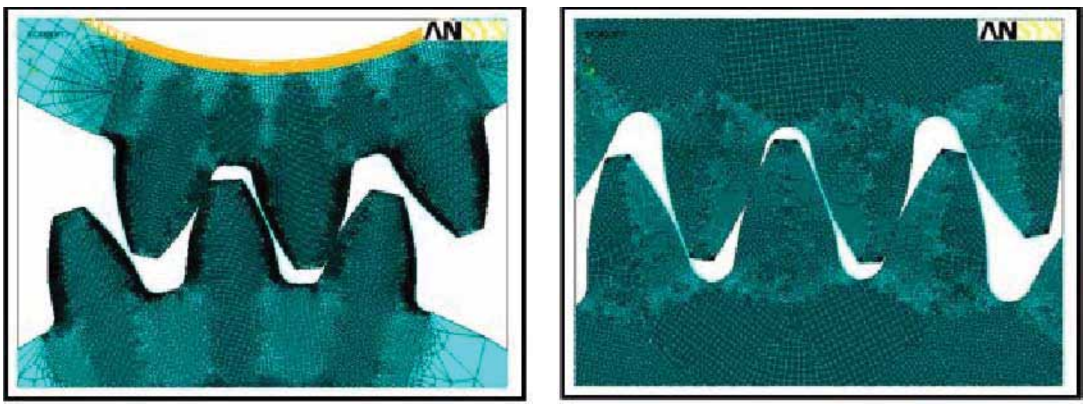


Figure 3—PLANE 82 higher-order plane strain element.



a) NCR gear b) HCR gear

Figure 4—Finite element-meshed model.

Various combinations of number of teeth, module, profile correction, addendum factor, etc., were analyzed to achieve a design very close to the existing NCR final drive data. The HCR gearing is designed in such a way that only sun, planet and annulus gears of the NCR final drive are changed by keeping the same center distance (93.013 mm), face width (64 mm) and keeping other members the same. A minor variation in the gear reduction ratio was necessary since it is very difficult to achieve the same ratio in view of various other constraints, such as center distance. This implies that to make use of the same gearbox for HCR gearing, with a restriction on contact ratio of 2.0106, the center distance should not be altered. However, considering the various parameters, such as tolerance on tip circle diameter and center distance, top land edge chamber, thermal effects, profile tip and modification, it is advisable to select a contact ratio greater than 2.2 wherever possible. Spur gears are used since their production is simpler and more economical than helical gears; moreover, they are free from axial loads. The concept for various factors that aid in obtaining HCR for spur gears is evolved from the contact ratio (*CR*) given in Equation 1—i.e., where r_1 and r_2 are the operating pitch radius of the pinion and gear, a is the operating pressure angle, m is the module and α is the addendum (based on the operating pitch radius), which is equal to one module for standard gears.

Since for the present investigation the center distance

continued

Table 1—Gear Parameters

Sl no.	Parameters	NCR	HCR
1.	Profile	Involute	Involute
2.	DIN accuracy class	7	7
3.	Module, ***m***	4.0 mm	2.5 mm
4.	Number of teeth in sun, ***Zs***	23	38
5.	Number of teeth in planet, ***Zp***	22	36
6.	Number of teeth in annulus, ***Az***	69	110
7.	Profile correction in sun, ***Xs***	0.3	0.109
8.	Profile correction in planet, ***Xp***	0.539	0.1
9.	Profile correction in annulus, ***Xa***	-0.3024	-0.3096
10.	Center distance, ***Cd***	93.013 mm	93.013 mm
11.	Reduction, ratio, ***Gr***	4.0	3.894
12.	Addendum factor, ***Ya***	1.0	1.25
13.	Contract ***CR***	1.343	2.0106
14.	Facewidth, ***F***	64 mm	64 mm

should not be altered, a close observation of the equation suggests that the contact ratio of spur gearing can be increased by several ways: (a) by reducing module; (b) by increasing the number of teeth; (c) by lowering the pressure angle; and (d), by increasing the addendum. In this paper the HCR is obtained by increasing the addendum factor and number of teeth by reducing the module. The important gear parameters of both NCR and HCR gear designs are shown in Table 1.

Material properties of the gear are taken to be Young's Modulus = 2.1×10^7 MPa and Poisson's ratio = 0.30.

FEA of NCR/HCR Gear Design

FEA is used to study in detail various parameters such as bending stress, contact stress, deflection, etc., for both NCR and HCR gearing.

Equation 1 see below (1)

Spur gear geometry. The profile of an involute spur gear tooth is composed of two curves. The working portion is the involute, and the fillet portion is the trochoid. Theoretical limit radius (Ref. 6) is an important parameter when gear kinematics is considered. It is the radius at which the involute profile on a gear should start in order to make use of the full length of the involute profile of the mating gear. The trochoidal tooth fillet, as generated by a rack cutter, is modeled exactly using the procedure suggested by Buckingham (Ref. 7). A *C* computer language code was developed for generating exact tooth profile with trochoidal fillet. The trochoidal fillet form is generated from the dedendum circle up to the limiting circle, where it meets the involute profile at the common point of tangency and the involute profile extends up to the addendum circle.

Gear models. The gear tooth under consideration for NCR gearing is a standard one, with a full depth of 2.25 times the module and the addendum of one unit module, and the gear tooth for HCR gearing is a full depth of 2.75 times the module and addendum of 1.25 times the module. Each generating cutter having a tip radius of 0.8 mm and 1.0 mm is used for the generation of HCR and NCR gearing, respectively. Since the gear fillet assumed as a constant radius curve by AGMA in its layout procedure is not the true representation of the spur gear geometry (with generated fillets), it was decided to consider the trochoidal fillet as a fair model in this paper. AGMA (Ref. 8) uses Newton's method of iterations while this paper deals with polynomial equations for direct calculations of the AGMA geometry factor, with minimum process time for computerized gear analysis.

In order to make the perfect gear geometry for NCR/HCR design data mentioned in Table 1, a *C* code is developed for generating the complete gear profile of both NCR and HCR with trochoidal fillet. The sun gear (23 teeth) and planet gear (22 teeth) mesh for NCR gearing, and the sun gear (38 teeth) and planet gear (36 teeth) mesh for HCR gearing, and are generated in a single-window FEA environment of *ANSYS Version 11.0*.

FEA models and meshing. The gears (both NCR and HCR) are kept in contact by positioning at the stipulated center distance (93.013 mm) with respect to the global coordinate system, and only the plane area models are used for the FEA. Quadratic, two-dimensional (2-D), eight-noded higher-order-plane strain elements (PLANE 82 of *ANSYS*) are used, as shown in Figure 3. To promote convergence of the contact solution, the finite element models are meshed with a very fine mesh where the tooth will experience the contact. The total number of elements used in HCR gearing is 38,044 and the total number of nodes is 115,118.The finite element meshed models of NCR and HCR gears are shown in Figure 4.

Loading and boundary conditions. The maximum torque (*Tc*) on the carrier of each final drive with a factor of safety of 1.17 is 44,975 Nm, and the sun gear is in mesh with four planet gears (N). Thus, the torque applied per unit face width on the sun gear (38 teeth) is 45 Nm (i.e., T_c/NFG_r). The load is applied in the form of torque in a clockwise direction from the input (coupling) side, and the planet gear (36 teeth) is fully constrained. Both the sun and the planet gears are arrested in radial direction with respect to a local

Equation 1:

$$CR = \frac{\sqrt{(r_1 + a)^2 - r_1^2 \cos^2\alpha} + \sqrt{(r_2 + a)^2 - r_2^2 \cos^2\alpha} - (r_1 + r_2)^2 \alpha}{\pi\, m \cos\alpha}$$

Table 2—Results Based on FEA for HPSTC/HPDTC.						
	Teeth	Bending Stress, MPa		Deflection - 100% load, mm	Deflection - 52% load, mm	Contact Stress, MPa
		100% load	52% load	Deflection Vector Sum	Deflection Vector Sum	
NCR	22	608.4	-	30.94E-03	-	1504.8
	23	673.2	-	49.15E-03	-	
HCR	36	-	482.1	-	21.22E-03	1074.8
	38	-	390.2	-	21.37E-03	

Table 3—Results Based on FEA for Tip Loading.						
	Teeth	Bending Stress, MPa		Deflection - 50% load, mm	Deflection - 20% load, mm	Contact Stress, MPa
		50% load	20% load	Deflection Vector Sum	Deflection Vector Sum	
NCR	22	386.9	-	23.9E-03	-	929.6
	23	406.7	-	32.65E-03	-	
HCR	36	-	282.5	-	17.39E-03	914.9
	38	-	255.5	-	17.75E-03	

cylindrical coordinate system.

Solution and Post Processing

Load sharing. The gear pair is rotated as a rigid body according to the gear ratio. The solution is repeated for both gears rotated with some amount of angular increment according to the gear ratio. Approximately 45 angular increments with a 0.5° step are used for this analysis, and the analysis is carried out with the help of customized *APDL* (*ANSYS Parametric Design Language*) looping program. Transmission error, torsional mesh stiffness, root stress, contact stress and load sharing ratio are obtained for all the positions. The nodal force at each node has been obtained for each individual gear tooth. By this methodology, the percentage of load sharing between the teeth for both sun and planet gears at any position was determined. Accordingly, the maximum percentage of tooth load for NCR and HCR gear designs—at the tooth tip and highest point of single-tooth contact (HPSTC) for NCR and the highest point of double-tooth contact (HPDTC) for HCR gearing—was determined. The individual tooth loads have been determined by comparing equally the total normal load with the sum of the normal loads contributed by each pair in contact.

It is observed from the above FEA that for NCR gearing, a 100% load is applied at the HPSTC condition and a 50% load is applied at the tip load condition. For HCR gearing, a 52% load is applied at the HPDTC condition and only a 20% load applied at the tip load condition.

Bending stress, contact stress and deflection. In this study, the stresses were calculated for corrected gears considering the trochoidal fillet form and using FEA, which includes the size and shape effects as well as stress concentrations. The ratio of the stress determined by FEA to that of the modified Lewis equation is considered a stress correction factor.

The FEA-calculated bending stress in the gear tooth fillet, contact stress and vector sum deflection were determined using *ANSYS Version 11.0* for both NCR/HCR gears and tabulated in Tables 2 and 3. Figure 5 shows the nodal stress plot for HPSTC in the case of NCR with the maximum stress occurring at the trochoidal fillet of the 22-tooth NCR gears. Figure 6 shows the nodal stress plot HPDTC in the case of HCR gears with the maximum stress occurring at the trochoidal fillet of the 36-tooth HCR gears.

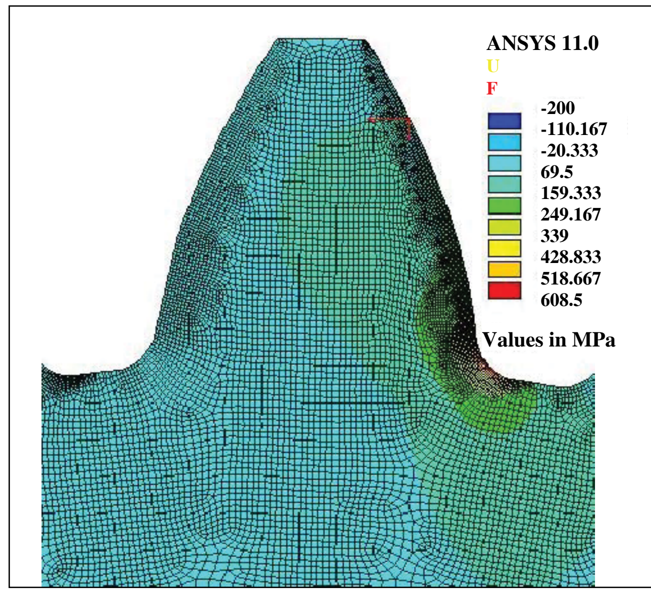


Figure 5—Stress plot for 22-tooth NCR gear with HPSTC loading.

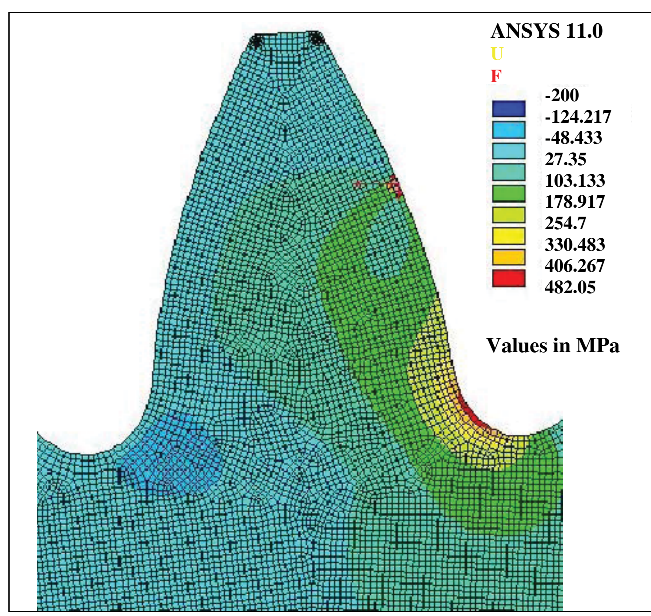


Figure 6—Stress plot for 36-tooth HCR gear with HPDTC loading.

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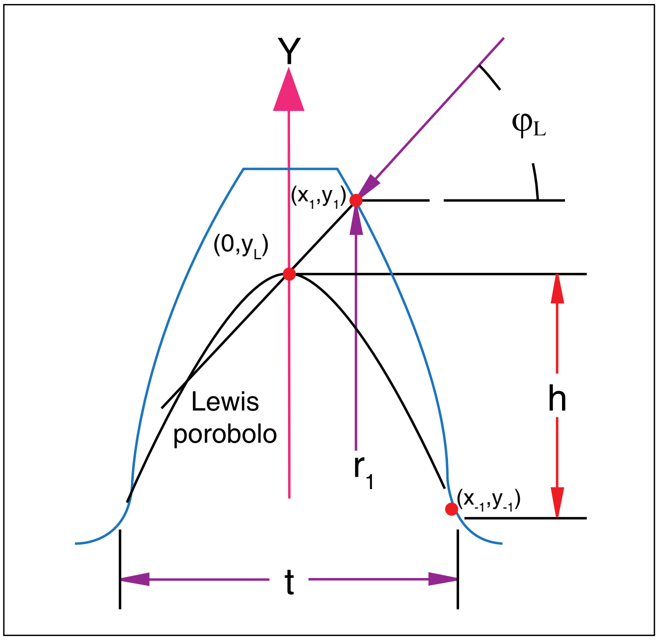

Figure 7—Critical section parameters.

AGMA approach. AGMA's specification provides charts for uncorrected gears and a semi-analytical method for corrected gears with constant radius fillet to calculate the geometry factor. AGMA's mathematical procedure was written in the form of *C* computer language code in this paper so that the geometry factor can be calculated analytically for gears with trochoid fillet.

Critical parameters. A *C* code was developed to calculate the geometry factor using the mathematical procedure specified by AGMA (Ref. 8). The procedure takes into account the effects of tooth shape, worst-load position, stress concentration and both tangential (bending) and radial (compression) components of the tooth load.

According to AGMA, a parabola (Refs. 9–10) is inscribed inside the gear tooth profile with its vertex at the sharp point and in tangent with the root fillet profile (Fig. 7). The plane passing through this point of tangency—and perpendicular to the tooth centerline— defines the critical section. In this standard, a semi-analytical method is used to calculate the geometry factor through the evaluation of r, t, h, φ_L. The height of the parabola (h) and corresponding tooth thickness (t) at the critical cross section can be calculated by finding the coordinates of the tangency point of the parabola and trochoid (Fig. 7).

The Y-coordinate of the vertex of the parabola Y_L can be calculated from the line equation whose slope is tan φ_L and passing through a point on the involute tooth profile (x_i, y_i). The values of x_i and y_i can be calculated from the parametric involute:

$$Y_L = y_i - x_i \tan \varphi_L \tag{2}$$

The vertex of the parabola (0, y_L) is calculated from Equation 2.

The coordinates of trochoid (x_t, y_t) are a straight line with two end points, and so the slope of the line is obtained from Equation 3:

$$\tan \theta = \frac{y_2 - y_1}{x_2 - x_1} \tag{3}$$

where:

x_1,y_1 are the coordinates of the trochoid and x_2,y_2 are the coordinates of vertex of the parabola.

The procedure for calculating the slope is repeated for all the points along the trochoid and slope where one point of the trochoid is compared with the other, and the maximum slope and the coordinates of the trochoid (Ref. 6) are considered. The length of the line joining the vertex of parabola (L) and the maximum coordinates of the trochoid are calculated from the straight line:

$$L = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \tag{4}$$

Thus, the height and tooth thickness of the parabola are obtained from h = Lcosθ and t = 2Lsinθ.

The critical parameters—diameter, height, thickness, stress correction factor, tooth form factor and *J* factor—are calculated based on *C* computer language code and tabulated in Tables 4 and 5 for tip and HPSTC/HPDTC condition, respectively.

Stress correction factor. The stress correction factor plays a major role when a machine member is subjected to fatigue-type loading. As gear teeth have to withstand repeated and fluctuating types of load, their failure is essentially attributable to fatigue phenomena. Abrupt changes in a cross section of any stressed member—such as occur in the root fillet area of gear teeth—give rise to large irregularities in stress distribution. It depends on the radius of curvature of the fillet at the critical section in the gear. The basic Lewis equation doesn't consider the size and shape effects of the rapid change in the fillet form at the root portion and the stress induced due to the radial component at the normal load. So, the bending stress obtained using this equation is less than the localized stress at the fillet. Studies through photo elasticity have revealed that stress concentration occurs mainly at the point of loading and at the root fillet.

According to AGMA, the stress correction factor (k_f) is obtained from an empirical relation gleaned from the experiments conducted by Dolan and Broghamer (Ref. 11) for a = 20° is given as:

$$k_f = 0.18 + \left[\frac{t}{r}\right]^{0.15} \left[\frac{t}{h}\right]^{0.45} \tag{5}$$

Geometry factor. For spur gears, the definition of the AGMA (Ref. 9) geometry factor *J* reduces to equation 6:

$$J = \frac{Y}{k_f} \tag{6}$$

The following reduced equations can be used for tooth form factor Y and stress correction factor k_f. Tooth dimensions used in calculation of Y are shown in equation 7:

$$Y = \frac{1}{\frac{\cos \varphi_L}{\cos \varphi}\left(\frac{6h}{t^2} - \frac{\tan \varphi_L}{t}\right)} \quad (7)$$

Considering the stress correction effect, the fillet stress is given by:

$$\sigma_{act} = \left(\frac{F_t}{b\, m\, Y}\right) k_f = \frac{F_t}{b\, m\, J} \quad (8)$$

In calculation of the AGMA bending stress number, HPSTC is considered the most critical point—provided there is load sharing between adjacent contacting tooth pairs. In case of not having load sharing, the tip of the tooth should be taken as the most critical point. Critical loading points for tooth stress analysis are HPSTC and the tooth tip.

Results and Discussions

In the continuous action of meshing, the load traverses throughout the involute profile of the gear. In the case of load sharing, the maximum stress occurs above the pitch circle (Ref. 12).

The bending geometry factors are evaluated for profile-corrected gears generated with rack-type cutters for both conditions where the load is applied at the tip of the tooth and at the HPSTC for NCR gears and HPDTC for HCR gears.

The planet gear (22 teeth) of module 4 mm, meshed with the sun gear (23 teeth) of the NCR type, and the planet gear (36 teeth) of module 2.5 mm meshed with the sun gear (38 teeth) of the HCR type, are all considered for analysis to evaluate various parameters for tip and HPSTC/HPDTC loading. All the data such as stress, deflection, stress correction factor, critical diameter and the corresponding tooth form factor, J-factor, height and thickness are tabulated in Tables 2–5.

Bending stress. Generally, bending stress will increase at the root with the addendum factor in view of the cantilever effect. However, in the case of HCR (CR > 2) gears, the load applied at the tip/HPDTC is less compared to NCR gears and thus the net effect will reduce the stress. It can be seen from Table 2 that the maximum load applied at the HPDTC—where two teeth are in contact—is only 52% in the case of the HCR planet gear (36 teeth) and so the maximum bending stress is 482.1 N/mm^2 as against 608.4 N/mm^2 in case of the NCR planet gear (22 teeth), where the maximum load is 100% in view of one tooth contact and results in a 26.2% lower stress value.

Similarly, the bending stress in the case of the HCR planet gear (36 teeth) is 37% less compared to the NCR planet gear (22 teeth) with the maximum load applied at the tip due to the load sharing of three teeth in contact. This load is only 20% compared to 50% for the NCR planet gear (22 teeth) in view of two teeth in contact as shown in Table 3.

Contact stress. This paper calculates the contact stress of contact teeth through calculating the tooth load distributed on the unit contact area of the tooth surface. Tooth contact stresses were analyzed using the Hertzian formula, which proved to be less than precise (Ref. 13). It can be seen from Table 2 that the maximum load applied at the HPDTC—where two teeth are in contact—is only 52% and therefore the maximum tooth contact stress is less—by 40%—in HCR compared to NCR. The reduction in contact stress is due to an increase of the addendum factor and the number of contact teeth, resulting in less load.

Deflection. As explained above, the load is less in the case of HCR gears compared to NCR gears in both conditions—i.e., tip loading and HPDTC. Also, in view of the higher number of teeth in HCR gearing, the tooth height is less and the tooth is more rigid. It can be seen from Tables 2

continued

Table 4—Results Based on *C*-Code for Tip Loading.

	No. of Teeth	Critical Diameter, mm	Thickness, t, mm	Height, h, mm	Stress Correction factor, K_f	Tooth Form Factor, Y	J-factor
NCR	22	41.33	8.83	7.67	1.369	0.5375	0.3928
	23	42.45	8.45	7.67	1.338	0.4827	0.3928
HCR	36	41.92	5.41	6.03	1.236	0.3764	0.3046
	38	41.92	5.47	6.03	1.243	0.3823	0.3076

Table 5—Results Based on *C*-Code for HPSTC/HPDTC Loading.

	No. of Teeth	Critical Diameter, mm	Thickness, t, mm	Height, h, mm	Stress Correction factor, K_f	Tooth Form Factor, Y	J-factor
NCR	22	41.12	9.09	5.18	1.629	0.8230	0.5053
	23	42.29	8.69	5.31	1.566	0.7032	0.4490
HCR	36	41.61	5.94	2.89	1.777	0.9090	0.5114
	38	44.11	5.96	2.88	1.784	0.9205	0.5161

and 3 that the deflection is 31.4% less in the case of HPDTC and 27.2% less in the case of the tip loading condition for the HCR planet gear (36 teeth) versus the NCR planet gear (22 teeth).

Stress correction factor. It can be seen from the stress correction factor equation that k_f is a function of h, t and r. HCR gears are designed by increasing the number of teeth and decreasing module. Therefore, the values of thickness and height are less in the case of HCR gears compared to NCR gears. Also, the cutter edge radius of an HCR gear is 0.8 mm for a 2.5-module gear, whereas the cutter edge radius of an NCR gear is 1.0 mm for 4-module gears.

The length and radius of the curvature at the critical point of the trochoidal fillet portion will decrease with an increase in the number of teeth, since the difference between form diameter and base circle diameter is reduced. Also, the increase in the number of teeth will increase the width at the critical cross section, and the slope of the line joining the critical point and load point will gradually increase. Table 4 reveals that the stress correction factor for tip loading is 9.7% less for the HCR planet gear (36 teeth) compared to the NCR planet gear (22 teeth). However, the stress correction factor for HPDTC is 9.1% greater in the case of the HCR planet gear (36 teeth) compared to the NCR planet gear (22 teeth), as shown in Table 5. Even though the stress correction factor is more, the bending stress will be much less (26.2%) in the case of HCR gears for the same tip-base pitch loading, given the 52% loading versus the 100% in NCR gears.

Conclusions

The FEA of a final drive gear assembly for both NCR and HCR gearing reveals that both the bending and the contact stresses are more than 25% less in HCR gears compared to NCR gears. The load carrying capacity of HCR gearing could be increased by at least 25% for the same weight and volume. Therefore, the concept of HCR gearing can be adapted to all the gear assemblies of the automatic transmission for increasing the load carrying capacity of the transmission within the same envelope, as well as increasing the mesh efficiency and decreasing dynamic loads and noise level.

In this paper, the actual shape of the trochoid is considered, whereas the fillet radius is assumed as a constant radius curve for calculating the geometry factor presented by AGMA (Ref. 8). With the aid of recent computing advances, finite element numerical methods were applied in the research of high-contact-ratio gears that accounted for the actual profiles, thus providing more realistic results.

References

1. Sivakumar, P., D. Hanumanna and K. Gopinath. "High-Contact-Ratio Gearing Concept for Military Tracked Vehicle Application." 17th National Convention of Production Engineers on Recent Trends in Design and Manufacture of Gears and Bearings, Chennai (2002) pp. 71–78.
2. Rosen, M.K. and H.K. Frint. "Design of High-Contact-Ratio Gears," *Journal of the American Helicopter Society*, (1982) 65–73.
3. Leming, J. C. "High-Contact-Ratio (2+) Gears," *Gear Design Manufacturing and Inspection Manual*, SAE, Warrrendale PA. (1990) Hi Arrow Gear Company, printed with AGMA permission, pp. 73–83.
4. Mohanty, S.C. "Tooth Load Sharing and Contact Stress Analysis of High-Contact-Ratio Spur Gears in Mesh, *IE Journal 84*, (2003), pp. 66–71.
5. *ANSYS Release 11.0*, "Structural Analysis Guide," ANSYS Inc., Canonsburg, PA, p. 200.
6. Sahir Arikan, M.A. "Direct Calculation of AGMA Geometry Factor *J* by Making Use of Polynomial Equations," *Mechanics Research Communication 29*, (2002) pp. 257–268.
7. Buckingham, E. "Analytical Mechanics of Gears," *Dover Publications,* New York, 1963.
8. AGMA 908–B89. Geometry Factors for Determining the Pitting Resistance and Bending Strength of Spur, Helical and Herringbone Gear Teeth.
9. AGMA 918–A93. A Summary of Numerical Examples Demonstrating the Procedures for Calculating Geometry Factors for Spur and Helical Gears.
10. AGMA 218.01. Rating of Pitting Resistance and Bending Strength of Spur and Helical Involute Gear Teeth (Obsolete).
11. T.J. Dolan, T.J. and E.J. Broghamer. "A Photoelastic Study of the Stresses in Gear Tooth Fillets," *Bulletin No. 355*, University of Illinois, Engineering Experiment Station, 1942.
12. Haung, T.M. and T.Y. Chien. "Design of High-Contact-Ratio Spur Gears Using Quadratic Parametric Tooth Profiles," *Mechanism and Machine Theory*, 33 (1998) pp. 551–564.
13. Li, S. "Effect of Addendum on Contact Strength, Bending Strength and Basic Performance Parameters of a Pair of Spur Gears," *Mechanism and Machine Theory* (2008).

Effects of Profile Corrections on Peak-to-Peak Transmission Error

Dr.-Eng. Ulrich Kissling

Management Summary

Profile corrections on gears are a commonly used method to reduce transmission error, contact shock, and scoring risk. There are different types of profile corrections. It is a known fact that the type of profile correction used will have a strong influence on the resulting transmission error. The degree of this influence may be determined by calculating tooth loading during mesh. The current method for this calculation is very complicated and time consuming; however, a new approach has been developed that could reduce the calculation time.

This approach uses an algorithm that includes the conventional method for calculating tooth stiffness in regards to bending and shearing deformation, flattening due to Hertzian pressure and tilting of the tooth in the gear body. This new method was tested by comparing its results with Finite Element Method (FEM) and *LVR* software.

This paper illustrates and discusses the results of this study. Furthermore the maximum local power losses are compared with the scoring safety calculated following the flash temperature criteria of AGMA925 and DIN 3990.

Introduction

Profile correction (PC) of gears is a commonly used method to reduce the transmission error (TE) of a gear pair, the contact shock (corner contact) and the scoring risk. There are different types of profile corrections: short or long linear corrections, short or long corrections in arc form, fully crowned profile and others.

The calculation of the meshing of a gear pair under load is very complicated and therefore time consuming. Over the gear meshing cycle—from the start of contact in the pinion root area to the end of contact on the tip—a sufficient number of steps must be calculated. Using an FEM program, this requires many hours. More specialized programs as *LDP* or *LVR* perform this process in much shorter time, but even then, the evaluation of different variants needs much time.

Based on a new approach for the calculation of the meshing under load, the calculation time could be even further reduced. An algorithm using a conventional method for the calculation of the tooth stiffness—considering bending and shearing deformation, flattening due to Hertzian pressure and tilting of the tooth in the gear body—is used. With this approach the calculation of a gear mesh is carried out within seconds. In combination with an efficient user interface, this allowed for an extended study of the effect of different profile corrections.

The aim of this study is to analyze the effect produced by short linear, long linear, short arc-like, long arc-like and fully crowned profile corrections on gears with different transverse contact ratio (ε_α), as standard-reference-profile gears and high-tooth-profile gears may show very different characteristics when using profile corrections.

Effect of Profile Corrections on Transmission Error and Noise in Literature

Tip relief is applied for two reasons—to minimize corner contact (tooth interference) and to reduce dynamic excitation (transmission error).

In literature, few if any conclusions about the effect of different profile corrections (or profile "modifications," as called by ISO) can be found. Some information exists in the American literature, mainly from or in connection with research done at the Ohio State University (Ref. 1). And in the German literature, where many publications about gear and gearbox design exist, scant information is found. For example, in the classic Niemann book about cylindrical gear design (Ref. 3), only a few words are devoted to the effect produced by profile corrections. Little more is explained in the book by Linke (Ref. 2), from Dresden University. And in the U.K., some specific literature is available (Ref. 4).

A simple variant of a profile correction is a tip relief. When defining a tip relief, two major parameters are important—the tip relief *Ca* (Fig. 1) and the relief length L_{Ca}. In literature, everybody agrees that the tip relief *Ca* has to be dimensioned in such a way that the tooth bending—and perhaps some part of manufacturing errors (pitch deviation)—are compensated. There is also agreement that the profile modification strongly impacts the peak-to-peak transmission error (PPTE). Furthermore, it is evident that the PPTE is quite directly related to the noise level produced by a gear pair.

There are basically two options for the length L_{Ca} of the profile correction—the so-called "short" and "long" relief designs (Fig. 2).

As for the optimum length L_{Ca} of the profile correction and thus the best result in reduction of the TE, opinions differ (Table 1). The indications in literature are partially contradictive. The reason is possibly that the effect of long or short profile correction depends also on the transverse contact ratio of the gear pair. It is also astonishing that in the literature few or no indications are given for the best type of curve to use for the profile correction. There are different possibilities; the simplest is a linear tip relief on both gears (or linear tip and root relief on one or both

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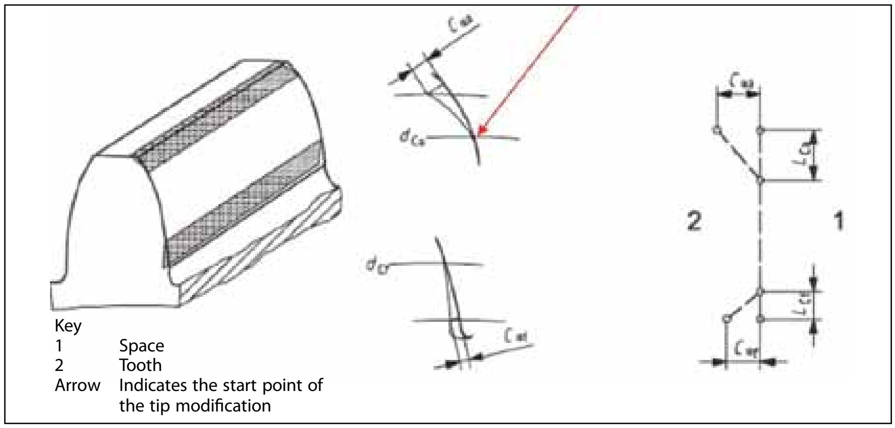

Figure 1—Linear tip and root relief as defined by ISO 21771:2007.

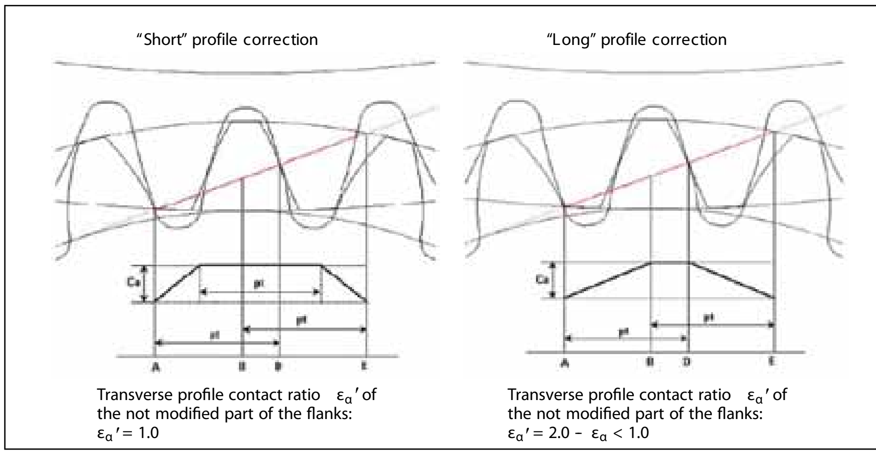

Figure 2—Definition of short and long profile correction (Refs. 1 and 4).

Table 1—Effects of Short or Long Profile Modification in Literature.

Author	Short profile correction	Long profile correction
Niemann (Ref. 3) p.112	Avoid corner contact No effect on TE	Avoids corner contact Reduces TE considerably
Linke (Ref. 2) p.465	Avoids corner contact Reduces TE	Avoids corner contact Reduces TE, but is worse for low load
Houser (Ref.1) p.25	Avoids corner contact No effect on TE	Avoids corner contact Reduces TE considerably at design load, but is worse for low load
Smith (Ref. 4) p.58	Reduces TE for low load	Reduces TE for high load

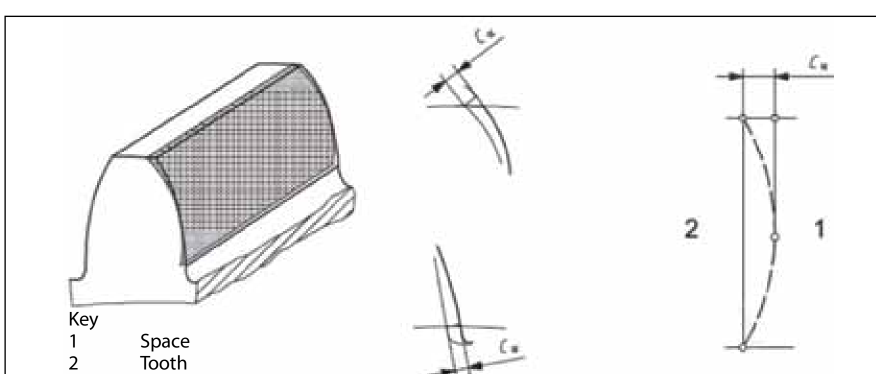

Figure 3—Profile crowning (barreling) as defined by ISO 21771:2007.

gears) (Fig. 1). Crowned profiles, for example, are often used in automotive gearboxes (Fig. 3). Another variant is a parabolic or arc-like tip (and/or root) relief (Fig. 4). Compared to the linear relief, these types of corrections have an advantage in that the pressure angle of the profile does not have an instant change at the start point of the modification (Fig. 4). Munro and Houser (Ref. 1) are using a parabolic correction, Smith (Ref. 4) is using profile crowning and Niemann (Ref. 3), most probably, a linear correction. But it is not discussed whether this type of curve has a major influence on transmission error.

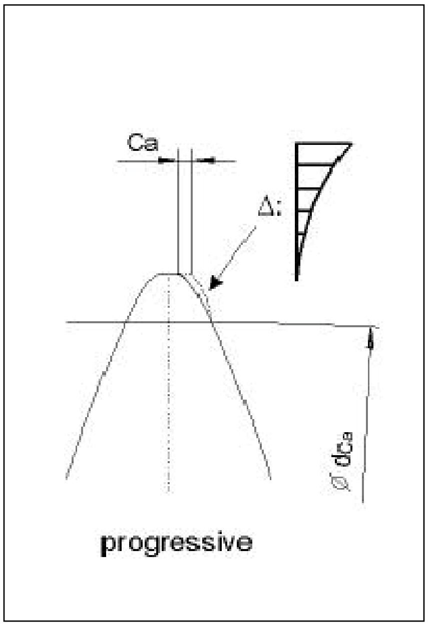

Figure 4—Arc-like or parabolic profile modification at tip.

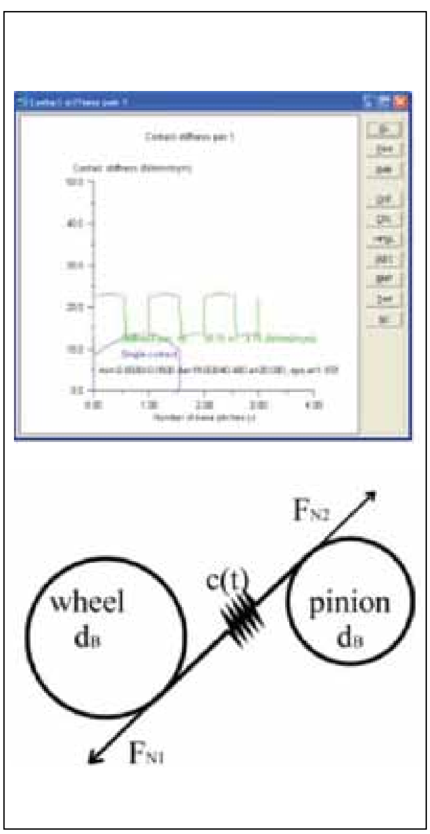

Figure 5—Typical course of the stiffness; model with spring.

A perfect involute gear pair with infinite stiffness has no transmission error. For the consideration of the effect of profile corrections, the bending of the teeth must be included. This is not a simple calculation task.

Calculation of Path of Contact Under Load and the TE

To get the TE of a gear set during meshing, the contact path under load is calculated. This means a contact problem must be solved—i.e., the number of tooth pairs in contact varies by one during the meshing and, most often, it changes from one pair to two pairs in contact. This effect causes the total stiffness in the engagement to change periodically (Fig. 5). The teeth themselves are deflected due to the torque applied, thus shifting the point of change from one to two pairs in contact and leading to premature contact.

There are often two different approaches in solving a problem in mechanical engineering—1) the very general FEM method and 2) the specific classical methods available for most of the common machine parts. The classical methods are tailored to one specific type of part—i.e., bolts, gears or bearings. The advantage of these methods lies in their fast and easy application. But in many cases, no classical method is available. Consider housings, for example, where the application of FEM is the only possibility. In other cases, the application of FEM would be much too expensive, like for a key and keyway on a shaft.

On the strength of a dissertation by Peterson (Ref. 5), proposing a classical method for the calculation of the tooth stiffness, it was possible to develop a quick and accurate method to solve this problem (Ref. 6). For the calculation of the stiffness, Peterson's model covers the deflection of the teeth, the bending of the teeth in the wheel body, the Hertzian pressure and the shearing-induced deformation. The gear is cut into several transverse sections and the stiffness is calculated for these slices. For a spur gear, the stiffness is multiplied by the width, which leads to the final value. For a helical gear, the beginning and end of contact of the slices is dependent upon the position of the slices along the tooth width. The final course of the total stiffness is calculated by integrating the stiffness functions for the slices over the width, while increasing the delay of initial contact. Figure 5 shows a graphical representation of the model. A spring is fixed on the path of contact, which means that it is located on the common tangent of the two base circles of the gears. This spring has a periodically changing stiffness c(t). If in this model the pinion is rotating with constant speed and torque, and the output torque is constant on the gear, the spring will be deflected periodically. This deflection is the transmission error, typically quantified in micrometers.

In the simulation of the meshing, the deflection of the teeth is given by the normal force applied to a single tooth divided by the stiffness. Since the point where the force is applied varies in the height direction, the stiffness will also depend on the meshing position. Further, if the second pair of teeth comes into contact, stiffness increases sharply and the deflection of the first pair of teeth is reduced. To find the correct point of contact, an iteration must be performed.

The reward for all this effort:

- Calculation of the real path of contact under load
- Course of the normal force on the flanks
- Determining TE, stress in the root areas of the teeth, Hertzian pressure, sliding velocities, local warming up (flash temperature) and prediction of local wear on the tooth flanks

Figure 6 shows an example of the

effect of the tip relief. In the top left diagram, the path of contact for the full involute gears is shown. In the middle part, the path is a straight line. In the section of contact start and end, however, the line is curved and the contact follows the tip circle of the pinion or the gear. This is the region of prolonged contact (corner contact). The tip relief is designed to compensate the deflection of the teeth and thus eliminate the premature contact. This, however, only works for a specific torque, precisely applied. The right column of diagrams in Figure 6 shows the influence of the short linear tip relief. The path of contact is almost straight again. The only deviation is a nick in the region of the beginning of the tip relief. This marks the rapid change of the pressure angle at this point (where the linear tip relief starts).

The course of the normal force for the gears without tip relief shows a typical picture for spur gears in that in the middle of the contact path, only one pair of gears takes the full torque. Before and after that, the normal force is shared over two pairs of teeth and thus only about 50% of the maximum value in the middle. The gears with tip relief have only one pair of teeth in contact at most times, so here the normal force is nearly constant and yet on the same level as the maximum of the gears without tip relief. Nevertheless, the maximum pressure on the flank is 20% less with tip relief since the premature contact leads to a contact shock with very high pressure. Finally, the amplitude of the transmission error (PPTE) remains the same with this type of tip relief. The tip relief results in a smoother course so that the higher frequencies are reduced. This leads to less acceleration and the smaller forces induced by the transmission error.

To check this calculation method, the same gears were calculated with *ANSYS* (Fig. 7). Both methods lead to very similar results. For the Hertzian pressure, the FEM results tend to zigzag more, caused mainly by the fact that the defined stress is given for a single point on a grid. Since the real contact point is usually somewhere between two grid points, the real maximum stress on the flank is usually larger than the plotted result.

Other comparisons were made with the *LVR* program (from Dresden University); these results also show a very good correlation.

Since the calculated results are very similar, the main difference between the two methods is the disparity in effort expended to achieve them. Consider: it took two days to get the FEM model set up, calculate the stresses and extract them for presentation; with *KISSsoft* (Ref. 7), the same task was accomplished in two seconds. Moreover, each variant for the tooth form—such as a different amount of tip relief, different geometry (such as changed addendum modification) or different tooling takes only a few minutes to analyze. This demonstrates the advantages of the classical approach.

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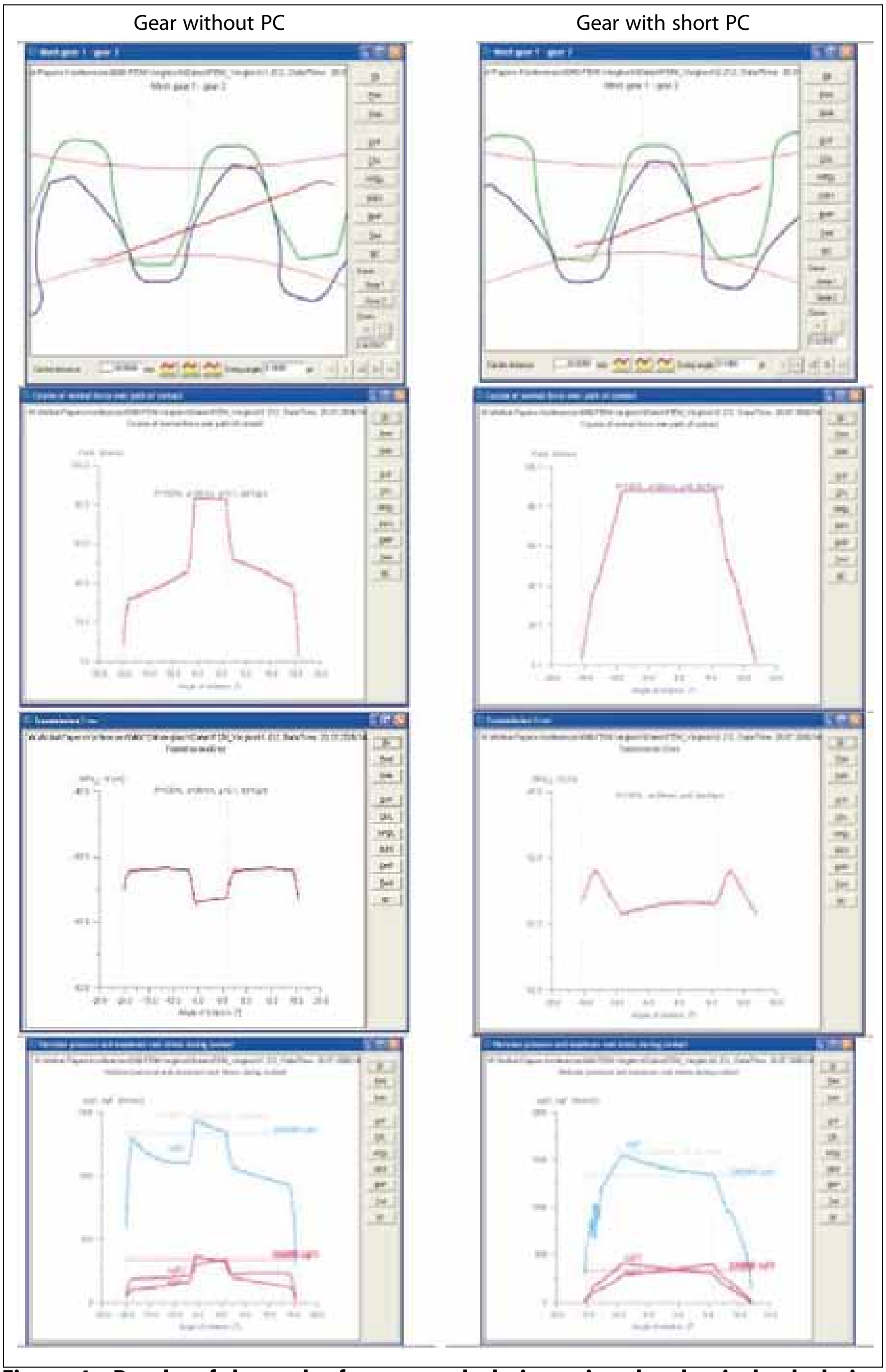

Figure 6—Results of the path of contact calculation using the classical calculation method implemented in *KISSsoft* (Ref. 7).

Study of the Influence of Different Profile Corrections

Introduction. With the discussed method, the calculation of a gear mesh is carried out within seconds. In combination with an efficient user interface, this enabled an extended study of the effect of different profile corrections. Of greatest interest was analyzing the behavior of gears with different transverse contact ratio (ε_α), as standard-reference-profile gears and high-tooth-profile gears may show very different characteristics when using profile corrections.

The aim of the study is to also analyze the effect produced by short linear, long linear, short arc-like, long arc-like and fully crowned profile corrections in the case of gear sets having a transverse contact ratio (ε_α) between 1.4 to 2.4. The profile correction was optimized for the design torque, which was defined based on a required safety factor of 1.0 for pitting and 1.4 for bending following ISO 6336. The tip relief was designed to eliminate the corner contact in the beginning and end of the contact at design torque, based on a perfect tooth form without manufacturing errors. The resulting PPTE was analyzed with different torques between 50% and 150% of the design torque. Furthermore, each variant was checked—including manufacturing errors—to evaluate the capability of the different corrections to compensate tooth form errors.

It is well known from literature that profile corrections are very important for spur gears, less so for helical gears. The reason is that helical gears and their helix angle shift the meshing contact from the left to the right side of the gear. So a gear pair with a sprung helix overlap ratio (ε_β) bigger than 1 also has, along with a badly designed profile correction, a very good PPTE. For this reason—the goal here being to analyze the effect of profile corrections—mostly spur gears were used.

Since a profile correction also has an important impact on the flash temperature and scoring risk, the highest flash temperature was calculated and compared. The calculation of the local flash temperature is calculated with two methods, i.e.—AGMA 925-A03 (Ref. 8) and ISO 6336-7. As Figure 8 shows, the flash temperature is reduced when using an optimized profile correction; the maximum temperature decreases from 120°C to 112°C and the flash temperature (difference between local temperature and gear body temperature)

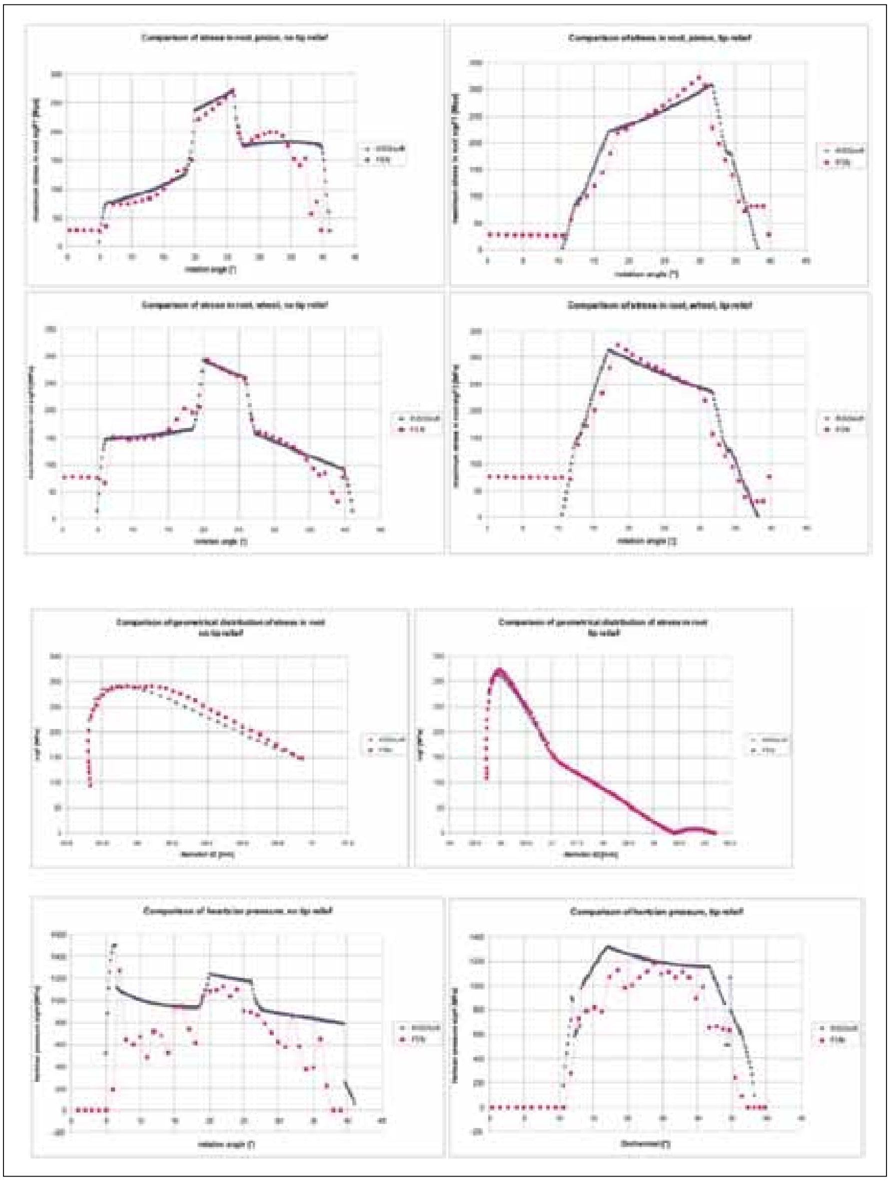

Figure 7—Comparison of the results of FEM calculation and *KISSsoft*.

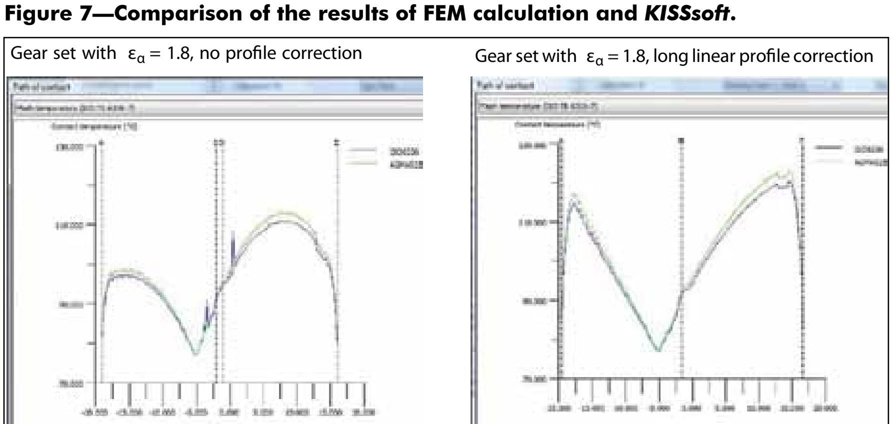

Figure 8—Flash temperature following AGMA 925-A03 (Ref. 8) and ISO 6336-7 (Ref. 9).

decreases from 43.6° to 35.7°—a significantly reduced scoring risk.

Short and long correction length and the PPTE. The profile correction, specifically the tip relief *Ca* and/or the root relief *Cf* (Fig. 1), has to be designed for a specific torque—normally for the medium or the most frequent torque. In this study, the design was done for the nominal torque (100%), but it is very important to also check the effect of a profile correction on the PPTE with different torque levels. In this study, the PPTE was calculated for 50%, 75%, 100%, 125% and 150% of the nominal torque.

Figure 9 shows the PPTE of gear pairs without profile correction. It is evident and logical that the PPTE is proportional to the torque in that the bending of the tooth increases with the load (torque) and the TE increases accordingly. It is evident from the graph that the PPTE decreases with higher transverse contact ratio. There is a significant reduction of the PPTE (about 50%) above $\varepsilon_\alpha = 1.8$. These are high-tooth gears that always have 2–3 teeth pairs in contact and, therefore, higher stiffness, normally lower stiffness variation and lower PPTE. This paper confirms these phenomena. Figure 10 shows, for example, that the PPTE of high-tooth gears ($\varepsilon_\alpha \geq 2.0$) is less than half of the PPTE of normal gears. This is valid *only* for gears without any profile correction. When applying a correction (Fig. 12), the PPTE is not proportional to the torque and the PPTE of high-tooth gears is less reduced when compared to normal gears.

The effect of a short profile correction is shown in Figure 11. As the ratio of PPTE with profile corrections to PPTE without correction is displayed, every result having a value bigger than 1 represents a situation in which the gear with correction is worse than the gear with no correction. With the exception of gear pairs with a very high ε_α (2.4), the short correction is always worse than no correction at all. For low load (75% and less), the increase of the PPTE can be

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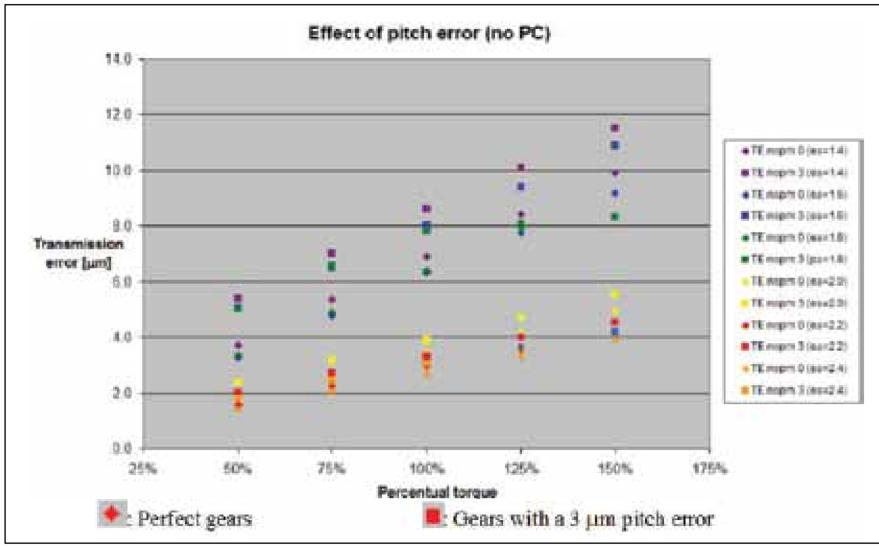

Figure 9—PPTE in µm for different gear pairs with ε_α = 1.4 to 2.4, without profile correction, depending on torque. For perfect gears and gears with pitch errors.

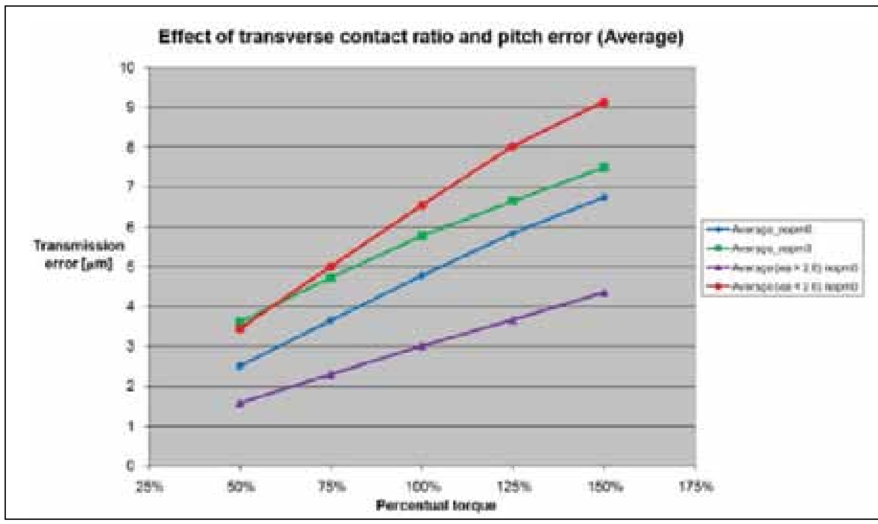

Figure 10—PPTE (same data as in Fig. 9) depending on torque, without PC. Curve "Average (ε_α < 2.0) nopm0" for gears having ε_α ≥ 2.0; Curve "Average (ε_α > 2.0) nopm0" for gears having ε_α ≥ 2.0; Curve "Average_nopm0" for all gears; "Curve "Average_nopm3" for all gears with pitch error 3 µm.

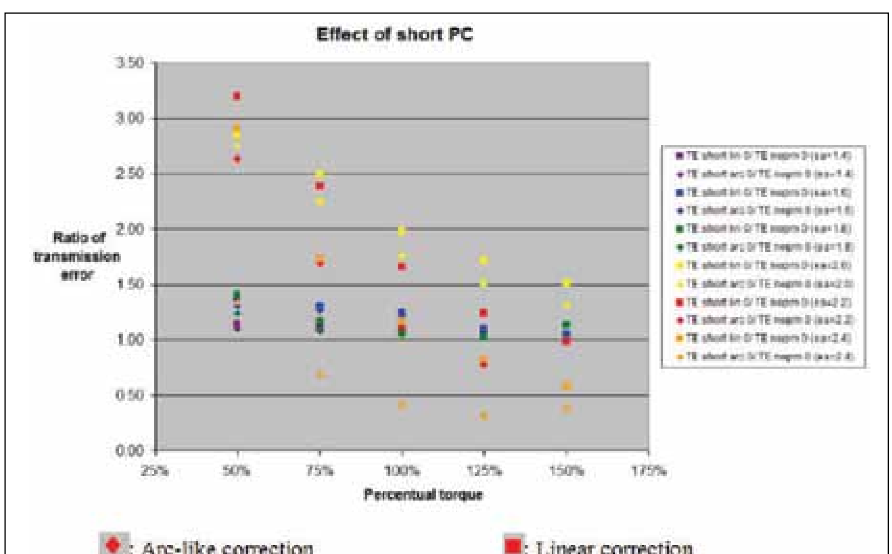

Figure 11—Ratio of PPTEwithPC to PPTEnoPC for different gear pairs, with ε_α = 1.4 to 2.4, with short profile correction, depending on torque.

300% and more.

The result is completely different when using a long profile correction (Fig. 12). All gear sets above 80% of nominal torque have a significantly reduced PPTE (30%–70%). Only for low load (60% and less of nominal torque) will the PPTE increase as compared to the gear set with no correction. But the increase is smaller than it is for short corrections.

To document such a significant difference between the short and the long correction—mainly for any transverse contact ratio ε_α—was certainly a surprise. The result is in agreement with some well-known authors—e.g., Houser (Ref. 1) and Niemann (Ref. 3). But the fact that—when using the long corrections—the transverse contact ratio of the unmodified part of the flanks is far lower than 1 (Fig. 2) served to reduce our expectancy of such a good result for the long correction.

Influence of curvature of the profile correction. It may be interesting to analyze the influence of different curvatures of the profile correction on the PPTE. For the short profile correction, a linear (Fig. 1) and an arc-like (Fig. 4) curve were used. The same was used for the long correction and profile crowning (Fig. 3).

When using the short profile correction (Fig. 13) for normal gears (ε_α < 2.0), the form of the curve has no significant influence. But for high-tooth gears, the arc-like curve is much preferred.

With a long profile or crowned correction, there is really no significant difference between the effects of different curve types when comparing the effect over the full ε_α scale. Rather, it appears that the linear correction is a bit better than the arc-like version (Fig. 14). It is particularly interesting when this effect is shown to be torque-dependent (Fig. 15). The linear correction is very effective for design torque, yet worse than the other corrections for lower torque.

Influence of manufacturing errors on the PPTE. The calculations pre-

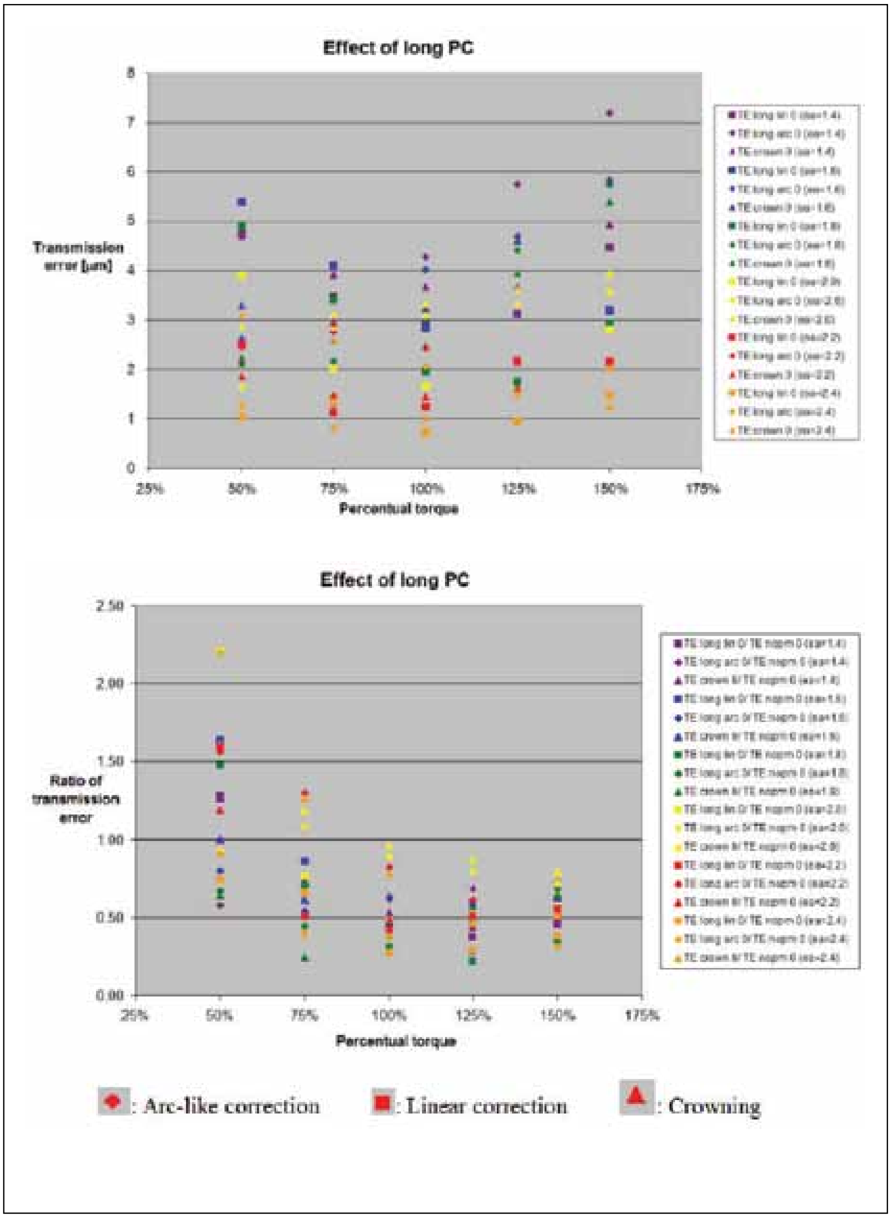

Figure 12—PPTE (above) and Ratio (below) of PPTEwithPC to PPTEnoPC for different gear pairs, with ε_α = 1.4 to 2.4, with long profile correction, depending on torque.

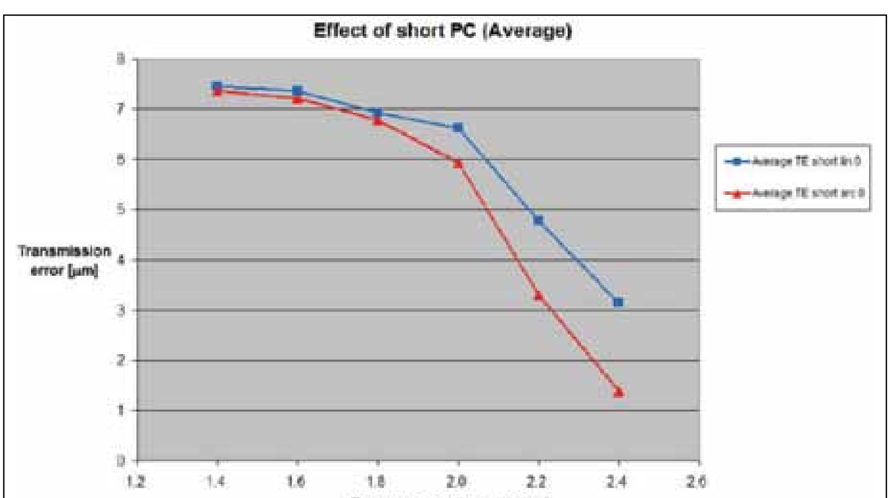

Figure 13—Mean PPTE (average over torque from 50 to 150%) depending on ε_α with short profile correction, for linear and arc-like correction curve.

sented here were repeated with a manufacturing error in order to evaluate the capability of the different corrections to compensate for tooth form errors. In this case a pitch error of 3 μm was applied—i.e., half of the maximal admitted error for Q-6 (ISO1328 or AGMA 2015) with gears of this size. The PPTE of gears with the manufacturing error is clearly increased, but the mean increase of the PPTE is much smaller than the pitch error (Table 2). Figure 10 shows that the 3 μm pitch error increases the PPTE on gears with no modification by only 1 μm or less.

If specific profile corrections are in fact best-suited to absorb pitch errors, it is not apparent—as the evaluation of the increase of PPTE due to a 3 μm pitch error in Table 2 shows. Arc-like (short and long) and short linear corrections yield the best results, but it is also assumed that further checks are performed to ensure that this result is indeed significant. In addition, profile errors and other manufacturing errors should be checked to ensure the clearest picture possible.

Supplementary study of the length of the profile correction. Thus far, the effect of short or long profile correction has been considered. The results showed clearly that the long correction reduces the PPTE. Houser recommends use of a "medium" profile correction, as "Long and short reliefs represent useful design limits for spur gears and generally some intermediate type of relief gives the best compromise, depending upon the range of operating loads that the gear meet (Ref. 1)." It is thus clearly possible that an intermediate length of the correction might provide even better results, and so is well worth checking.

The PPTE calculated on a specific gear with a different length of profile correction is shown in Figure 16. Here the PPTE typically increases slightly—from zero to the short profile correction. With increasing correction length, the PPTE decreases significantly and is quicker with the linear correction than with the arc-like correction. The PPTE reaches a minimum around the long profile correction. With the linear correction, the minimum is reached shortly before the long profile correction, the arc-like correction following

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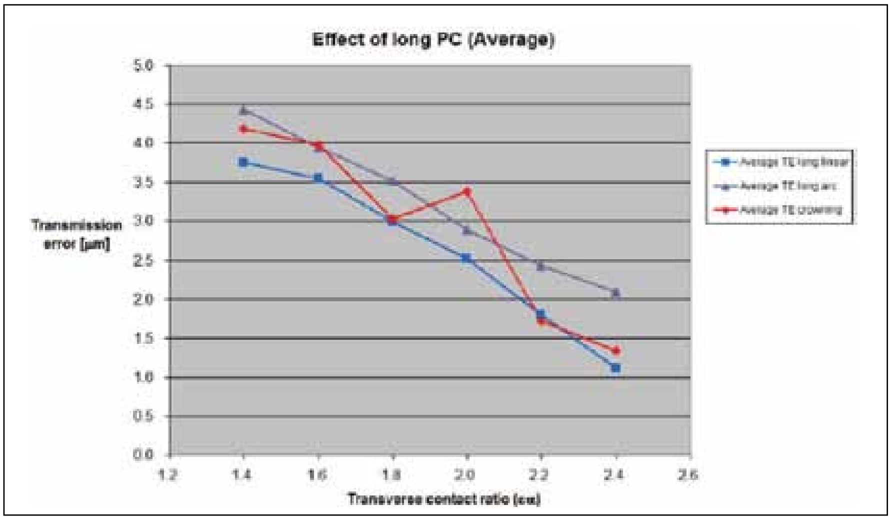


Figure 14—Mean PPTE (average over torque from 50 to 150%) depending on ε_α with long profile correction, for linear, arc-like and crowned correction curve.

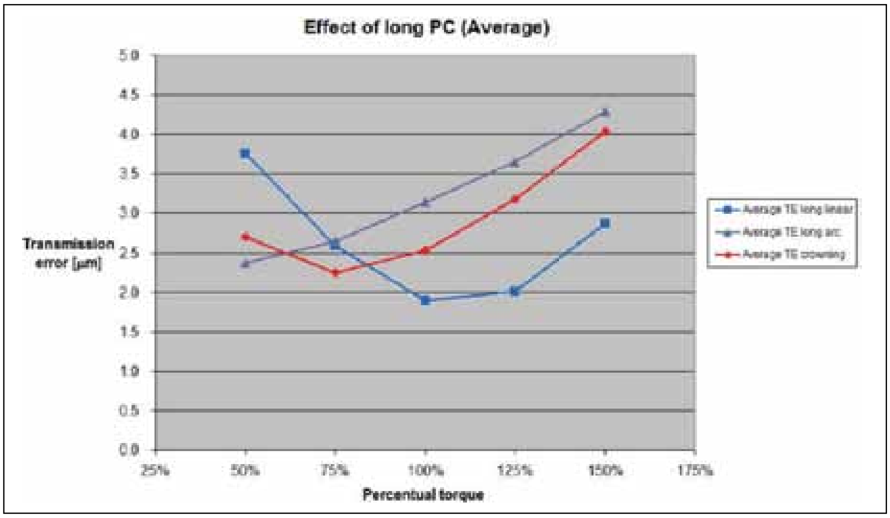


Figure 15—Mean PPTE (average over ε_α from 1.4 to 2.4) depending on torque with long profile correction, for linear, arc-like and crowned correction curve.

Table 2— Mean increase of PPTE due to a pitch error of 3 μm for the nominal torque (100%).

Profile correction	Mean PPTE (μm) with no pitch error	Mean PPTE (μm) with pitch error of 3μm	Mean increase of PPTE (μm)	Increase of PPTE in % of the pitch error
No correction	4.8	5.8	0.99	33.0
Short, linear	6.2	6.9	0.69	23.2
Short, arc-like	5.4	6.1	0.71	23.8
Long,linear	1.9	2.9	1.05	35.0
Long, arc-like	3.1	3.9	0.78	26.1
Crowning	2.5	3.7	1.18	39.2

shortly after. Clearly, the curves may change with torque and gear geometry, but the tendency is repeatable.

Different Profile Corrections and Flash Temperature

Normally the local flash temperature is highest at both the beginning and end of the contact between two gears. As the tooth thickness reduction produced by a profile correction is reducing the Hertzian pressure at these exact points, the result of the reduced load is that the local temperature at beginning and end of the contact will decrease. It is therefore logical that any profile correction will be helpful for reducing the risk of scoring.

Figure 17 shows the relative reduction of the flash temperature when using a short PC; Figure 18 shows the same with a long PC. The results are very similar, with no significant difference between the short and long correction. But with few exceptions, the reduction of the flash temperature when using any PC is very relevant.

It is revealing that the reduction of flash temperature (always compared to the gear without PC) is smallest with $\varepsilon_\alpha = 1.4$; then the temperature decreases significantly with higher ε_α and the optimum $\varepsilon_\alpha = 2.0$ (a temperature decrease of 60%); and finally—with even higher ε_α—the reduction is again less significant. Indeed, there is no significant influence in different curvatures of the profile correction on the flash temperature.

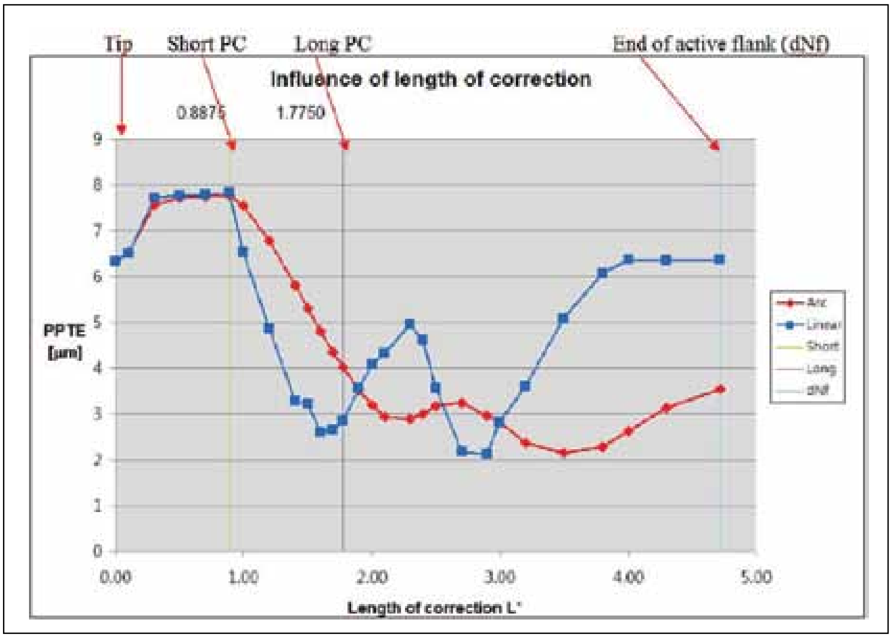


Figure 16—PPTE at design torque depending on the length of profile correction (for a gear set with ε_α = 1.6), when using linear or arc-like tip correction.

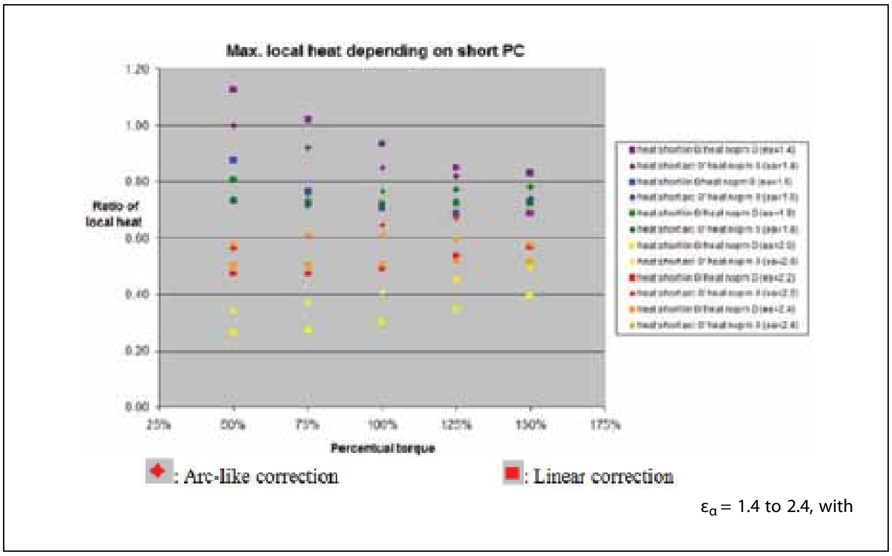


Figure 17—Ratio of HEATwithPC to HEATnoPC for different gear pairs, with ε_α = 1.4 to 2.4, with short profile correction, depending on torque.

Dimensioning the Tip Relief *Ca*

It is perhaps important to discuss the layout of the optimum tip relief *Ca* (Fig. 1). The tip relief was designed in order to eliminate corner contact at the beginning and end of the contact at design torque without reducing the length of the contact between the gears. Figure 19 illustrates how the effect of the tip relief must be checked.

To be clear, tip relief was not varied in this study. Without any profile correction, the PPTE is quite proportional to the torque (Fig. 9). But upon applying a profile correction, the PPTE is lowest at 75% of design torque—and rises with smaller torque. So decreasing the amount of *Ca* by 5% does not provide the same result as would a change in torque of +5%. Although it might work, somebody could suggest, if torque and PPTE are proportional.

Regardless, the amount of *Ca* is an additional parameter to investigate.

Summary

The effect on the transmission error and the scoring risk produced by short-linear, long-linear, short-arc-like, long-arc-like and fully crowned profile corrections to gears with different transverse contact ratio (ε_α) was analyzed. There is little in literature regarding these issues. Important parameters were systematically varied and hundreds of PPTE calculations performed.

High-tooth gear sets (with transverse contact ratio $\varepsilon_\alpha \geq 2.0$) have in most cases only about half of the PPTE, in comparison with normal gear sets with no profile correction (PC) applied. With PC, high-tooth gears also have lower PPTE, but the difference to a normal gear is smaller.

A PC, short or long, effectively reduces the scoring risk and the contact shock (corner contact). For the PPTE, the difference between the short and the long correction is that for any transverse contact ratio, ε_α is very significant. Where short PC shows—even at design torque—a small increase of the PPTE compared with gears without PC, long PC shows a reduction of 30–70%—a result that has been supported by a number of authors. But the fact remains that when using long correction, arriving at such an overall good result is surprising. It is nevertheless important to know that any PC increases the PPTE with small torque (50% or less of design torque), compared to gears without PC.

The influence of different curvatures of the profile correction on the PPTE is less significant. For the short profile correction, a linear and arc-like curve were used. The same was also used for the long correction and profile crowning. When applying the short profile correction to normal gears ($\varepsilon_\alpha < 2.0$), the form of the curve has no significant influence. But for high-tooth gears, the arc-like curve serves best. With a long profile or crowned correction there is no significant difference between the effects of different curve types.

Differing parameters—such as the amount of tip relief *Ca* or the type of curve of the correction—have significant, but not always equal, influence on the PPTE. It is always recommended in a specific gear transmission case to calculate and optimize the transmission error when adaptive software is available.

Furthermore, in this paper only the peak-to-peak value of the transmission error was considered, which is normal practice in industry.

But we are convinced that the slope of the TE curve is also important, as a steeper slope will produce higher accelerations and vibrations. To date, these phenomena have yet to be researched accurately.

References:

1. Munro, R.G. and D. Houser. “Transmission Error Concepts,” The Ohio State University GearLab, 2002 (and similar publications of the OSU GearLab).

2. Linke, H. *Stirnradver Zahnungen* (*Cylindrical Gears*), Carl Hanser Edition, ISBN 3-446-18785-5, 1996.

3. Niemann, G. and H. Winter. *Machine Elements II*, 2nd Edition, Springer Edition, ISBN 0-387-11149-2 (English Edition), 1983.

4. Smith, J.D. *Gear Noise and Vibration*, 2nd Edition, Marcel Dekker Edition, New York.

5. Peterson, D. “Auswirkung der Lastverteilung auf die Zahnfusstragfähigkeit von Hochüber deckenden Stirnradpaarungen,” Dissertation, TU Braunschweig, 1989.

6. Kissling, U. and M. Raabe. AGMA 05FTM04, “Tooth Meshing Stiffness Optimization Based on Gear Tooth Form Determination for a Production Process Using Different Tools,” October, 2005.

7. “Calculation Software for Machine Design,” *www.kisssoft.com.*

8. AGMA 925-A03, “Effect of Lubrication on Gear Surface Distress.”

9. ISO 6336-7, Technical Report, “Micropitting,” (not yet published).

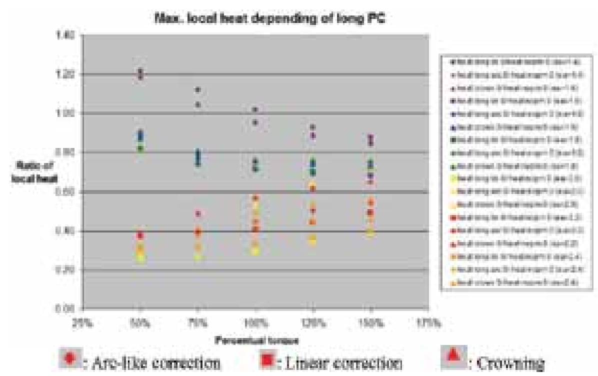
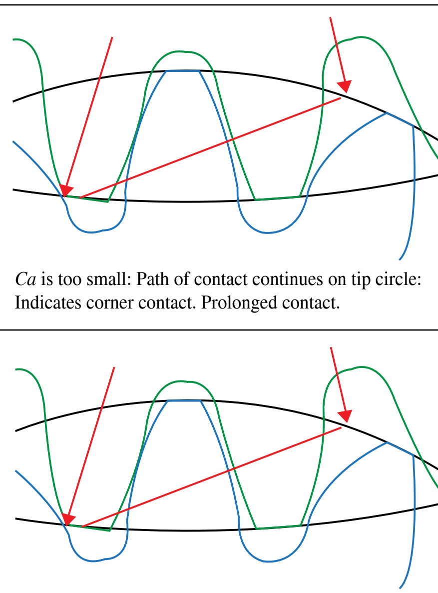


Figure 18—Ratio of HEATwithPC to HEATnoPC for different gear pairs, with ε_α = 1.4 to 2.4, with long profile correction, depending on torque.



Ca is too small: Path of contact continues on tip circle: Indicates corner contact. Prolonged contact.

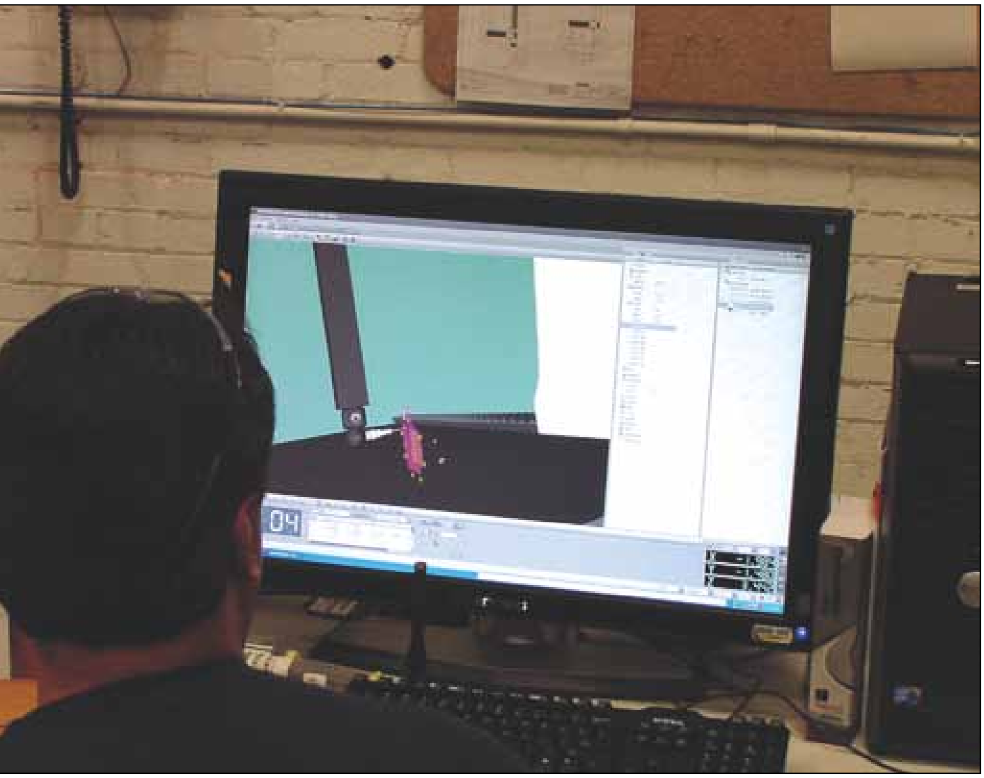
Ca is too small: Path of contact continues on tip circle: Indicates corner contact. Prolonged contact.

Figure 19—Check of the tip relief *Ca*.

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

Cotta Transmission Installs CMM with Gear Checking Module

XSPECT SOLUTIONS PROVIDES WENZEL BRIDGE-TYPE CMM EQUIPPED WITH *OPENDMIS* SOFTWARE FOR BASIC GEAR MEASURING CAPABILITY WITH CMM FLEXIBILITY



The Wenzel LH 12.30.10 bridge-type CMM is equipped with *OpenDMIS* software that includes a basic gear measuring module.

Beloit, Wisconsin-based Cotta Transmission Company LLC, an industrial and specialty transmission manufacturer, recently purchased and had installed a new Wenzel LH 12.30.10 CMM, equipped with *OpenDMIS* software with a special gear checking module.

The organization had been using an older-model 1970s CMM, and the company was extremely dissatisfied with the results they were getting from the older machine, says Todd Wells, Cotta quality manager. In fact, the operators were using the machine manually because of fears it would crash.

"They would often re-inspect product multiple times because they had little confidence in the results," Wells says.

A team was assembled to rectify the situation. The 1970s CMM that Cotta was using had been rebuilt once already, and when the company conducted an accuracy study, it was obvious it was not repeatable anymore.

"For example, we performed one study where the same part was inspected several times on a program that was written to run in automatic mode," Wells says. "The measurement results varied more than 220 percent from the required design tolerance."

With this new knowledge of the CMM's inability to repeat, the team mandated sub-contracted CMM inspection for specific parts with tolerances too critical for the old CMM, and until a new CMM could be purchased.

"We estimated that our work level would require an expenditure of at least $100,000 over the next 12 months to accommodate sub-contracting to an outside CMM service," Wells says. "We needed a new CMM to insure our commitment to meet the needs of our customers and to continue to deliver a competitively priced, quality product on time."

Cotta engineers explored the possibility of purchasing a new Wenzel CMM. The team liked its *OpenDMIS* software, Wells says, so they contacted Xspect Solutions, Wenzel's North American operation, where regional sales manager Nick Moceri and president Keith Mills put together a program that gave Cotta the machine they wanted within their budgeted cost and delivered on time.

"It actually ended up being ahead of time and included an offer that many other CMM manufacturers failed to beat," Wells says.

Keith Mills explains: "Equipment suppliers like Xspect Solutions understand that manufacturers are pinching pennies just like everyone else. They're looking for the best quality product at a reasonable cost. Wenzel CMMs are considered by many to be the best constructed and most mechanically accurate CMMs in the world. Precision manufactured impala black granite bases and bridges, intrinsic precision and hemispherical-cylindrical air bearings and standard Renishaw probing systems offer volumetric accuracy of 2.5 microns. As a result, Wenzel machines are typically not the cheapest CMM on the spreadsheet. However, for Cotta, we were able to put together a proposal that involved a special CMM that we had loaned to another customer while waiting for a larger Wenzel machine to be built for them. Because we already had the 'loaner' CMM being returned, we were able to make the necessary arrangements to tie in the logistics and machine exchange, as well as customize the CMM to meet Cotta's accessories and software needs. The new machine and software would be able to handle the entire range of products Cotta is producing."

Wells adds, "We had been looking at machines equivalent in size to the Wenzel 12.30.10 that were 1995 vintage. We ended up with a 2008 Wenzel structure with new controller, probing,

continued

New Wenzel LH 12.30.10 bridge-type CMM installed at Cotta Transmission to inspect a wide range of industrial and commercial transmission components.

PC and software for a very attractive package price. In addition, we received software that included the gear measuring module, allowing us to develop basic gear data right on our CMM."

The gear measuring module allowed Cotta to move its small gear measuring machine out of the inspection lab and into a location closer to the gear manufacturing department. Within a week of installation, technicians had successfully created part programs from CAD and inspected a number of part designs.

"We duplicated the study we conducted on the old CMM on the new Wenzel and the results showed a 213 percent improvement in the measurement variation," Wells says.

"We did another interesting thing," Wells says. "Because our old CMM was not worth rebuilding again, we decided to dismantle it and use the granite base and bridge and turn them into inspection surface plates. We had them lapped and calibrated and have them in use again in our shop. Xspect Solutions also offered to take our old Renishaw PH9 probe in trade for the new PH10M that was supplied with the CMM, and also gave us a useful styli change rack that mounts directly on the base plate."

The Wenzel LH 12.30.10 is a bridge-type CMM with a measuring envelope of 1200 x 3000 x 1000 mm, which provides adequate table capacity for some of the larger transfer cases that Cotta produces. With this machine design, the Y-axis guideway is machined directly into the granite base plate, providing optimal long-term accuracy and stability. The machine has a maximum 3-D measuring speed of 700 mm/sec with maximum acceleration of 2,000 mm/sec^2. It is equipped with a Renishaw PH10M probing system and a HT400 teach pendant, which eliminates the tedious keyboard interaction necessary with conventional CMM teach pendants.

"The installation and calibration of the Wenzel CMM was well within our needed time frame, which was notable because the machine was configured when the installation was taking place," Wells says. "Communication with Xspect Solutions' administrative and technical personnel has been seamless, including the coordination of any of the loose ends that normally occur with a project like this. We were even allowed to tour one of Wenzel's other customers to get familiar with the same CMM prior to the arrival of our new machine. This has been a very successful supplier/customer project."

For more information:

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Wixom, MI 48393
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Fax: (248) 295-4301
www.xspectsolutions.com

Cotta Transmission used the granite base of the old CMM as an inspection surface plate in its shop.

The 28th edition of IMTS takes place at McCormick Place in Chicago, September 13-18.

IMTS 2010

Poised for Manufacturing Resurgence

Manufacturing is a hot topic everywhere these days, what with economic stimulus plans targeting the struggling industry worldwide. Many hopes are tied to a manufacturing recovery to bring us further up out of the economic doldrums of 2007–2008. Most indicators show that manufacturing is climbing back, so what better time for the International Manufacturing Technology Show (IMTS) 2010 to witness first hand the next generation's technology.

The biennial Chicago event takes place September 13–18 at McCormick Place. This is the 28th edition of the premier manufacturing technology show in North America. More than 1,100 exhibitors will span 1.2 million net square feet of exhibit space, attracting more than 92,000 buyers and sellers from over 116 countries. Visitors will see more than 15,000 new machine tools, controls, computers, software, components, systems and processes for improving efficiency.

The gear pavilion can once again be found in the North Hall. The other pavilions should also be of great interest. The metal cutting pavilion consists of everything from machining centers and assembly automation to flexible manufacturing systems and lathes. The tooling and workholding systems pavilion features jigs, fixtures, cutting tools of all types and accessories. In the alternative manufacturing processes pavilion, visitors can find waterjet, plasma-arc and laser systems, welding equipment, heat treating and other processes. The other pavilions include abrasive machining/sawing/finishing; controls and CAD/CAM; EDM; machine components/cleaning/environmental; and quality assurance.

Another major attraction is the Industry and Technology Conference, which focuses on discussing new industry opportunities. The sessions aim to explore innovative technologies, business development and optimization, as well as workforce efficiency and productivity. Special emphasis this year will be placed on maintaining focus on short- and long-term goals during a tough economic environment. The conference is running from Tuesday, September 14–Friday, September 17 located in the West building.

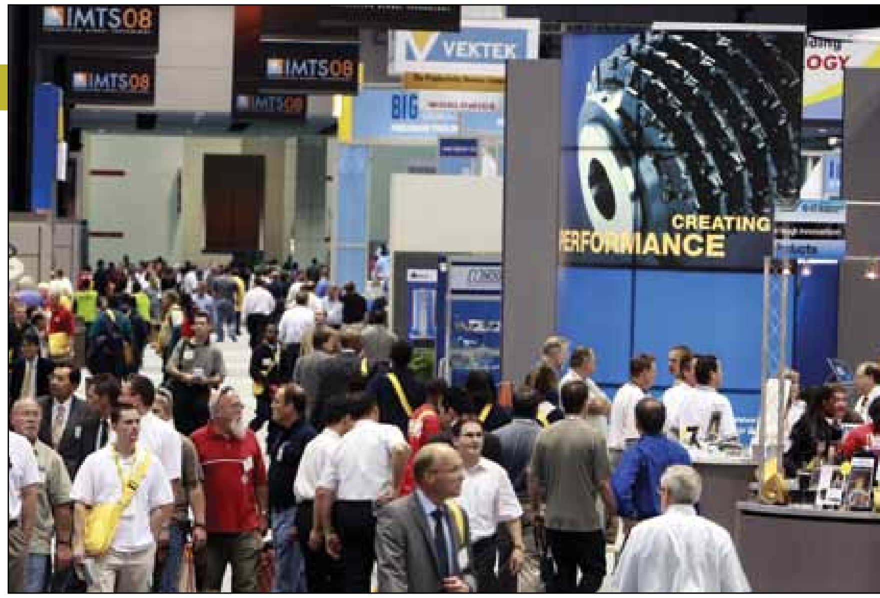
The conference program focuses on six topic tracks that include materials engineering, which covers physical properties and R&D; machining technology and trends, which covers general cutting, turning, milling, grinding, tooling/workholding; alternative manufacturing processes looks at waterjet, laser, EDM, welding, fastening/joining; metrology, covering measuring, testing, 3-D inspection and standards; plant operations, including lean manufacturing, CAD/CAM, training/workforce, government, energy efficiency and the MTConnect open standard; and rapid prototyping.

Although none of the sessions address gear generation specifically, there are many relevant topics that should be of interest. Some of these include New Technologies for Machine Tool Automation, from 11–11:55 a.m. on Friday; CAD/CMM, A New Category in the CMM Industry, from 11–11:55 a.m. on Thursday; Gaining 50 Percent Productivity with Workholding, from 11–11:55 a.m. on Wednesday; Advanced Grinding Technology Leads to Measurable Gains, from 9–9:55 a.m. on Tuesday; Cutting Tools Engineered for Medical, from 1–1:55 p.m. on Tuesday; and there are also various lean and green topics, as well as various general manufacturing sessions.

New to IMTS this year is the Industry Inspiration Day, as part of the September 13 kick-off for the Industry

continued

The gear generation pavilion in the North Hall is one of many attractions gear buyers will be targeting.



Along with the trade expo, other major attractions of IMTS 2010 include the Industry and Technology Conference and a full-scale exhibition of Lockheed Martin's F-35 Lightning II Joint Strike Fighter.

and Technology Conference. A roundtable panel discussion concludes a luncheon keynote program that will be held from 12–3 p.m. Keynote topics are aerospace, medical, automotive and energy.

"IMTS attendees repeatedly tell us that they come to the show to learn, to network and to find new resources and innovative manufacturing technology resources," says John Krisko, IMTS director, exhibitions. "We are committing significant energy and resources to make the conference the premier educational offering available to the manufacturing industry."

Representing the aerospace industry at the Industry Inspiration Day luncheon is Allan McArtor, chairman of Airbus Americas, who oversees the activities and strategy for Airbus in the United States, Canada and Latin America. Rene van de Zande, president and CEO of the Emergo Group, a consulting firm specializing in international medical device registrations, quality system compliance and medical distribution management, will cover the medical device and in vitro medical device industries. For the automotive sector, Jim Tetreault, vice president of North American manufacturing for Ford Motor Company, will lead that keynote discussion. And rounding out the panel is Denise Bode, CEO of the American Wind Energy Association, who is a nationally recognized energy policy expert.

IMTS attendees registered for a conference session will be admitted to the luncheon program. Exhibiting company representatives will be eligible to attend on an RSVP basis.

Another special feature exclusive to IMTS 2010 is an exhibition of a full-scale model of Lockheed Martin's F-35 Lightning II Joint Strike Fighter. The F-35 Lightning II is a 5th generation fighter featuring fully-fused sensor information, network-enabled operations, advanced sustainment and lower operational and support costs. Lockheed Martin is developing the F-35 with its principal industrial partners, Northrup Grumman and BAE Systems. Two separate, interchangeable F-35 engines are under development: the Pratt & Whitney F135 and the GE Rolls-Royce Fighter Engine Team F136.

The United States intends to buy 2,443 F-35s with more than 4,000 forecast to be built for U.S. and foreign customers combined. The F-35 program's overall value is estimated at $323 billion, the largest defense program ever, according to the Association for Manufacturing Technology (AMT), IMTS show organizer.

"While the manufacturing technology featured at IMTS stands alone as a must-see, what's really exciting is seeing the end result from some of those machines," Krisko says. "Everyone at the show will have the opportunity to learn about the plane's construction and the manufacturing technology behind it. We are thrilled to have this amazing example of an end product featured at IMTS."

The F-35 will be on display in the front of McCormick Place's West Building in booth W100. Photo opportunities may be available to attendees.

Make sure not to miss the next two issues of *Gear Technology*, which will feature much more IMTS coverage. In August, *GT* will feature detailed booth previews, so visitors can have a sneak peek at what gear-related products they may be interested in seeing. Also, a consolidated listing of booth numbers of most interest to gear industry visitors will help plan and sort through the often overwhelming complete listing found at the show. The September/October show issue will include more product previews and last-minute information about IMTS.

As always, stay tuned to *geartechnology.com* for the latest news and information on all gear-related, as well as IMTS updates. For direct information from AMT, visit *www.imts.com*, or follow the show on your favorite social network, Facebook, Twitter or LinkedIn (where you can also find the latest from *Gear Technology*'s sister publication *Power Transmission Engineering*).

August 17–18—NFPA Industry and Economic Outlook. Westin Chicago North Shore Hotel, Wheeling, IL. AGMA members are invited to join the National Fluid Power Association (NFPA) for the Industry and Economic Outlook Conference. The event offers hard economic data and expert analysis along with additional focus into the technology breakthroughs likely to impact mobile and industrial markets. The conference includes analysis of markets critical to AGMA members and gear manufacturers: industrial, construction, heavy trucks and agriculture/farm machinery. Familiar past-AGMA speakers will provide macro-level analysis and forecasts, including Jim Meil, Eaton Corporation, Eli Lustgarten, ESL Associates and Alan Beaulieu, Institute for Trend Research. Prior to July 9, AGMA members can register for this conference for $750 ($850 after), by registering as "Invited Guest" at the conference website, *www.nfpa.com/Events/2010_IEOC_ProgramDetails.asp*.

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, Nova 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 offshore wind turbines. For more information, visit *www.offshorewindexpo.org*.

U.S.

DEMAND FOR SYNTHETIC LUBRICANT, FUNCTIONAL FLUID TO REACH $4.8 BILLION IN 2013

U.S. demand for synthetic lubricants and functional fluids will expand more than three percent per year to $4.8 billion in 2013, with growth rising at an even faster pace in volume terms to reach 520 million gallons. These and other trends are presented in Synthetic Lubricants and Functional Fluids, a new study from Cleveland-based industry research firm The Freedonia Group Inc.

According to the study, engine oils and hydraulic and transmission fluids will experience the fastest gains as synthetics finally begin to penetrate the conservative medium- and heavy-duty truck market, and as increasing new vehicle lubricant performance requirements and growing consumer acceptance further expand synthetics' share of the light vehicle market. "There are a number of issues that have held synthetics back, though the primary one has been the prevailing conservative approach of 'If it isn't broke, don't fix it,'" says Ned Zimmerman, industry analyst for Freedonia.

While engine oils and hydraulic and transmission fluids will achieve relatively strong growth going forward, other types of synthetic lubricants and fluids are expected to realize a slow decline in demand through 2013, largely as a result of falling average fluid prices.

The largest market for synthetic lubricants and functional fluids is light vehicles. This reflects not only consumer uptake of engine oils and transmission fluids, but also the universally synthetic nature of antifreeze, brake and de-icing (windshield wiper) fluids. The fastest growing market for synthetic fluids will be the medium- and heavy-duty truck market. Increasingly stringent engine specifications, as well as a move by many engine manufacturers to specify low viscosity engine oils for their 2010 emissions-compliant engines, will finally lead many fleet operators to evaluate and use synthetic engine oils and hydraulic and transmission fluids. Synthetics will benefit from their better performance under load in low viscosity formulations, as well as from the reduced maintenance and downtime costs that result from synthetics' extended drain intervals. The latter will be increasingly important to fleet operators looking to cut costs.

From a product standpoint, the greatest declines will be in heat transfer and metalworking fluids. In addition to declining vehicle antifreeze demand, the greater use of fill-for-life coolant systems in industrial equipment and the increased recycling of deicing fluids at airports will contribute to falling heat transfer fluid demand. Synthetic metalworking fluid demand will suffer from increasing

U.S. SYNTHETIC LUBRICANT & FUNCTIONAL FLUID DEMAND
(Million Dollars)

Item	2003	2008	2013	% Annual Growth 2003-2008	% Annual Growth 2008-2013
Synthetic Functional Fluid Demand	2,145	4,140	4,840	14.1	3.2
Engine Oils	525	1,820	2,590	28.2	7.3
Heat Transfer Fluids	970	1,345	1,180	6.8	-2.6
Hydraulic & Transmission Fluids	215	390	530	12.6	6.3
Metalworking Fluids	195	200	170	0.5	-3.2
Dielectric Fluids	70	105	95	8.4	-2.0
Other	170	280	275	10.5	-0.4

substitution of bio-based fluids for synthetics. "This substitution is not universal, but occurs most often where lubricant is released into the environment, or where there is to be likely human contact with the lubricant on a regular basis," Zimmerman says. "In these cases the bio-based lubricant is typically perceived as being more environmentally friendly, and less likely to be toxic to humans.

"Due to differences in how frequently the different types of lubricant need to be changed, a small impact on volume demand may exist."

Reflecting their heavy use in engine oils and hydraulic and transmission fluids, Group III base oils and polyalphaolefins will be the fastest-growing synthetic chemicals, with esters also achieving positive value growth through 2013.

Due to recent growth and technological development in the synthetic lubricant market, this Freedonia study chose to focus on that area. A more generalized report is also produced, but due to the scope, it is not possible to focus on synthetics in this kind of detail, according to Zimmerman.

"While it is true that synthetic lubricants and functional fluids are not universally superior to mineral oil-based lubricants and fluids for all applications and under all use scenarios, for many applications synthetics have a demonstrated advantage," he says. "This is particularly true in the large volume engine oil market where the synthetic lubricants can facilitate extended drain intervals, particularly relative to lubricants formulated with Group I and Group II base stocks."

Excel Gear

MAKES TWO KEY APPOINTMENTS


Denis Bermingham

Denis Bermingham has been named manager of manufacturing engineering and special projects for Excel Gear Inc., and William Powers was named marketing manager. N.K. Chinnusamy, president of Excel, made both hires, saying they were the result of the company's recent growth and anticipated expansion into new market segments.

Bermingham has a background in engineering, metalworking and machine tool building, as well as metallurgy and heat treatment. He will oversee Excel's manufacturing engineering and special projects. He also will continue the company's ongoing lean manufacturing implementation.

Bringing 30 years of manufacturing and machine tool experience to Excel Gear, Bermingham worked the majority of his career at Ingersoll Milling Machine in Rockford, IL, in the manufacturing engineering, assembly, engineering and prototyping departments. He has a degree in industrial technology.

"I joined Excel Gear to become part of the technical/manufacturing environment here," Bermingham comments. "We can offer customers innovative solutions with excellent quality and value. I'm very excited to be part of this team."


William Powers

Powers brings 30 years' experience in the gear and machine tool business to Excel. He previously served as an account manager, project manager and supervisor of customer training with Ingersoll, as well as other metalworking/automation systems companies. He holds a degree in business administration and will oversee all the marketing and business development for Excel.

"Chinn has structured a first-class company at Excel, supplying engineering-based products, brought to market by a very highly-skilled and dedicated team," Powers says. "All customers receive the highest quality possible, backed by service and application assistance that's second to none. It's a great working environment, and I look forward to the challenges of our changing markets."

Broadwind

APPOINTS BOARD CHAIRMAN

David P. Reiland was appointed chairman of the board of directors for Broadwind Energy Inc. Reiland has served as a member on the board since April 2008.

Reiland previously worked for Magnetek, starting in 1986, where he served as chief executive officer and president from 2006 to 2008, and he continues to serve on its board of directors. Magnetek develops, manufactures and markets power and motion control systems, including systems that deliver power from renewable energy sources, including wind turbines, to the utility grid. Reiland currently chairs Broadwind's Finance Committee and serves on the Audit and Executive committees.

According to Broadwind CEO, J. Cameron Drecoll, "We are delighted to announce Dave's appointment as chairman of the board. He has played a key role since joining the board two years ago and has been instrumental in helping the company navigate through the economic downturn and position itself for the recovering markets. Broadwind will further benefit from Dave's financial acumen, manufacturing experience and wind energy knowledge."

Reiland succeeds James M. Lindstrom as chairman of the board. Lindstrom works for Tontine Associates LLC, an investment firm based in Greenwich, CT. It is affiliated with a group of investment funds that collectively are Broadwind's largest stockholder. Lindstrom resigned from the board in connection with Tontine's decision to distribute a portion of its ownership position in Broadwind to its investors.

Reiland comments, "Tontine's vision helped establish Broadwind as a key player in the U.S. wind industry, and we appreciate Jim's commitment as chairman in positioning the company for long-term success as the wind energy market recovers."

Solar Atmospheres

BREAKS GROUND IN CALIFORNIA

Solar Atmospheres, Inc. recently broke ground on May 3, 2010, for its new plant site in Fontana, California. This new addition to the Solar Group will bring a greenfield vacuum heat treating and brazing facility to the West Coast. According to William R. Jones, CEO, Solar Atmospheres Inc., "This was a major and serious decision considering the current market conditions, but the project will definitely be worth it in the long run."

The new site is located in San Bernardino County and is approximately 40 miles east of downtown Los Angeles. The building itself will be a total of 25,000 square feet with a two-story office building included. The plant will be equipped with roof skylights, a poured cement foundation and insulated frame work. All of the vacuum furnaces will be powered by an electric, three-megawatt power entrance from Edison Electric. Required process gases will be supplied by Air Products. Water cooling for the furnaces will be a single-close loop, air cooled heat exchanger that will be providing 1,500 gal/minute. Also, the building will include two 10-ton, full-span bridge cranes that will service the entire facility.

From left to right: Paul Biane, San Bernardino 2nd District County Supervisor, Scott Vanhorne, Field Representative to the Supervisor, Olin Lord, President and Gregg Lord, Vice President, Stewart Development/Lord Construction and Derek Dennis, President of Solar Atmospheres of California attend the groundbreaking ceremony in Fontana, CA.

The furnaces for the new plant are now being constructed by Solar's sister company, Solar Manufacturing. The new plant will start out with four production furnaces of varying sizes. The first is a 24-foot-deep, high-performance, car bottom-type vacuum furnace with a load capacity of 50,000 lbs. The second is a six-foot-deep, 10-bar quenching capability, high-vacuum furnace that can process up to 3,000 lb. loads. This furnace will allow Solar to process many types

of parts, including those requiring the company's patented low-pressure vacuum carburizing service. The third furnace is a five- foot-deep, 2-bar cooling, high-vacuum furnace. The new site will also have a five-foot- deep, re-circulating air temper furnace. It is anticipated that these furnaces will serve many industries within the greater Southern California area. Included in these industries would be aerospace, high-end metallurgy, such as titanium, tantalum and columbium, alloys of stainless steel, and the heat treatment of tool steels.

Solar Atmospheres of California is expected to have about 30 employees within the first two years of operation. Although the primary employment will be from the local area, selected specialists will be relocating from the Solar East Coast plants to assist in the initial plant start-up. Sales are projected to be $12 million in two years. The official opening date of this new state-of-the-art facility is expected to be the first week of September, 2010.

1Q2010 Workholding Shipments Rose

At $50 million for the first quarter 2010, shipments of workholding equipment were up 10.7 percent from the first quarter 2009, according to the Advanced Workholding Technologies (AWT) Group of The Association for Manufacturing Technology (AMT). Workholding equipment shipments within the U.S. by the 38 companies participat-

continued

ing in the AWT statistical report totaled $42.6 million while exports totaled $7.4 million.

The AWT report shows domestic workholding equipment shipments increased 13.6 percent while U.S. exports decreased 15.5 percent from fourth quarter 2009. Data was compiled regionally. The Midwest increased 7.5 percent from fourth quarter 2009 and was the largest domestic destination with 39.5 percent of total domestic shipments. Central region growth was 24.7 percent, making it the second largest share of domestic shipments with 18.8 percent domestic share. Northeast shipments fell 6.1 percent. The South had 13.6 percent of the first quarter 2010 domestic shipments, with an increase of 14.4 percent from the previous quarter. The West is the smallest domestic market despite a 34.2 percent increase from fourth quarter, which is the largest market growth for first quarter 2010. Employment levels were up 2.7 percent from the previous quarter, but these numbers are still down 9.8 percent compared to the first quarter of 2009.

The Advanced Workholding Technology Group is comprised of AMT members who produce chucks, jaws, collets, vises, fixtures and other workholding equipment. The AWT statistical program is open to any OEM workholding manufacturer or U.S.-based company that is a sole distributor of a foreign-built workholding product line. Participation involves completing a confidential survey each month. OEMs interested in participating should contact Kim Brown, industry economist, at (703) 827-5223 or *kbrown@amtonline.org*.

Romax

Opens Dedicated Wind Energy Technical Center

Romax Technology is opening a new technical center in Colorado in response to the growing demand for technical consultancy services from the U.S. wind energy industry. Located in Boulder, CO, the facility will provide a center for Romax's wind engineering capabilities enabling the delivery of key projects with local wind energy clients and partners.

Adding to the company's 10 worldwide offices and complementing a technical and sales team in Troy, MI, the facility will focus solely on the delivery of products and services for wind energy.

Recent growth in the wind industry has created strong demand for Romax's wind energy products and services, which include component and system level drivetrain design and simulation, as well as manufacturing, testing and certification support. "Over the past four years, the U.S. wind energy market has earned its position as one of the largest in the world, with domestic and foreign manufacturers all aspiring to meet the needs of this fast growing market," says Ashley Crowther, U.S. engineering director for wind energy at Romax.

The technical center will initially support American wind initiatives, such as the National Renewable Energy Laboratory (NREL) Gearbox Reliability Collaborative, as well as helping wind turbine and component manufacturers to supply products to the U.S. market. Boulder Wind Power (BWP) is the first long-term technical partner to be supported by the Romax Technical Center.

Identifying Romax as a key technical partner, BWP intends to design, develop and eventually manufacture large, multi-megawatt, direct drive wind turbines. Romax will lend its expertise to achieve a reduction in development time, providing BWP with design, analysis, dynamics and instrumentation experience for the entire direct-drive turbine drivetrain.

Zeiss

ADDS MARUKA AS DISTRIBUTOR

Carl Zeiss Industrial Metrology recently announced that Maruka U.S.A. will be the new distributor of Zeiss metrology equipment for Kansas and Western Missouri. Maruka has measurement centers in Wichita, KS and Lee's Summit, MO, and will represent the full line of Zeiss coordinate measuring machines (CMMs).

"Maruka's commitment to the success of their customers and over 50 years of experience makes them an invaluable partner. We are confident in their ability to support the Zeiss product line with a qualified staff in the Kansas and Western Missouri region," says John Gryzbowski, national sales manager-west, Carl Zeiss IMT Corporation.

continued

Carl Zeiss metrology equipment, such as this Contura G2 CMM, is available in Kansas and Western Missouri by Maruka U.S.A.

Maruka Machinery Co. Ltd. in Japan was established in 1946, and the U.S. branch opened in 1968. Maruka has been serving the manufacturing industry with metalworking, plastics processing and fabrication equipment for over a half a century. "All of us at Maruka are looking forward to being a part of the Carl Zeiss team while utilizing our facilities and experience to relay success to our customers," says Brent Eagleburger, sales manager at Maruka U.S.A.

Bonfiglioli Yaw and Pitch

DRIVES POWER GERMAN OFFSHORE WIND FARM

Germany's first offshore wind farm, Alpha Ventus, features yaw and pitch drives from the Bonfiglioli Group. The wind farm features a dozen 5 MW towers and is expected to generate enough electricity to power 50,000 homes.

Located in 30-meter waters, 45 kilometers (28 miles) off the German island of Borkum in the North Sea, the proj-

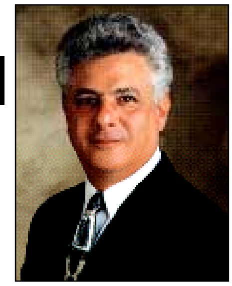
ect represents an investment of 250 million euros. Alpha Ventus is the first of several wind farms Germany plans for its northern coastline. The government approved plans to develop up to 40 offshore wind parks that could provide electricity to eight million households.

According to Sonia Bonfiglioli, CEO of the Bonfiglioli Group, the company's gearboxes were chosen to control the yaw angle of each turbine tower, as well as the pitch of the blades. "Due to the location and high power output of each wind tower, each component had to be both highly reliable and high performing," she says. "Bonfiglioli, thanks to our years of experience in applied technology, was among the few manufacturers who could provide the right solution for the project."

During an official commissioning ceremony, Norbert Röttgen, Germany's federal environment minister, said, "Investors, turbine manufacturers and grid operators have all taken a great risk with this test field. Their steadfast commitment, perseverance and creativity have paid off. The experience gained during the construction of Alpha Ventus will benefit all future offshore wind farms."

Bonfiglioli forecasts its 2010 revenues will top 98 million euros within the wind power sector.

PUBLISHER'S PAGE



continued from page 9.

that make up the operations of AGMA and highlight the advantages of participating in those activities. In May, we had a "Voices" column by Joe Franklin, AGMA president. This issue includes a column by Arlin Perry, who is the former chairman of the AGMA Foundation. In future issues, we expect to hear from many more of the association's leaders.

We have also recently been honored by The Gleason Works and Dr. Hermann Stadtfeld to exclusively serialize his upcoming new book on gear tribology. We'll be running the series chapter by chapter over the next year or so. You should be able to get enormous new and useful information from this series, no matter what bevel gear system you're using.

We've improved our sales effort by bringing advertising sales in-house. Many of you have had the chance to work directly with Dave Friedman, our new advertising sales manager. He brings a wealth of industrial publishing experience to our organization. His experience, his understanding of marketing and his ability to listen to your needs make him the ideal person to help you make the most of our products and services. You can reach him at *dave@geartechnology.com*.

I've been thinking a lot lately about leadership, integrity and service—all values I hold very highly. Over the past couple of years, I've noticed some disturbing trends in both the publishing marketplace and the used machinery marketplace.

I get a lot of e-mails offering me fake Rolexes, but I'm smart enough to know that the value is in the real thing. Although the fake may look the same and be offered at a bargain price, it doesn't provide the quality that is needed. The same is true of magazines.

Believe it or not, there seems to have been some confusion in the marketplace about the ownership of *Gear Technology* and its mail list. Let me make it clear for everyone. Randall Publications LLC is the owner and publisher of Gear Technology, The Journal Of Gear Manufacturing; *Power Transmission Engineering* magazine; *www.geartechnology.com* and *www.powertransmission.com*. This company is owned solely by myself, with my wife, Marsha. We have been the only owners that Randall Publications LLC has ever had.

The need for leadership, integrity and service may be even greater in the used machinery business. For many years I was president of Cadillac Machinery Co., Inc., one of the most respected and reliable used machinery dealers in the world. Cadillac was known the world over for the quality of its work and the integrity of what it offered.

My new company, Goldstein Gear Machinery LLC, will never be as big as Cadillac was, but the values upon which it's founded still come from me. Goldstein Gear Machinery is represented in the marketplace by *www.gearmachineryexchange.com*, where you can find available gear machines, tooling, and accessories—both those being offered by Goldstein Gear Machinery and those being offered by gear manufacturers who want to dispose of excess equipment.

To help you better understand what you're buying in the used gear machinery market, I'm offering a free service to the industry. At www.*gearmachineryexchange.com*, I will be providing a historical database of gear machine serial numbers. This database will help you understand the year of manufacture of a machine being offered to you, no matter where in the world. The database combines over 40 years of experience at Cadillac and Goldstein Gear Machinery, and it includes almost 15,000 machines that I have had contact with over my career. On the website, you can find serial numbers by manufacturer to get a very close approximation of the year of manufacture, if not an exact match. Hopefully this will help provide a higher level of honesty and transparency to the marketplace.

I am extremely proud of the improvements we've made over the past year. Considering all we were able to accomplish amid the distractions of my transition, I'm confident that—now that it's over—Gear Technology and the entire Randall Publications family is poised for unprecedented growth and success. We look forward to serving you over the coming years, and we thank you for your continued support.

Michael Goldstein

Michael Goldstein,
Publisher & Editor-in-Chief

P.S. We will be at IMTS 2010, in booth # N-7572. See our advance coverage of the show beginning on page 65, and stay tuned for extensive booth previews and listings in the next two issues. Also, if you happen to be in Chicago Sept. 13–18, stop by and visit with our editors and staff.

*All circulation statistics based on publisher's own data.

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GEARWORKS

Brad Foote Gear Works, Inc. is growing. We have several immediate job openings in our Cicero, Illinois location:

Engineering Manager (2010-114)
Manage Engineering Department and Staff. Minimum (10) years' experience supervising engineers in a precision machining engineering operation for industrial applications. BS in Mechanical Engineering, strong leadership skills and proven ability to successfully lead and manage technical teams required. Previous experience with heat treating and metallurgy preferred.

Design Engineer (2010-115)
Perform engineering calculations of stress, strength, deflections, and critical speeds for new or redesigned product line. Analyze and verify calculations prepared by other draftsmen. Minimum (5) years of design experience in mechanical power transmission. B.S. degree in mechanical engineering or (10) years experience in the design of gearing and reducers.

Qualified applicants are encouraged to e-mail their resume to hr@bwen.com. Please reference the job code and title in the subject line of your e-mail submittal. Brad Foote Gear Works, Inc. is an Equal Opportunity Employer (EOE).

Get Your Geek on At Edmund Scientific

A treasure trove of gear and power components for aspiring engineers and dedicated hobbyists.

Addendum devotees rejoice—the Addendum Search Committee has stumbled across a wonderful website chock-full of gears, gadgets, pumps and pulleys and anything else one might need to build a model-size, high-speed gearbox or power transmission assembly.

The site is Edmund Scientific, founded back in 1942 by Norman W. Edmund, an amateur photographer who began selling specialty lenses via mail order. By 1948, he had branched out to offer "science hobbyists and engineering enthusiasts around the world a wide range of exciting science products."

"Science enthusiasts, hobbyists, teachers, inventors and people who generally love science and technology are who we serve," says Noel France Vache, communications coordinator and community relations. "Our customers are all ages, though a large portion of our market consists of science-savvy adults between the ages of 21 and 56."

Make no mistake—these are not toys—except perhaps for men of a certain age. Go to the site (*www.scientificsonline.com*) and click on the Engines, Motors, Gears & Pumps selection—you'll see planetary gearbox sets, universal gearboxes, a four-speed crank axle gearbox, numerous motors and a V-8 combustion engine. Prices range from a few dollars to more than several hundred dollars, so there's even something here for tinkerers on a budget.

V-8 Combustion Engine (upper left); Jensen Electrically Heated Steam Engine (upper right); AC/DC Motor Generator (lower left); and Universal Gearbox (lower right).

But where, you may well ask, does Edmund find this stuff? There's geeky-neat stuff like the photon solar racer kit; or a four-in-one multipack of hydraulic machines; a solar car kit (skill level II); or a hydraulic mini platform lifter.

"We have product developers on staff with our organization and also a dedicated team of category managers who source all our products," says Vache. "For Edmund Scientific specifically, the items are sought out that are the highest quality, science-related items that are unique in our market place.

"All our gear- and motor-related items are used in hobby projects as components in electricity and engineering products, or to teach young, aspiring scientific minds about gears and motors by giving them as educational gifts."

So if you're nurturing a future mechanical engineer in the family, or are inspired to invent a better mouse trap, Edmund Scientific is definitely the place.

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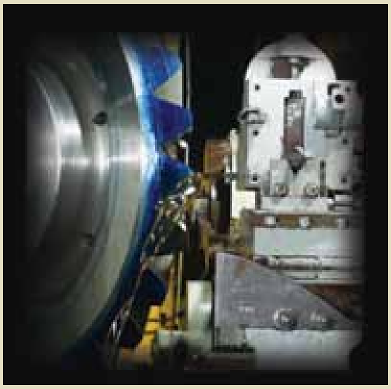

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