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SEP/OCT 2014

SOFTWARE SURVEY: 20 QUESTIONS

COMPUTER AIDED MANUFACTURING

WHO's AFRAID OF INNOVATION?

GEAR TECHNOLOGY 30 YEARS 1984–2014

TECHNICAL

- ASK THE EXPERT: TRIBOLOGICAL NOMENCLATURE
- REDUCING GAS USE IN U.S. WITH HIGH-TECH BEVEL GEARS
- MICROPITTING OF LARGE GEARBOXES VIA GEOMETRY, OPERATING CONDITIONS
- SIMULATION OF DEVIATIONS IN HOBBING, GENERATION GRINDING

ADDENDUM

- FROM BAUHAUS to GEARBOX?

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THE JOURNAL OF GEAR MANUFACTURING

PTG-1

GS 400

Affordable hob sharpening and in-house tool maintenance

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

Shaving cutter and master gear grinding

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

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SANDVIK Coromant

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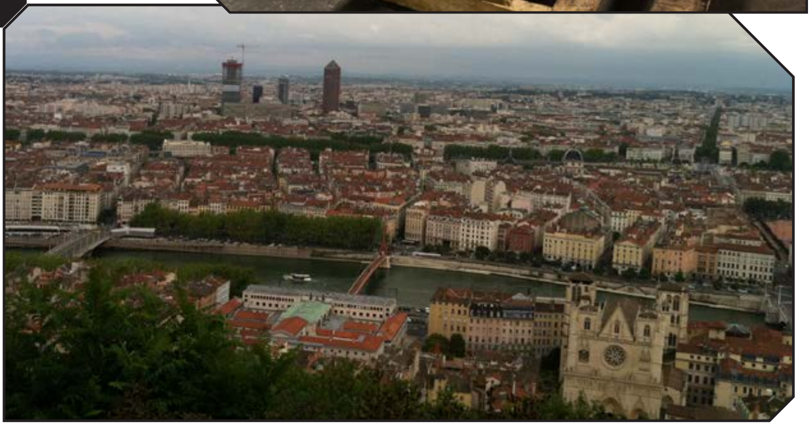
contents

SEP/OCT 2014

22

66



38

features

technical

Vol. 31, No. 7 GEAR TECHNOLOGY, The Journal of Gear Manufacturing (ISSN 0743-6858) is published monthly, except in February, April, October and December by Randall Publications LLC, 1840 Jarvis Avenue, Elk Grove Village, IL 60007, (847) 437-6604. Cover price $7.00 U.S. Periodical postage paid at Arlington Heights, IL, and at additional mailing office (USPS No. 749-290). Randall Publications makes every effort to ensure that the processes described in GEAR TECHNOLOGY conform to sound engineering practice. Neither the authors nor the publisher can be held responsible for injuries sustained while following the procedures described. Postmaster: Send address changes to GEAR TECHNOLOGY, The Journal of Gear Manufacturing, 1840 Jarvis Avenue, Elk Grove Village, IL, 60007.

gear TECHNOLOGY

Vol. 31, No. 7

departments

THE GEAR INDUSTRY'S INFORMATION SOURCE

www.geartechnology.com

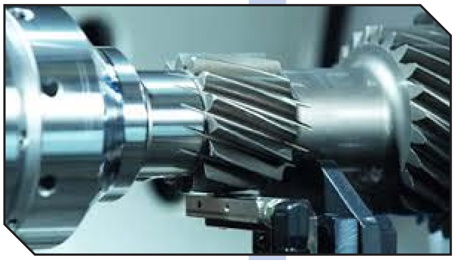
IMTS 2014

The 30th edition of IMTS – The International Manufacturing Technology Show 2014 was the fourth largest IMTS in history and the largest six-day show ever with registration of 114,147 representing 112 countries. This was a 13.9 percent increase over IMTS 2012. IMTS covered more than 1.282 million net square feet of exhibit space and hosted 2,035 exhibiting companies. IMTS 2016 will be held at Chicago's McCormick Place Sept. 12-17, 2016. For additional information, visit *www.geartechnology.com* for the latest news and post show reports.

Call for Papers

The ASME 2015 Power Transmission and Gearing Conference is an integral part of the ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conferences (2015 IDETC/CIE). This event will take place in Boston, Massachusetts, August 2-5, 2015. Visit *www.asme.org* for details.

GT Videos



Fäessler has taken the gear honing process a step further and has enhanced the economic feasibility and increased the process capability. Of special interest are the tool developments, machine developments and new process strategies. See a video on the gear honing process currently on the Gear Technology home page *(www.geartechnology.com)*.

Upcoming Events

Visit our online events calendar to learn more about upcoming events for the gear industry. *(www.geartechnology.com/events.htm)*.

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Cracking the WIP

Publisher & Editor-in-Chief
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Over the past few months I've talked with several different gear manufacturers who are in the process of upgrading their gear making equipment with modern CNC machine tools. Each of these manufacturers has come to the realization that in order to stay competitive, he needs to streamline operations and become more efficient.

I know that sounds obvious, but in each of these cases, the journey toward modernization hasn't been quite so simple, nor the decision to invest so easy. Each of these gear manufacturers is extremely successful in his area of expertise, having developed a reputation for quality, earning business that others struggle to keep.

Up until now, they've done so largely by relying on high-quality, highly productive manual machine tools, operated by expert machinists who understand all the nuances of gear manufacturing.

Investing in new equipment requires overcoming a number of hurdles. For these manufactures, one of those hurdles was the fact that their older machines still produce quality gears. Another is the fact that those machines are all paid for. Why change things up when what they have is so clearly profitable?

But perhaps the biggest hurdle to overcome was the perceptions of their own employees about what a successful manufacturing operation looks like. Many of the operators, managers and owners at these gear companies have grown comfortable in their old ways of thinking and doing. They see skids and pallets in front of every machine and smile because they know that their capital equipment is busy. When gears are being cut, they're making a profit. By the old way of thinking, stacks and stacks of work in process (WIP) were a good thing. Those stacks signaled a healthy demand for a manufacturer's capabilities. For the operator on the shop floor, they signaled job security.

So when the owners and managers finally come to realize what those stacks *actually* represent—an enormous investment of time and money that's completely tied up and not doing any productive work—they still have to overcome the apprehension of the employees who aren't sure about concepts like just-in-time or lean manufacturing.

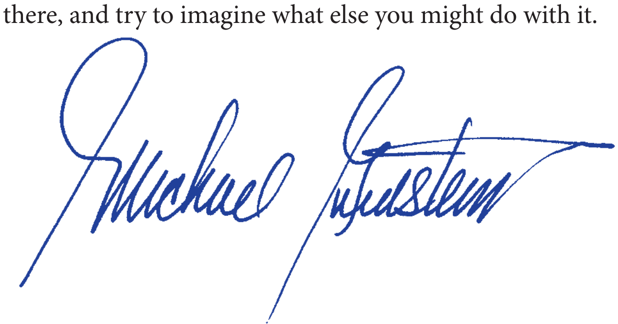
But they *are* overcoming it, at least in the cases of the manufacturers I've been talking to. More importantly, they're realizing that applying the just-in-time concept results in freeing up substantial sums of money. Instead of investing in inventory and work-in-process, these manufacturers are finding that they can instead invest in newer machine tools and automation that further improve their efficiencies and capabilities.

And their employees are finding that fewer pallets in front of their machines is actually a positive sign. Employment at these companies hasn't shrunk, it's grown. In fact, as the companies have become more productive and efficient in their operations, they've been able to take on more work, and they've needed more employees. But instead of just standing by machines, human resources have been redeployed in more productive and efficient endeavors. Formerly hesitant employees are happy to be learning the new skills required by the new machines.

I know many of you out there still rely on older machines. *Your* employees may be uncomfortable with change, and the cost of new machine tools is a substantial hurdle all by itself.

But it seems like the time for investing is now. For most of us, business is pretty good. Except for those serving certain industries, manufacturers have steady work, solid order backlogs and good expectations that the economy will stay on track. We witnessed this first-hand at IMTS, where we saw a steady stream of manufacturers looking at the latest technology. Attendance at IMTS reached 114,000, nearly a 14 percent increase over the previous show in 2012. The exhibitors we talked to were delightfully satisfied with both the number and quality of visitors, and we talked to a number who sold machine tools right on the show floor.

If you didn't make it to IMTS, you should at least consider whether now is the right time to look at upgrading your equipment. Take a look at the latest offerings from our advertisers, who are the leaders in their fields, offering the best quality and latest technology. Then take a look at your own shop floor. If there are pallets and skids stacked in front of machines, try not to see job security. Instead, recognize all the money that's tied up there, and try to imagine what else you might do with it.




Hunting For
High Quality Gears?
Forest City Gear Leads the Way
US Navy MH-60S Seahawk helicopters patrolling for mines out ahead of surface vessels use a powerful and precise Carriage Stream Tow and Recovery System (CSTRS) to quickly raise and lower mine-hunting and destruction equipment. Very high-precision gears from Forest City Gear help to ensure that the mission goes as planned. In this and many other aerospace and defense applications, Forest City Gear is helping customers meet their gear challenges – no matter how difficult to detect.
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11715 Main Street, Roscoe, IL 61073
815-623-2168

Leading by Example — Remember When?

From the Editors: In January of this year we at *Gear Technology* got hip to the fact — in un-hip, belated fashion — that we needed a Blog Site and someone to do the blogging. Lucky for us, we already had that someone right here — in plain sight. That someone was Charles D. Schultz, P.E. — current *Gear Technology* Technical Editor and a still-in-the-game, gear industry lifer with lengthy and rewarding tenures at Falk (Rexnord) Gear and other stops along the way. Add to that the countless hours Chuck has contributed (and continues to do so) over the years to the AGMA, serving with distinction on its various technical committees. Today, along with his *Gear Technology* contributions, Chuck runs his own consultancy — Beyta Gear Service. We think we found the right guy for the job. There's a lot of clutter out there in the blogosphere. (Non-blogging curmudgeons will enjoy what for them may be the best characterization of blogging ever uttered. It reads like latter-day H.L. Mencken, but comes from the Elliott Gould character in the 2011 film *Contagion*: "Blogging is graffiti with punctuation.")

A funny line, indeed — but it doesn't play here.

For proof, read Chuck's Blog from July 24 and you'll agree. It's one of a series of Blogs Chuck has been doing on leadership in the workplace, although in this instance he recalled a memorable boyhood Scouting experience to make an indelible impression. We liked it so much we thought it deserved as much exposure as we could bring to bear, so we're reprising it here as a Voices piece. (Chuck's Blog appears at *geartechnology.com* every Tuesday and Thursday.)

"If You Would Lift Me Up, You Must Be On Higher Ground."

Ralph Waldo Emerson

Leadership 101 — Commitment

Much of what I believe about leadership I learned from the scouting program. I was a scout as a boy and when my children reached that age we enrolled them as scouts and took leadership training. The adult training programs are among the best I ever attended. Scouting gives you the opportunity to be a follower and a leader; you can learn a great deal about both in a single rainy weekend.

When NASA announced plans to go to the moon, the scouting movement saw a good way to interest boys in science. *Life* magazine published a big photo spread of astronauts in survival training and the next thing you knew, we were on a survival campout in homemade tents of thin plastic sheeting. Naturally, the sky opened up on us and we found ourselves in ankle deep mud wrapped in our tents and reflective survival blankets.

At least some of us did.

During the stormy night a few of our adult "leaders" extracted their sons from the quagmire and relocated them to regular tents or cabins. My old man, a World War II veteran, viewed the camp-out as a "character building" exercise and left his sons to sleep in the muck. In fact, he gave up his bunk in a cabin to join us in a plastic tent of his own construction that held up about as well as the kid-built ones. The "mudders" lost trust in the adult leaders who pulled their sons out of the mess and left them to get soaked. They respected my father for joining them. I know this because 25 years later they told me so at his funeral. Grown men remembered that soggy adventure like it was yesterday.

I have had the opportunity to work for both types of bosses over the years, and believe the first building block of a good leader is commitment. People want to know the boss is willing to sleep in the muck with them if that is what the mission requires. Giving the "team" an extensive task list for the weekend before leaving early on Friday simply doesn't work. Involvement is much different than commitment. A chicken is involved in a ham and egg breakfast. A pig is committed to it.

Charles D. Schultz

Chuck's favorite picture of his Dad — Vincent David Schultz, U.S. Navy Seaman 1st Class — taken April 10, 1946 — his 21st birthday. His rite-of-passage was no party, however. Rather, here he is topside off Bikini Atoll awaiting the "A Bomb Tests" while trying to rack up enough "combat points" to earn passage home, which he did, later that year.

Klüber Lubrication

INTRODUCES LATEST LUBRICANTS

Klüber Lubrication, a worldwide manufacturer of specialty lubricants, has introduced Isoflex Topas NB 52 and Isoflex Topas NB 152, two rolling and plain bearing greases based on a synthetic hydrocarbon oil and a barium complex soap. The products are suited for amusement industry applications, such as roller coaster wheel bearings, in order to optimize operational reliability, cut servicing costs, conserve energy and extend maintenance intervals.

The special barium-soap thickener used in the Isoflex Topas NB 52 and 152 greases offers good load-carrying capacity, as well as resistance to water and ambient media. Both products protect against corrosion, as well as oxidation and ageing. Isoflex Topas NB 52 is suitable for temperatures ranging

from –60°F to 250°F and short peak temperatures up to 300°F depending on the application. Isoflex Topas NB 152 can be used in a wide service temperature range of –40°F to 300°F.

Isoflex Topas NB 52 is a versatile grease for many applications, including rolling and plain bearings subject to high speeds, high loads or low temperatures; tooth flanks in precision gears, such as bevel gears in milling machines and electromechanical actuators for valves; and for electric contacts and components to reduce insertion forces. Isoflex Topas NB 152 is compatible with many plastics and is used primarily for medium speed rolling and plain bearings, such as coaster wheels, wheel bearings in racing cars, fan bearings and pump bearings. The grease is also suitable for plastic/plastic or steel/plastic friction points.

"Using Isoflex Topas NB 52 and Isoflex Topas NB 152 greases leads to more consistent torque over a wide temperature range as well as longer component life when exposed to water or aqueous media," said Stephen Mazzola, director of engineering and technical services for Klüber Lubrication North America L.P.

For more information:
Klüber Lubrication North America L.P.
Phone: (603) 647-4104
www.klueber.com

Gehring

INTRODUCES MODULAR HONING MACHINE LINE

Gehring has introduced a new line of modular honing machines for precision metal components. These modular standard machines offer a systematic approach that is advantageous in establishing a highly efficient manufacturing process. Integrating the technologies of the Gehring Group into these new modular product standards, the Lifehone and Powertrainhone made their debut at IMTS 2014 in Chicago.

Small bore diameters often place demands on the production technology different than large ones. Due to customer requests and feedback from the market, Gehring showcased the new Lifehone machine with market proven components in a modular design. This new machine with inner column construction combines modern design with optimized accessibility. The rotary table is placed around the inner column for a quick access to the process stations, a good overview and a quick and easy changeover.

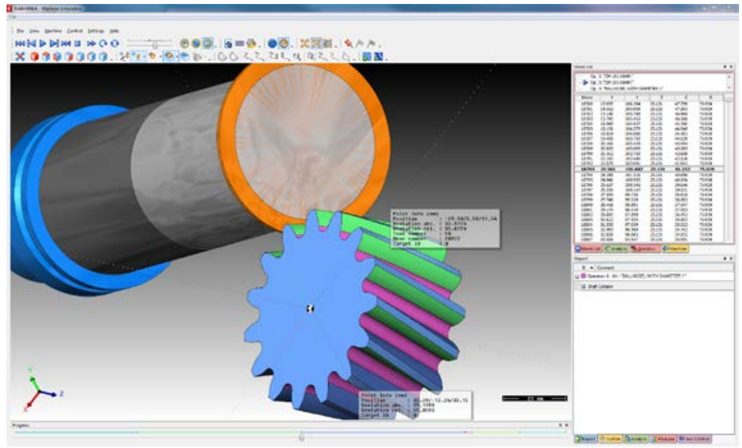
Alternatively equipped with a six- or eight-sided inner column, users can fix up to seven honing spindles. With this, Gehring can assure short cycle times and multistep processes. Pre- and post-gauging stations are fixed on the opposite side to optimize the interior space the best way possible. The compact design offers a low space requirement. The Gehring Operator Panel can be led around the machine so that it is easily visible from any location, thus ensuring optimum flexibility and ease of use.

All of the Lifehone machines are characterized by ease of use and high performance. The Lifehone can be constructed as a multi-spindle transfer solution for mass production, or as a single-spindle design for small production batches as well. The Powertrainhone is also part of a new machine generation with a unique modular concept. The innovative modular design system is comprised of standardized functional components which can be combined with tailor-made honing centers. This configuration enables new freedom and flexibility in production compared to modern hone systems with a conventional layout.

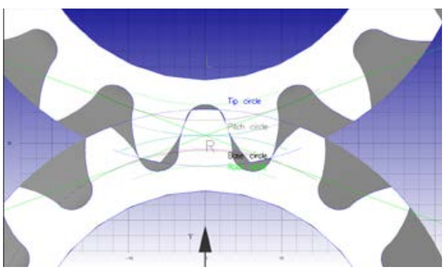
For more information:
Gehring
Phone: (248) 427-3901
www.gehring.de

Sandvik Coromant

INTRODUCES INVOMILLING 1.0



Sandvik Coromant introduced InvoMilling 1.0, a system for the flexible manufacturing of gears and splines on universal five-axis machining centers, during IMTS in Chicago. The InvoMilling solution consists of software supported by dedicated milling cutters as well as expertise from the Sandvik Coromant gear application team. With the CAM software InvoMilling 1.0, the CNC program is generated to produce different gear profiles with a limited range of standard-stocked precision tools. The solution has proven to be effective for manufacturing of gears and splines with great flexibility and high quality.

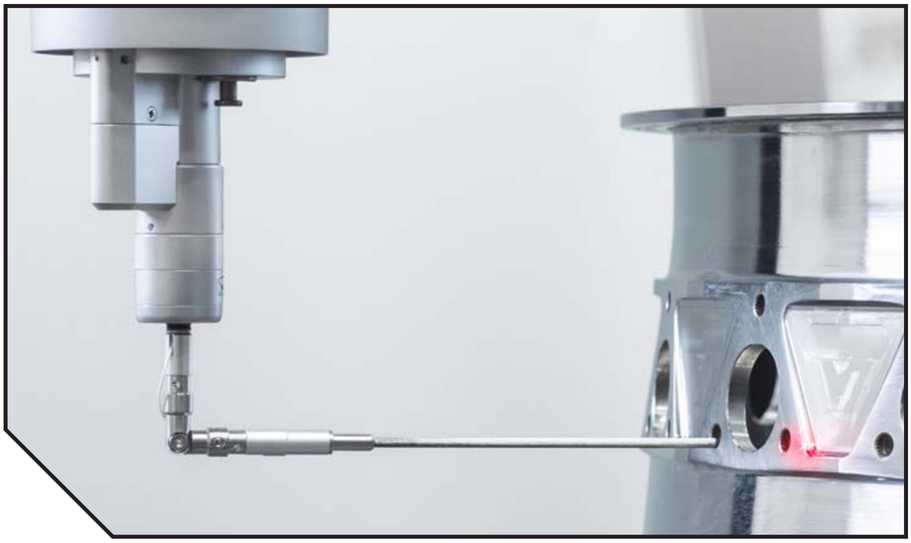


The InvoMilling software is user friendly with excellent graphics, milling path generation and simulation functionality. It is developed by Sandvik Coromant and Euklid, a company with expert competence in gears and advanced CAD/CAM solutions. Combined with the dedicated InvoMilling cutters CoroMill 161 and CoroMill 162, the new software offers exceptionally short lead-times for production of a very wide variety of gears and splines. InvoMilling is a suitable solution when machining small- and medium-sized batches and when short lead times are a priority.

For more information:
Sandvik Coromant
Phone: (800) 726-3845
www.sandvik.coromant.com

Hexagon Metrology

OFFERS HP-O NON-CONTACT SCANNING PROBE



Hexagon Metrology has announced the release of the HP-O non-contact scanning probe for high accuracy measurement and inspection applications. The non-contact probe is an alternative to conventional tactile analog measurement and scanning probes. The device exerts no physical impact on a part, delivering force-free measurement of blisks, blades, gear profiles and flank lines, and other potentially deformable parts, without a loss of accuracy. The HP-O probe's 3 mm diameter and measurement range of up to 20 mm provide access to points that are not accessible to tactile probes. Optical measurements can be captured in single point or scanning mode.

The HP-O probe delivers superior repeatability of under 0.3 μm when used with the Leitz PMM-C coordinate measuring machine (CMM) from Hexagon Metrology. Utilized for ultra-high accuracy inspections, HP-O's scanning technology can be used to inspect metallic or sensitive part surfaces with mirror-like or polished finishes, eliminating the need to spray a part's surface. With an acceptance angle of ±30 degrees, the probe can measure difficult-to-access features at a scanning speed of 1,000 points per second for rapid throughput.

"The accuracy and reliability of the new optical measurement solution are comparable to tactile scanning probes without their drawbacks," said Ingo Lindner, product line manager at Hexagon Metrology. "The HP-O probe is compatible with existing part programs and has flexible configurations to facilitate inspections of even the most complex parts."

The HP-O's scanning technology is not affected by ambient light, and is based on frequency-modulated, interferometric optical distance measurement. The probe's dense data acquisition does not suffer from degradation at higher speeds. The HP-O's high throughput capability renders it ideal for scanning large parts and parts that are rotationally symmetric. It is multi-sensor compatible in a single part program using a standard tool changer.

For more information:
Hexagon Metrology
Phone: (847) 931-0100
www.hexagonmetrology.us

Sunnen

OFFERS HTA SERIES TUBE HONE

The HTA Series tube hone offers increased part capacity and stroker torque for bore resurfacing of hydraulic actuators, extruder barrels and die casting shot tubes, or manufacture of gas flow meter tubes. Standard models are available for parts from 6.5 ft. (2 m) to 32.8 ft. (10 m) in length, sized in 6.5 ft. (2 m) length increments. All models handle parts with bore ID of 2.5 to 21 inches (63.5-533 mm), maximum OD of 24 inches (610 mm), and weights to 8,000 pounds (3628.7 kg). The HTA can also be custom-configured for part lengths up to 65.6 ft. (20 m), or with a powered section only for unhindered part lengths. Stroker torque capability has been increased by 35 percent over the previous HTA model via a heavy-duty stroker drive gearbox. Width of the steel-impregnated polyurethane belt has been increased from 0.9 inches to 1.9 inches (22 mm to 50 mm), providing a 20:1 safety factor.

The HTA hone is suited for resurfacing and repair work where light-duty stock removal up to 0.030 inches (0.76 mm) is needed to oversize deeply scratched bores.

An electronically controlled, 3-hp (2.24 kW), AC gear motor powers the spindle at 20-300 rpm, while the servo-driven stroking system has a speed range of 5-90 ft/min (1.52-27.4 m/min). The all-electric machine eliminates the noise, leaks, valve adjustments and performance variability inherent to hydraulic systems.

The HTA Series includes high-end features, such as Siemens drives and PLC-control with touch-screen HMI for setting all machine parameters.

For more information:
Sunnen Products Company
Phone: (314) 781-2100
www.sunnen.com

Mitutoyo

INTRODUCES QM-HEIGHT DIGITAL GAGES

Mitutoyo's next generation QM-Height digital height gage line offers accuracy of 4.5 μm and significant improvements in design and capability to previous generation QM-Height gages. High accuracy/high resolution Mitutoyo Absolute linear encoders for position detection ensure precision and dependability. A large stationary display panel with user friendly icon control keys and GO/NG LED indicator improve user operability.

Enhanced measurement and memory capabilities in the new QM-Height allow the capture of complex dimensional data. Measurement capabilities include; height, as well as step, inside/outside widths, inside/outside diameters and circle pitch (height components), free-form surface maximum/minimum heights and displacement by scanning measurement. The QM-Height remembers the preceding measurement (height component) and can display the difference (pitch) between results below the measurement.

Two new models in the QM-Height line offer a pneumatic flotation system and an ergonomic positioning grip allowing the base of the gage to rise and smoothly move along surface plate for easy positioning.

All new QM-Height models offer long battery life with standard AA batteries (4) — Up to 300 hours (80 hours with regular use of pneumatic flotation function). QM-Height packages include an AC power adapter for uninterrupted use. All new models are fully compatible with existing Mitutoyo Digimatic peripherals. Output options include Mitutoyo Digimatic and USB. Wireless output is also possible using Mitutoyo's U-WAVE wireless communication system.

For more information:
Mitutoyo America Corporation
Phone: (888) 648-8869
www.mitutoyo.com

Cimcool Fluid Technology

INTRODUCES INSOL LUBRICATION

Cimcool Fluid Technology is pleased to introduce InSol lubrication. This new technology coupled with unique surfactants and inhibitors provides excellent multi-metal performance without the use of extreme pressure additives. Productivity gains up to 20% have been observed when compared to chlorinated lubricants, and the technology works on both machining and grinding operations.

"InSol Technology puts lubricant at the cut zone-tooling interface so the lubricant and cooling are optimized. Since InSol Technology works though controlled water solubility, this great performance lasts longer due to low depletion rates. Best of all, InSol Technology can help out on tough to process alloys without using materials that can drive waste hauling costs up," states Bruce Koehler, product manager, Cimcool Fluid Technology. "When you couple that with process savings, lower tooling usage and more productivity output, this is what manufacturers need to help control costs and improve efficiency."

What is InSol Technology? The performance is dependent upon blends of raw materials that have solubility ranges from limited to complete. By carefully optimizing the selected materials, that puts nearly 100% lubricant at the cut zone where it counts. But because the material is mostly water soluble, it virtually never depletes when regular makeup concentrate is added. "The reason these new products are so special is that we have seen grinding ratios increase by 50% and cutting forces decrease by 30% or more; both of which drive productivity and cost savings for our customers. Imagine using a fluid that virtually looks like water that can increase your productivity so significantly. We are using this technology in our new high-performance fluids for aerospace and medical device applications as well as high-performance parts made from hard metal alloys including titanium. This technology will be available in our Cimtech 300 series as well as our new Cimtech 600 series which combines our MSL (Milacron Synthetic Lubricant) patented lubricants and InSol Technology for even more performance," said Koehler.

For more information:
Cimcool Fluid Technology
Phone: (888) 246-2665
www.cimcool.com

Birchwood Technologies

RELEASES SAFE SCRUB ST

Safe Scrub ST Heavy-Duty Cleaner easily removes oil and surface soils on metal parts. Safe Scrub ST is an effective biodegradable liquid cleaner that can be used on metal parts before or after processing. This liquid cleaner is used to emulsify oil from iron and steel parts, and then hold the oil residues in solution to prevent them from re-depositing on the parts.

Safe Scrub ST is an environmentally friendly choice because it contains biodegradable surfactants and no EPA regulated metals. Safe Scrub ST effectively removes these types of fluids: mineral oil, grinding coolant, drawing/stamping lubes, and hydraulic oils, as well as water soluble/synthetic fluids.

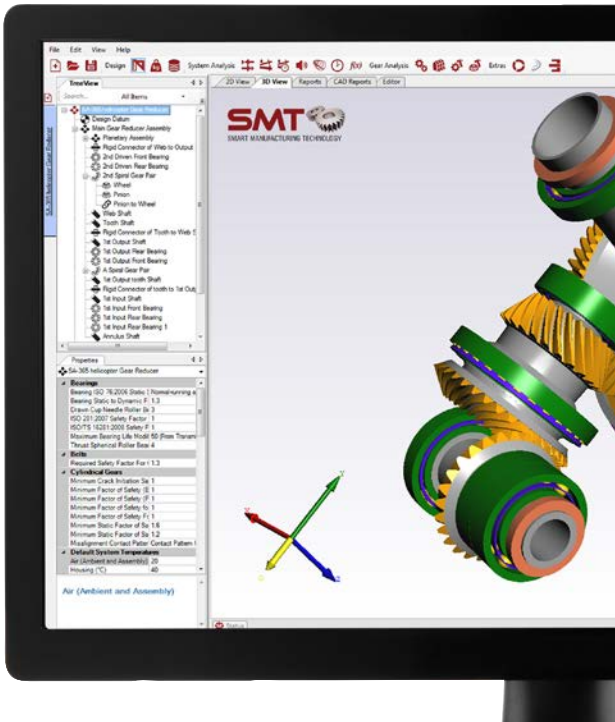
Supplied as a liquid concentrate, it can be used as stand-alone cleaner after metalworking operations or as a pre-cleaner prior to metal finishing operations such as black oxide coating or phosphating. Safe Scrub ST mixes easily with water and is designed for medium to heavy-duty soak tank cleaning of iron and steel parts. It operates at temperatures of 120 to 180°F, effectively lifting oil residues from the metal surface and holding them in suspension. When the solution is allowed to cool, much of the emulsified oil will float to the surface, allowing removal of the oil with an oil skimmer or coalescing filter and maximizing the working life of the Safe Scrub ST cleaning solution.

Safe Scrub ST's unique blend of detergents makes it free-rinsing in cold water, giving it the ability to produce water break-free surfaces that are receptive to subsequent coating and finishing operations. Safe Scrub ST is suitable for metal part cleaning and maintains a high level of cleaning power while minimizing the amount of product to do the job effectively.

For more information:
Birchwood Technologies
Phone: (952) 937-7931
www.birchwoodtechnologies.com

SMT

RELEASES MASTA SUITE 6



SMT (Smart Manufacturing Technology Ltd.) has released the latest edition of its drivetrain design and analysis software, *MASTA Suite 6*. Since its first release over 10 years ago, *MASTA* has been used to facilitate development and manufacture of transmission and driveline technologies.

MASTA Suite is package of drivetrain design, analysis and manufacturing simulation tools. With integrations to CAD, Gleason's *CAGE* and other third-party tools, it is designed to help engineers cut costs and time-to-market while enabling innovation.

This latest edition of the software was developed based on feedback from users over the years, and one of the primary goals was to give users greater control and a more ergonomic workflow. To accomplish this, the new version adds new zooming tools, scaling legends and additional tabs to make navigating and understanding the system easier. In addition, a customizable editor makes Load Case and Duty Cycle configuration precise and even faster

SMT has built the development of *MASTA Suite 6* around what the company refers to as its four Cs. Their goal is for the software to be comprehensive, concise, customizable and compatible.

Comprehensive – *MASTA Suite 6* includes access to a complete set of gear, shaft and bearing development and analysis tools.

Concise – With the software, engineers can accurately and rapidly calculate industry ratings based on full system inputs. Improvements to the user interface and workflow ensure that *MASTA* fits the engineer. This not only allows new users to learn the software quickly but seasoned users will also find efficiency enhancements to their development cycle.

Customizable – Results reporting is fully customizable in a report builder, allowing it to be flexibly tailored to the needs and brand of the client, including the creation and saving of templates to use again and share with others. The

software package is also more modular in design, allowing you to tailor your installation to your business's needs.

Compatible – *Masta Suite 6* is designed for ease in importing and converting from various 3D model file formats. Seamless integration with Gleason's *CAGE* software closes the development cycle for bevel gears, allowing designers to work within the constraints of machine calibrations. Furthermore, *MASTA Suite 6* is supported from Windows XP onwards and certified compatible for Windows 7, 8 and 8.1, allowing anyone with a license to share the same professional experience between different operating systems.

In addition, *MASTA Suite 6* introduces a number of new modules. Two new fluid film bearing modules allow for development of tilting pad thrust bearings and tilting pad journal bearings. Also, additional modules have been added for gear shaving. These include a new plunge shaver micro geometry analysis module and a module for simulating conventional shaver dynamics to ensure consistent shaving quality throughout the cutter's life.

The software's customizable reports have also been enhanced with additional features, including a style editor and custom templates that can be shared across an organization.

"*MASTA Suite 6* represents a great milestone for the company and is a testament to its success in markets worldwide." says Euan Woolley, technical director at SMT. "We've had phenomenal feedback from our users, so when working on this edition we really wanted to demonstrate they lay at the heart of its development."

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67-69 Hounds Gate,
Nottingham, NG1 6BB
United Kingdom
www.smartmt.com

Mazak

ADDS TURNING TO MACHINING CENTER FOR PROCESS INTEGRATION

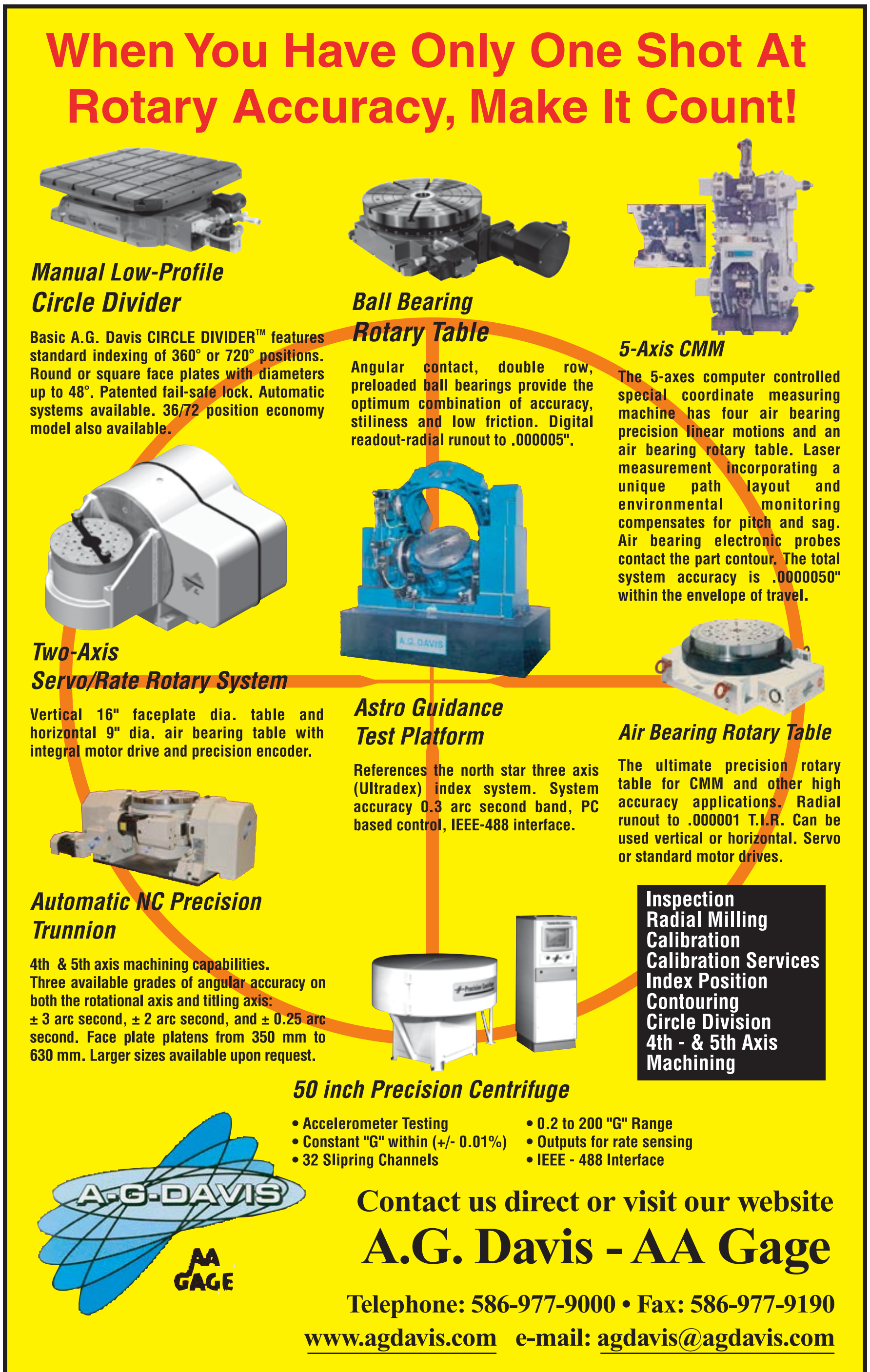
Mazak introduced turning capabilities into its VariAxis Series of multiple-surface, simultaneous five-axis machining centers with the VariAxis i-700T. An 18,000-rpm, 40-hp 40-taper spindle on the VariAxis i-700T features a compact nose design for better part access during side machining operations, where pallet interference might otherwise be a problem. A 30-tool automatic tool changer adds part processing flexibility and contributes to continuous non-interrupted machining operations.

With a Y-axis travel of 43.30" and X-axis of 23.62", the VariAxis i-700T easily accommodates workpieces measuring up to 28.74" in diameter and 19.69" high. Its roller gear cam-driven rotary/tilt table, with 360 degrees of rotation in the C-axis and +30 degrees through -120 degrees of tilt in the A-axis, is supported at both ends and provides stable high-accuracy five-axis machining.

The VariAxis i-700T sports the new Mazatrol SmoothX CNC that is a key element — along with new machine hardware and servo systems — of Mazak's Smooth Technology.

At IMTS, Mazak paired the VariAxis i-700T with an optional two-pallet changer to demonstrate how easy it is to achieve continuous part processing. This simple and efficient automation feature enhances productivity by allowing operators to load, unload and inspect a part on one pallet, while the machine continues to work on a part fixtured on the other pallet.

For more information:
Mazak Corporation
Phone: (847) 885-8311
www.mazakusa.com



Dillon Manufacturing

AIR CHUCKS PROVIDE MAXIMUM GRIPPING SURFACE

Dillon pin-location top jaws hold small and delicate parts — such as those often machined using air chucks - firmly without damaging or marring their surface. The jaws are milled with very close tolerances to correctly fit the chuck.

The jaws can be customized per customers' requests. Two types of jaws are offered, blank or (blocks) top jaws in 1018 steel or 6061 aluminum, or full circled or (pie shaped) top jaws in A356 aluminum, 6061 aluminum or 1018 steel as standard materials. Other materials per customer specification can also be used. They are ideal for all types of air chucks, including Northfield, Microcentric and more. Typically available with production lead times of 3 days or less

Dillon Manufacturing, Inc. manufactures a complete line of standard and custom workholding solutions including chuck jaws, chucks, vises jaws, soft jaws, hard jaws, collet pad jaw systems, chuck lubrication, and more. All products are made in the USA and Dillon is ISO 9000:2008 registered.

For more information:
Dillon Manufacturing, Inc.
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www.dillonmfg.com

Gear Manufacturer Benefits from CAM Initiatives and Advanced Manufacturing Technology

Multiple CAM initiatives at Snyder Industries are improving safety, quality and productivity for parts ranging from 50 to 5,000 lbs.

Turnaround is a big problem for many manufacturers today because customers in every industry want progressively faster deliveries of smaller part quantities without sacrificing quality or increased prices. This has been a particular challenge for Snyder Industries, Inc. because the parts they make are very large, ranging from 50 to 5,000 lbs. Enormous amounts of material are removed to arrive at the finished part. This can be time-consuming unless workflows and g processes are optimized for high productivity.

To overcome that challenge, over the last decade Snyder has replaced nearly all of its machining equipment with advanced multi-axis machining centers and CNC lathes with live tooling. The high spindle speeds, along with the ability to stage many different types of work for continuous production on pallet-based machining centers, has substantially improved the company's productivity and allowed it to simultaneously keep pace with the needs of a very diverse customer base. The company is actively working to continuously reduce costs and increase productivity by taking full advantage of all the capabilities offered by its CAM software (*Mastercam X6 Mill and Lathe* from CNC Software, Tolland, CT).

Rock Around the Clock

Snyder serves heavy industry, manufacturing a wide variety of cast and hardened steel components, including internal and external gears, planetary cages and wheel units, drive shafts, haulage sprockets, bearing carriers, couplings, and custom fabrications.

To shorten its manufacturing lead times, the company does almost all of the work in-house. For example, Snyder has a resident metallurgist, and the company operates several heat treatment and specialized metal treatment processes that may be required in the manufacture

Big gears, fast turns—Snyder Industries manufactures gears ranging in size from 50-5000 lbs. To reduce lead times the company replaced nearly all of its machining equipment with advanced multi-axis machining centers and CNC lathes with live tooling. The company is actively working to continuously reduce costs and increase productivity by taking full advantage of all the capabilities offered by its CAM software.

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CAM software
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of a finished part. These include quench and tempering, carburizing, induction hardening, gear hardening (utilizing the NATCO Intensifier method), shot peening, sandblasting and weld fabrication. According to Production Operations Manager Aaron Bruning, eliminating the lead time for external vendors of these services has slashed days, sometimes weeks, off quoted lead times that Snyder can offer to its customers.

The company operates two ten-hour shifts, five days a week. There are 36 CNC mills, lathes and machining centers. Two *Mastercam* programmers generate all of the programs needed to keep work running efficiently. Perhaps the greatest gains in productivity have come from increased reliance on two 20-pallet Mazak Integrex, multi-tasking centers. Bruning said, "Five years ago some parts might need six operations using six separate machines. Those same parts are now being manufactured in one operation on our multi-axis system. We can do all of our milling, turning, side holes and planetaries. We have really turned things around in terms of productivity."

However, Bruning is also convinced that there is much more to be achieved. "I don't think our best today will be our best tomorrow," he said. "Because we are constantly pushing after process improvements, our team keeps coming up with a better approach and a better product."

Multiple CAM Initiatives

With the recent purchase of new CNC Gleason and Fellows gear cutting machines, Snyder is doing almost everything on advanced CNC equipment, and the company is intent on taking advantage of the untapped capabilities of its CAM software to improve its manufacturing processes. Here are some of the initiatives that are underway:

On-Machine Inspection. One important area of improvement is the integration of in-process on-machine gaging into its processes. Bruning explained that setting up some of the larger parts it manufactures could take as much as ten hours. That setup has to be repeated when parts have to be taken off the machine for in-process gaging on a CMM. Increasingly, Snyder is building in-process gaging into both its setup procedures and its inspection routines. Probing during setup allows for a faster and more accurate orientation of the part with more precise tool offsets.

During manufacturing, spindle probe data delivered directly to the inspection software is used to generate reports just as if the part had been measured on a CMM. Some customers have already reviewed this inspection process and have granted Snyder permission to supply in-process results captured at the machine instead of a CMM for mandatory in-process inspections.

To integrate probing into CNC processes, programmers insert manually generated probing macros at predetermined intervals in the CAM program. One of the first things Synder intends to do as it transitions into *Mastercam X7* software is investigate the utility of generating probing macros semi-automatically using the new Productivity Plus probing module within the software.

Machine Simulation. Heavy equipment part designs are typically delivered to Snyder Industries as prints. One of the first things his company does is model everything in *Mastercam* — not just the part, but also the pallet setup and the machine itself. Being able to view a complete simulation of the part being manufactured gives the programmers confidence that the part can be manufactured at high speeds without encountering any interference.

While thorough machine simulation is essential for productive 5-axis milling, it is also highly useful for multi-axis turning as well. Bruning explained, "It really gives you an idea of where everything is going to fall. Is the part going to fit? Before it was a guessing game. Do we have enough travel? Do we have enough reach? Are we going to be high enough? That has helped out quite a bit."

While not all of the machines at Snyder have been modeled for machine simulation in *Mastercam*, it is one of the company's objectives.

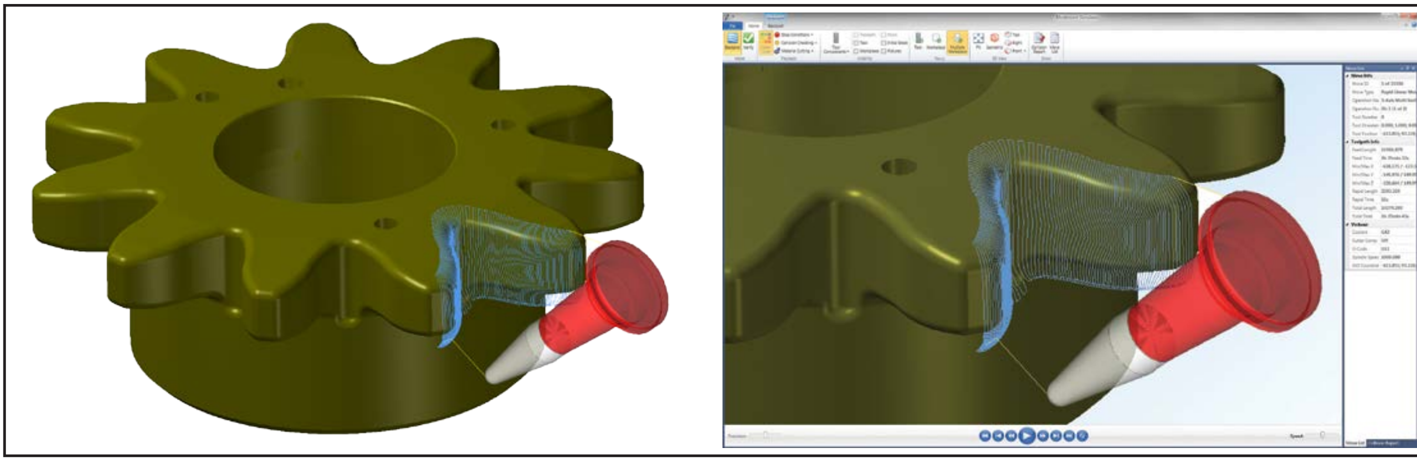
More Definitive Setup Sheets. Snyder Industries uses the graphical outputs from the software's machine simulation mode to generate setup sheets with images and text that leave no doubt how a given part is to be processed on the machine. For the tool room staff, these sheets clearly call out all the tools required, including lengths, diameters, etc., so there is no guesswork.

Bruning said, "The more information we put out there for the operator, the less time they spend trying to figure out how to run the part, or figure out the right tooling and fixtures. All of this cuts down on scrap and costs."

Bar Coding. Snyder Industries is now in the process of implementing a bar coding system that will allow users to automatically call up a program and tool room people to access carbide tools from a vending system simply by scanning the code. This system will further reduce the potential for human error at the machine and provide for more accurate management of tooling costs.

Advanced multi-axis lathe programming. The company has dramatically improved lathe productivity with the new multi-axis lathe programming capabilities introduced in *Mastercam X6*. Manufacturing Process Leader, Dan Szynkowski, said, "What took me five hours to write with a conventional lathe programming software, I can do in two hours now in *Mastercam*. And you have more confidence because you see it on the screen. We are doing multi-axis milling, surfacing, blending radii, dynamic milling, and OD threading, even polar milling. To be able to see it on the screen and to be able to trust it and send it out to the machine is just huge."

Material Aware Toolpaths. The last three versions of the software have introduced a succession of material-aware dynamic tool paths that operate at high speeds, minimal engagement and adjust feeds and speeds to avoid burying the tool in the material. These tool paths also reduce tool wear by using as much of the tool's flute as possible with every cut. Snyder has been applying these tool paths as often as possible for efficient blending of surface transitions, automated precision programming of radii,



Zooming in on dynamic tool motion using backplot simulation gives the programmer confidence that he can use *Mastercam*'s Dynamic Motion Technology to achieve high material removal rates without encountering interferences.

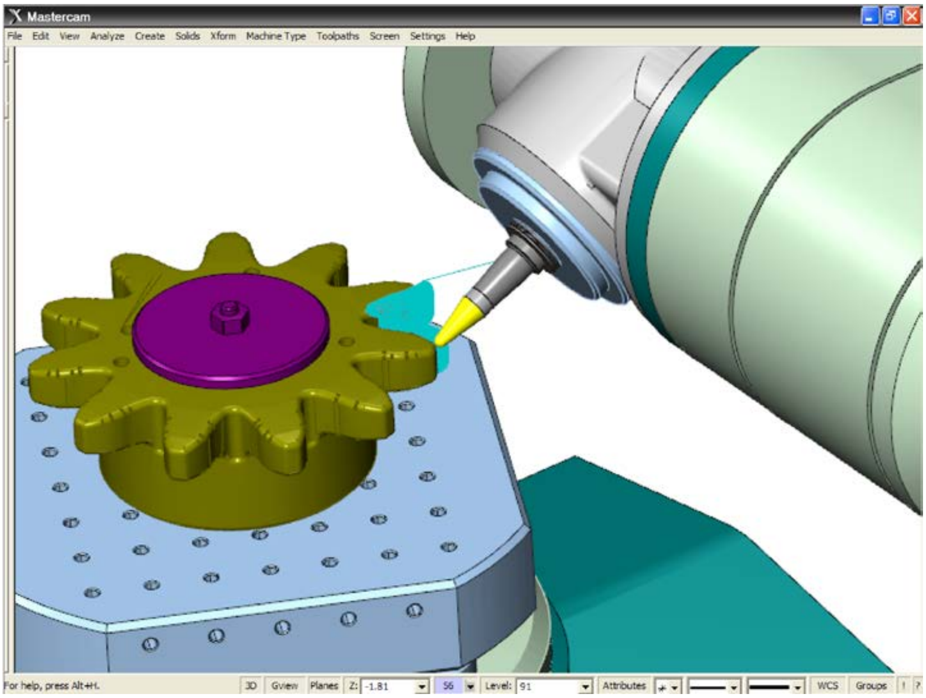
and hybrid roughing and finishing prior to sending parts for conventional gear cutting. In addition to improving part quality, reducing the need for secondary deburring operations and improving machining productivity, these tool paths have been extremely reliable, giving programmers great confidence in the programs they send out to the shop floor.

Safety. CAM initiatives at Snyder Industries improve safety, improve the working environment and reduce costs. The fewer times workers have to move or reposition parts because setups are not right or inspections can be performed on-machine, the less potential for accidents. As for burrs, said Bruning "Our programmers can go into areas where we have problems with sharp edges and blend them all. So there is less chance of cutting a strap or cutting a finger, or having customers send back parts because of burrs." CNC deburring also eliminates the cost of an expensive manual operation.

One Final Detail. The final step in manufacturing is to custom engrave the customer's label into the part. These high-resolution representations of each customer's identification can be quite intricate. Bruning believes the engraved ID label makes a visual statement about his company's attention to detail.

Snyder Industries began its transition to CNC equipment about six years ago. Today, the company is continuously engaged in a variety of CAM initiatives:

- On-machine probing for setup and inspection
- Machine simulation to improve unattended manufacturing confidence
- Setup sheets generated from CAM to improve setup accuracy and tool management effectiveness
- Bar coding for human error reduction
- Advanced multi-axis lathe programming
- Material aware toolpaths to improve quality and productivity
- Safety, which improves working conditions and reduces costs



Heavy equipment part designs are typically delivered to Snyder Industries as prints. One of the first things the company does is model everything in *Mastercam*—not just the part, but also the pallet setup and the machine itself.

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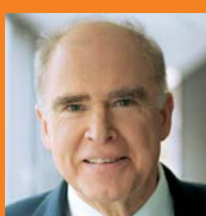
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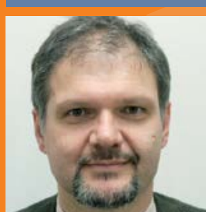
Enrico Sedoni

Panel discussion

How will the future drive system look like?


Prof. Dr Ferit Küçükay

Chairman of the CTI Symposium:
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Getting the Right Tools

Charles D. Schultz, Technical Editor

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***Gear Technology* readers work at many different companies, and no two readers have the same responsibilities.** So there is little chance that they need the same software to assist with their work. Gone are the days when companies wrote their own code and process engineers thumbed the same tattered reference book. Software vendors have been amongst the most loyal supporters of this publication and regular readers have no doubt seen their advertisements, product announcements, and occasional editorial contributions.

As a service to readers, we have put together this survey of commercially available software and offer a bit of guidance on how to select the right package for your needs. We have not "tested" all of the products mentioned, and urge readers to contact the vendors for trial versions before committing to a purchase. Features vary as widely as cost, so verify that the package you test has the calculations you need.

Gear software used to be home-grown because there just wasn't a big market for such specialized calculations. Each company tasked someone with "mechanizing" the complex and often confusing gear geometry, rating, and manufacturing procedures to save time, get consistent results, and avoid costly mistakes. I was one of those guys for several years; it was very stressful waiting for the inevitable "bugs" to show up. As soon as an equivalent commercial product was available we bought it.

The software we purchased was great for designing gearboxes and included a routine to evaluate lubricant effectiveness. It did nothing for our manufacturing engineer; no span measurement, no over pin measurement, and no quality tolerances were calculated. Manual calculations and, sometime later, spreadsheets, had to be developed and maintained to obtain these very necessary numbers. Our shop also had at least four brands of hobbing machines with vastly different change gear formulas besides those incredibly complicated bevel machines. I wouldn't want to attempt a bevel machine set-up with manually calculated numbers. Thankfully, the bevel machine builders were amongst first to offer dial up support services.

Another important aspect of commercial software is the availability of training classes for new users. Maintaining computer code is difficult enough; writing instructional material adds another level of complexity. Training will assist newer engineers in using the product as the supplier intended, while demonstrating features which may not be widely understood. It may also bring to light the use of non-standard nomenclature and hidden design rules within your organization. This problem cropped up the first time the American Gear Manufacturers Association (AGMA) offered training on its ISO 6336 software in 1997. Some rather experienced gear engineers got "schooled" in rack offset coefficients and their use of transverse tooth forms. These misunderstandings prevented them from learning the new program in the time allowed.

If your work is primarily the design of new products, your software needs are different from a co-worker who prepares shop routings or a consultant who studies gear failures. Many software packages are offered in modules so you can have the features you need without paying for things that will never be used. If you don't make bevels or worm gears, you omit those modules and save money. Others offer modules with "machine design" calculations such as key stress, bearing life, and shaft stresses. A growing trend links gear files directly to CAD modeling software such as *ProEngineer* and *SolidWorks*.

To assist you in finding the right software, we sent a list of questions to potential suppliers and tabulated their answers in the accompanying table. Here's what we asked them, along with a bit of background on why in fact the question was asked:

Does your software apply to spur, helical, internal, epicyclic, bevel, and worm gears?

Why buy a tool that you will never use? If your company never makes bevels or worms there is no value in having software to rate them. It is certainly possible to rate a planetary gearbox as individual meshes but a software package that looks at the entire system is a great time saver.

Does your software calculate ratings per AGMA? ISO? DIN? JIS? BS? API?

We live in a worldwide market and customers want to know how your products rate per the standards accepted in their industry. The ability to use the same input format and get multiple results saves time and aids in understanding the net results of the different rating methods.

Does your software consider lubrication (scuffing, scoring, wear, micropitting, flash temperature, specific sliding)?

Gears operate in a power transmission system. Gear proportions, geometry, tooth modifications, and surface finishes have an effect on lubrication requirements. A software package that can check on the lubricant selected will save time and money.

Does your software recommend rack offset coefficients?

There are many reasons why designers use non-standard, outside diameters. Also known as "long and short addendum," several theories are used to determine the optimum amount of "rack offset" for a specific set of gears. A program that shows the user the minimum offset to avoid undercut or the maximum offset to avoid pointed teeth is good; one that understands durability or strength optimization is better.

Does your software recognize different materials and heat treats?

Especially with international sourcing, the ability to compare ratings between different materials and heat treatments is important. The ease with which a program does this can greatly affect the designer's productivity. For manufacturers with unique material selections, it may be important that default settings can be changed.

Does your software allow for Miners' rule analysis?

Some applications involve varying loads, and speeds are best analyzed using Miner's Rule. If a software package doesn't handle this complex calculation the designer will have a lot of spreadsheet work to do.

Does your software calculate highest point of single tooth contact, lowest point of single tooth contact, form diameter, and tight mesh condition?

Profile modifications need start and top points. Gear grinders need to know what inspection limits apply. In some applications, tight backlash restrictions may affect center distance tolerances.

Does your software allow for high contact ratio (Mp>2.00) gearing?

Automotive and aerospace designs are increasingly using deeper than standard tooth forms yet some software won't run gearsets with the high contact ratio that results.

Does your software recommend crown and tip relief values?

Modern gear grinding machines can create almost any modification the designer can think of. But which modifications make the most sense? A program that recommends values based loading conditions would be appreciated.

Does your software calculate load distribution factors for complex modifications?

Load distribution factors (Cm) have a major influence on net gear rating. A variety of methods are in use to calculate load distribution factors—some of which require very complex analysis. Building this into the program and linking it to the tooth modifications would help determine the effectiveness of the modifications.

Does your software simulate actual tooth profiles?

The widespread use of 3-D software has made clients expect to see colorful "moving pictures" of new designs which require accurate tooth profiles.

Does your software export simulated tooth profiles to CAD programs or for use in EDM or water jet cutting?

Non-traditional manufacturing techniques like electro discharge milling and 3-D printing depend upon imported tooth profile coordinates.

Does your software calculate quality tolerances per AGMA A or Q levels?

Quality tolerancing systems have been revised a number of times in recent years and have sometimes gotten ahead of the inspection machines installed. A program with flexibility to provide values in both current and legacy standards is much appreciated.

Does your software calculate quality tolerances per ISO, DIN, JIS, or BS?

A worldwide market means worldwide sourcing and the quality standards of many organizations. Being able to calculate tolerances to a variety of standards is a plus.

Does your software calculate span measurements?

Calculating span measurements for highly modified gears is time consuming. Having it built into the software

Software Article								
Question	Vendor>	MITcalc	Dontyne	Excellent	Romax	KissSoft	AGMA	PowerGear
1	Spur	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Helical	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Internal	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Eppicyclic	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Bevel	Yes	Yes	Future	Yes	Yes	Diff.Program	No
	Worm	Yes	Yes	Future	Future	Yes	No	No
2	AGMA	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	ISO	Yes	Yes	Yes	Yes	Yes	Yes	No
	DIN	Yes	Yes	Yes	Yes	Yes	No	No
	JIS	Yes	No	No	Partial	No	No	No
	BS	Yes	Yes	No	Partial	No	No	No
	API	Yes	Yes	No	Partial	No	Yes	No
3	Lubrication	Partial	Yes	Yes	Yes	Yes	No	Yes
4	Rack Coeff	Yes	Yes	Yes	Yes	Yes	Yes	Yes
5	matl & HT	Yes	Yes	Yes	Yes	Yes	Yes	Yes
6	Miner's Rule	No	Yes	No	Yes	Yes	Yes	Yes
7	HPSTC, etc.	No	Yes	Yes	Yes	Yes	Yes	Yes
8	HCR OK?	No	Yes	No	Yes	Yes	No	Yes
9	Tooth Mods	No	Yes	Partial	Yes	Yes	No	Yes
10	Cm	Yes	Yes	Yes	Yes	Yes	No	Yes
11	Tooth Profiles?	Yes	Yes	No	Yes	Yes	Yes	Yes
12	Profile Export?	Yes	Yes	No	Yes	Yes	Yes	Yes
13	AGMA Tol?	No	Yes	Yes	No	Yes	Yes	Yes
14	Other Tol?	No	Yes	ISO, DIN	Partial	Yes	No	Yes
15	Span Measure?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
16	Ball or Pin?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Specify Pin Dia?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
17	PM Gears?	No	No	No	No	No	No	No
	Plastic Gears?	No	No	No	No	No	No	No
18	Geo Warnings?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
19	Warning Override?	Yes	Yes	Yes	Yes	Yes	No	Yes
20	Training Available?	No	Yes	Yes	Yes	Yes	Yes	Yes

reduces processing time and insures consistent results.

Does your software calculate pin or ball measurements? Can pin or ball diameters be specified?

Some gears are not suitable for span measurements and pin or ball measurements are needed. Then there is the question of just how many sizes of pins or balls have to be on hand. Good software and simplify this situation.

Does your software have an option for powdered metal or plastic materials?

Not everyone makes cut metal gears.

Does your software provide warnings for questionable geometry?

Some gear designs violate the design rules found in various reference books. It is good to be advised when this occurs.

Can the warnings be overridden?

Not everyone agrees with the design rules which are not built into actual rating standards. Some designers are not troubled by a slight amount of undercutting or narrow top lands. The "override" option is also important for failure analysis and reverse engineering.

What training is available?

Not all programs are user-friendly, or easy to understand. Good instruction manuals or a training class can speed implementation and insure accurate results.

These questions were sent to the software vendors and their answers are tabulated in the attached chart. You may have additional concerns and questions which are best discussed directly with the vendor. Run a few problem sets through the trial version and make sure you understand the features and options available. If moving from another software system it is important to compare results between the old and new methods. Don't be surprised at slight differences in span or over pin measurements, as methodologies vary. On rating calculations certain factors — such as I and J geometry factors — are greatly influenced by specific cutting tool inputs. What's more, programs use different default tool geometry, so you must make sure your calculations match your production parts. A factor-by-factor comparison is a worthwhile exercise until you develop confidence in the results.

In the end, having confidence in your calculations is the primary requirement for gear analysis software. All the colorful renderings and impressive graphs are useless if you worry about the backlash matching up with the span measurements. The software reviewed here has a wide variety of features and price points. Some vendors offer outright sales, others prefer renewable leases. All of them want to help you design, analyze, and manufacture gears in the shortest possible time.

For more information:

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Who's Afraid of Innovation?

Dr. Michael Platten, Romax Technology Ltd.

There are varying opinions as to what constitutes innovation, but in our industry and in the engineering world as a whole, we typically think of innovation as being the use of technologies different from those we use at the moment to do things better, faster and cheaper. Of course we all have design and manufacturing methods that improve with time, and we continue to make progress and do things better. But innovation is something more than that; it is out of our comfort zone. Put simply, innovation implies risk.

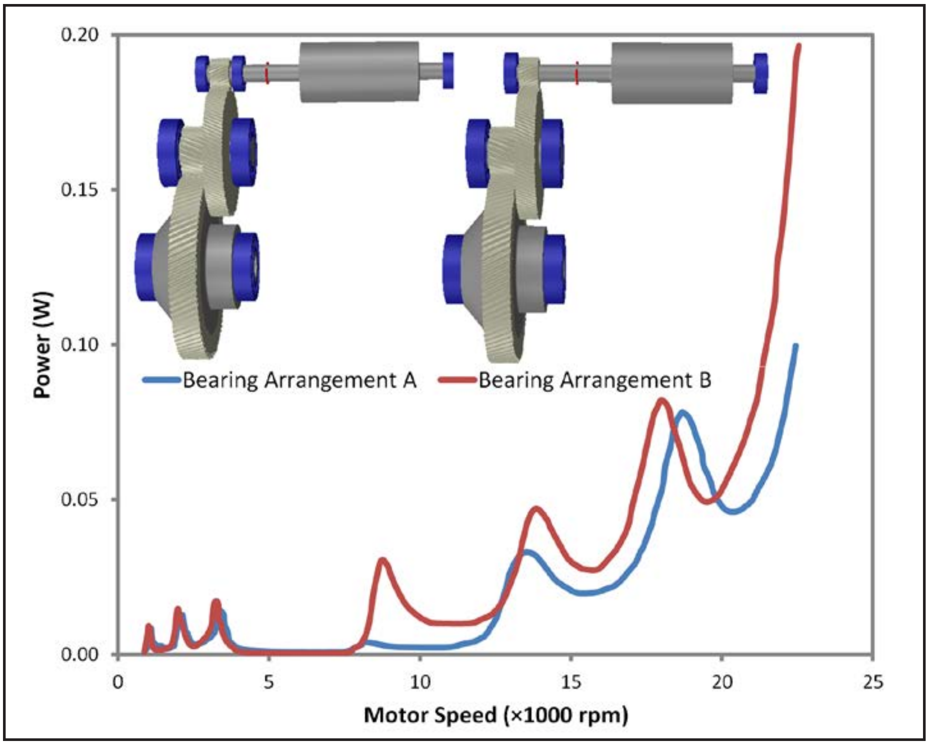

Figure 1 **Two competing bearing arrangements are compared for noise performance in the early *Concept* layout stage by estimating total potential bearing vibratory power. Option A is much better at high speeds, but requires an extra bearing which increases cost.**

Why Innovate?

There are three fundamental demands from an engineering perspective that drives us to innovate:

Demand from the customer for better performance at lower cost.

"Give me more for less" has always been and will continue to be the primary requirement from the customer. Performance of a design is measured by whether it meets certain targets and avoids failure modes, which are in turn determined by customer requirements. Inevitably, design targets will sometimes conflict. In the case of an automotive transmission, we may be looking at reducing weight while improving efficiency and noise without compromising durability. These requirements are interdependent, and if we are to be radical in our designs, we need to ensure that improving one thing does not break something else.

Demand for new technology either to keep up with the competition, to meet the challenges of legislation or sometimes just technology for technology's sake.

Experience and incremental improvement play a major role in the design of "conventional" drivelines, but new driveline concepts do not have this history of successes and failures behind them. Novel drivelines can have new kinds of failure modes or vastly different performance targets from conventional ones. In addition, new concepts are often heavily patented, and designers need to find ways to avoid infringements. This means that we as engineers must rely heavily on simulations that we can trust. We must also ensure that any knowledge gained is retained for the future.

Demand for reduced development time and cost.

These days, the mantra of the entire engineering world is cost reduction and faster time-to-market. Shorter, cheaper development means that more must be done in less time, so the design and analysis phases need to be streamlined and efficient. We must also consider that tooling lead times for items like gears and castings remain relatively long, so these designs must be finalized early.

To really make an impact on development cycle time, design problems need to be identified at the design phase rather than the prototyping phase to minimize prototype cycles. Of course, design problems are better (and more cheaply) solved in the design phase instead of taking remedial action later on — provided you have the CAE tools and associated development processes in place to do it. This "Right First Time" approach is critical to the management of innovation risk.

Mitigate the Risk

Many writers on innovation focus on the environment, freedom and organizational support needed to promote innovation. However, businesses still need to make money. This balance between the huge opportunities available to those who innovate and the risk (and it will happen sooner or later) of investing in something that never quite works is a constant worry. Even the aerospace industry — by nature one of the most conservative of development environments — is having to become considerably more adventurous in its engineering outlook for geared power systems to meet delivery targets that have been shortened literally by years and to comply with aggressive legislation on efficiency and noise.

The most fundamental way to mitigate innovation risk is to have a solid business plan against which new developments can be measured. Regular reviews of technological readiness must be performed and those that carry them out must have the power and the will to pull the plug when necessary.

In the end, though, it is people, not organizations, that innovate, and innovative people need to have a broad knowledge of the technologies around them. I defined innovation as "the use of different technologies from those that we use at the moment" not simply "the use of new technologies." Although original research is a part of the innovation package, engineers can make great leaps in development by taking successful technologies from other areas and applying them to their own problems — a much less risky approach.

My colleagues and I were recently called upon to help in the development of a locomotive electric drivetrain. The basic design had remained unchanged for more than forty years simply because it worked and there was no reason to do anything different. New legislation in environmental noise meant that major reductions in gearbox noise had to be made. We were quickly and successfully able to adapt our methods for gearbox noise simulation and experience in optimizing designs in the automotive world (where customer pressure and competition have demanded such improvements for a long time) to this new application.

Even when corporate inertia can be successfully overcome, innovators still need the right tools and methods to actually make innovation a viable business option. Development processes are defined largely by the available tools and methods. If all you have is a hammer, then everything starts to look like a nail; it is a cliché, but true nonetheless. As tools and methods develop, it is inevitable that design processes will also develop to make best use of them.

To grasp the opportunities of innovation, the engineer must first and foremost have the right tools available to quickly and confidently assess if there is any merit in a new idea, and the means by which this is achieved in practice is simulation.

The Innovator's Toolbox

"Simulate early; simulate often" is the creed of the engineering innovator. The ability to weed out designs destined for failure through simulation is by far the most efficient way to win at the innovation game. However, there are some key principles of simulation that must be adhered to if our "Right First Time" philosophy is to be achieved. These principles cascade directly from the engineering demands and innovation challenges we have been discussing.

Fast to build; fast to solve

To simulate early and often you need to be able to get ideas from brain to computer as smoothly as possible and run simulations fast. You want to be able to identify if an idea is a go or no-go with the minimum of investment. If you are comparing many different competing concepts, time is just as important. Models must be quick to edit and update

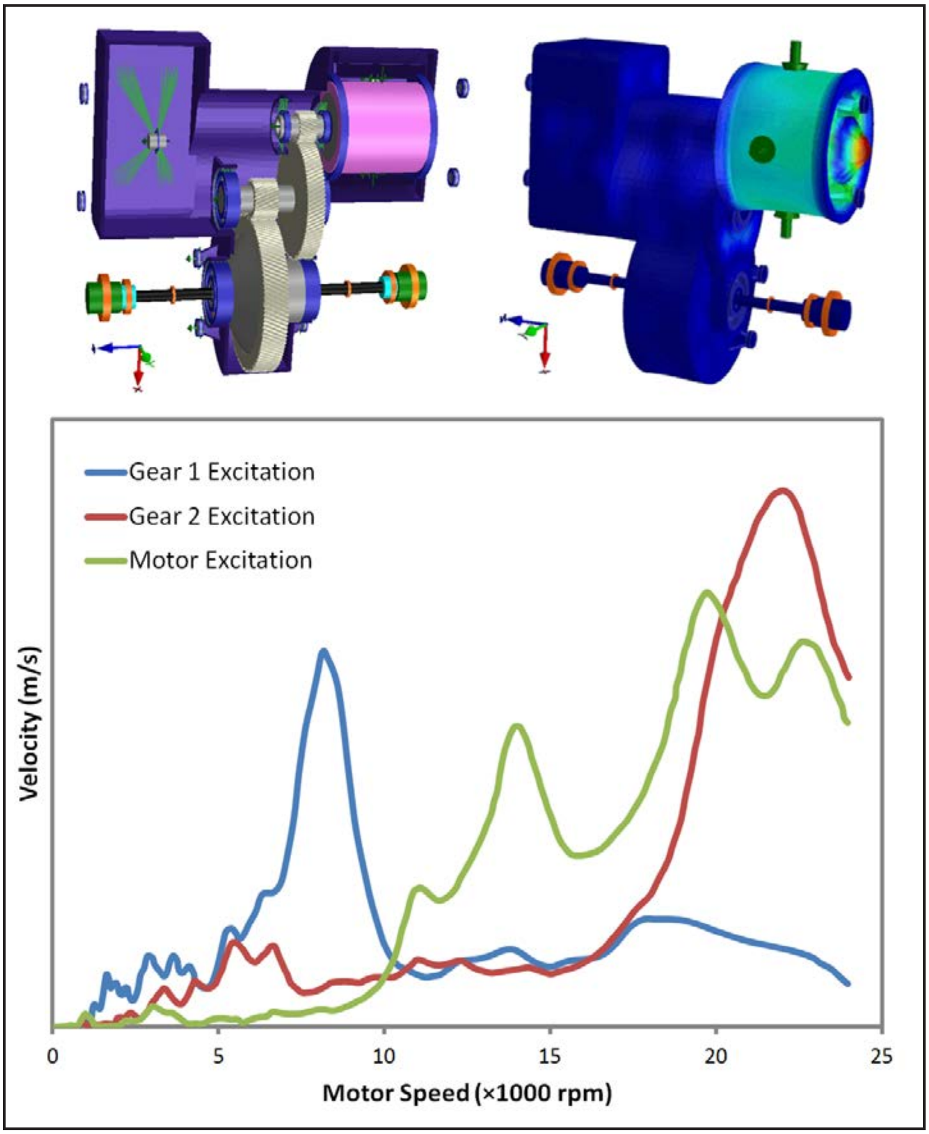

Figure 2 **Internal details of the gearbox are finalized, but the housing is only a simple representation. Average housing vibration responses from different excitation sources have been calculated and a potentially problematic mode shape of the complete driveline has been identified.**

as well if you want to do "what-if" studies, explore more of the design space or re-simulate as the design evolves.

Right model at the right time

We want our simulations to be as accurate as necessary, not as precise as possible. There is no point building a detailed model or using a complex analysis method at an early stage in the process. Use simple models and methods early on; then move to more clever simulations when more detail about the design is available. Just because a simple model gives approximate results does not mean it is useless, especially when you are benchmarking multiple design candidates; a detailed simulation when there is so much uncertainty in the design wastes time and yields false precision.

One model for many purposes

The ability to use the same model to investigate many different performance criteria means that you only have to build the model once. The models that we create at Romax are based on a description of the transmission system from which we derive different mathematical models for investigating cost, durability, efficiency and dynamic performance. When the design changes, you only have to update the appropriate parameters in the system description and all of these targets can be re-assessed in minutes.

Give engineering insight.

Finally, we want our tools and methods to give engineering answers to engineering questions. Where possible the simulation tools used should not just give us reams of numbers; they should also give the engineer an idea of what to do next. The huge quantities of information CAE simulations produce need processing tools to help us explore the data, reduce it into manageable and meaningful reports and highlight problem areas. A simulation may tell me that the stress at point *x* is *y* but what does this actually mean? How does it relate to the targets that affect whether a customer will buy the transmission that I am developing?

ODIN-Romax in Action

ODIN (Optimised electric Driveline by Integration) is an EU-funded consortium whose aim is to develop new methodologies for the design of an innovative electric vehicle drivetrain. Romax's role in the consortium is to deliver the CAE tools and methods for the analysis of the complete system and to use them to influence the design process from beginning to end to deliver a product which is "Right First Time."

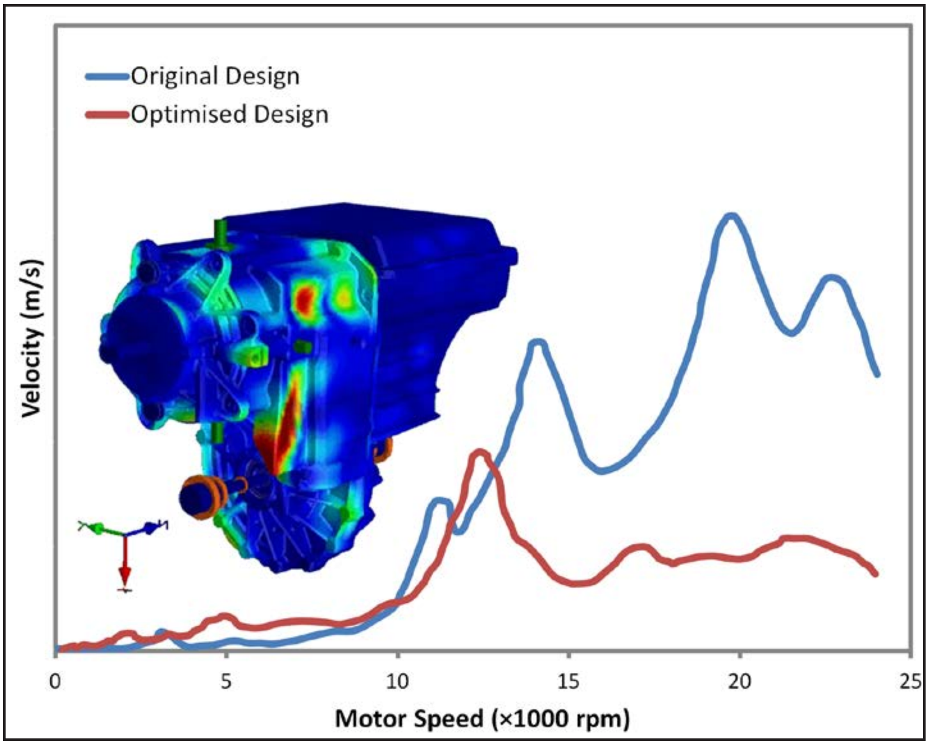

Figure 3 The detailed housing has now been defined. Quantitative predictions of housing vibration have been calculated and used to optimise the housing design. A significant vibration reduction has been achieved, giving confidence that all major problems have been avoided prior to prototyping.

Concept selection

The first phase of the project was to identify the most promising of many proposed basic concepts based on key targets focused primarily on cost and dynamic performance. Romax's *Concept* software was used to rapidly iterate through all the proposed layouts to narrow down the field. Traditionally, predicting noise and vibration performance is considered to only be feasible once a detailed design is finalized. By using very simple models and simple metrics, the concept layouts could be benchmarked to identify those with the best chance of having good noise performance.

Concept development

At a later stage in the concept development phase, Romax was able to use *RomaxDesigner* (A CAE tool for the detailed simulation and analysis of transmissions for durability, efficiency and dynamics) to compare two different layouts for the assembly of the combined motor, transmission and control system. Here, the housing design had not yet been finalized, but a simplified housing was used to identify the best arrangement and to highlight areas which had the potential for problem vibrations. This information was used to guide the detailed design of the housing.

Detailed design

With the first detailed design of the housing in place and all internal gear, shaft and bearing and motor details finalized, it was then possible to simulate the first quantitative predictions of noise and vibration caused by gear and motor forces. Again problems were identified and ways to adjust the design were identified and applied.

Next steps

The next stage of the project, which is currently in progress, is to prototype the design and test its performance against the original design targets in a real electric vehicle. By using simulation of noise and vibration to lead the design right from the start, an innovative concept with the best chance of success has been selected, and potential problems have been identified and remedial action taken to avoid them long before the detailed design was finalized. Finally the detailed simulation of the final design has predicted that the targets will be met before any metal has been cut. Of course there may be further challenges to overcome once the prototype has been tested, but the risk of a significant problem derailing the project has been vastly reduced by applying CAE tools which comply with the principles of innovative software outlined in this article and by simulating early and simulating often to give the best chance of getting it "Right First Time."

Facing Your Fears

Hopefully you have seen that innovation is nothing to be scared of. Yes, there are organizational challenges and there may be resistance to making changes to the old ways of working, but there is no magic to it. It just requires careful planning and continual monitoring of risk. Central to this risk management are the CAE tools and methods which allow us to quantify that risk through the assessment of design performance.

Romax engineers have made many innovative advances in transmission and driveline engineering over the last 25 years by applying these principles to the creation of CAE tools that we and others use to design and optimize across all engineering sectors. In four years we were able to reduce the time taken to design wind turbine drivetrains by 70%. With over 30 certified designs — more than any other organization — we continue to be radicals in a conservative world and are all the more successful for it.

Visit *www.fp7-odin.eu* for more information on the ODIN project.

Dr. Michael Platten is a noise and vibration specialist with 20 years of experience. For the last eight years he has worked in the dynamics of transmissions and drivelines and as a Product Manager he is responsible for all noise, vibration and dynamics software at Romax Technology.

Simulate Early to Speed the Design Process

Interview with Andy Poon, CEO, Romax Technology

Randy Stott, Managing Editor

Romax Technology would like to change the way simulation software is used by the design community. According to company CEO Andy Poon, using software to simulate mechanical systems earlier in the design process gets engineers to better designs, faster.

"A lot of simulation companies focus solely on the accuracy of their simulations," Poon says, adding that although accuracy of simulation is something Romax is well known for, "we're much more interested in how simulation can better inform the design process."

Romax has been developing simulation software for 25 years. Over that time, the company has engaged in consulting work with engineers responsible for developing automobile transmissions, wind turbines and aerospace drives, among other things. Many of the features of their software have come out of that consulting experience, allowing Romax to continually increase the accuracy and detail that go into their simulation software.

A significant amount of their work has been in the automotive industry, where a lot has changed over the last decade, Poon says. Not only do automakers have to contend with demands for increased efficiency, reduced weight and reduced noise, they also have to deal with an increasing variety in the types of transmissions available, from increased speeds in automatic transmissions to hybrid-electric drivetrains and more. All of those options and demands have made the engineer's job much harder, Poon says.

"Simulation earlier in the design process is the key to producing the most accurate and best designs," Poon says.

Dynamic Fusion software from Romax uses dynamic multibody dynamic modeling to help engineers model and optimize transmissions quickly. Unlike traditional simulation software, which could take days to generate a single model, *Dynamic Fusion* is optimized to generate models in minutes. This allows it to be used much earlier in the design process, Poon says. Also, it can be tailored to tackle very specific design issues, such as gear rattle or driveline shunt.

But the real power of using simulation early in the process, Poon says, is that it can help engineers quickly determine whether their initial designs have any problem characteristics, and it can help them focus on the issues that are of most importance, such as noise or efficiency. Early simulations also help designers better evaluate the trade-offs that come with design choices.

"Simulations that take days and days to run are of limited use in design," Poon says. "You need to be able to compare the different trade-offs."

Part of Romax's mission is educational, Poon says. "Where we're most successful is when the client is open to talk about their design process. Simulation *can* be just a glorified calculator, but it's far more powerful when integrated into an overall design philosophy."

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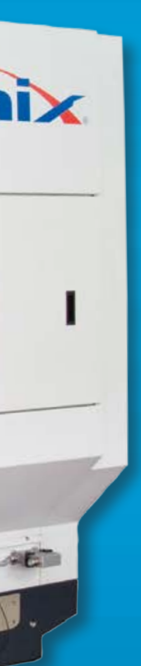

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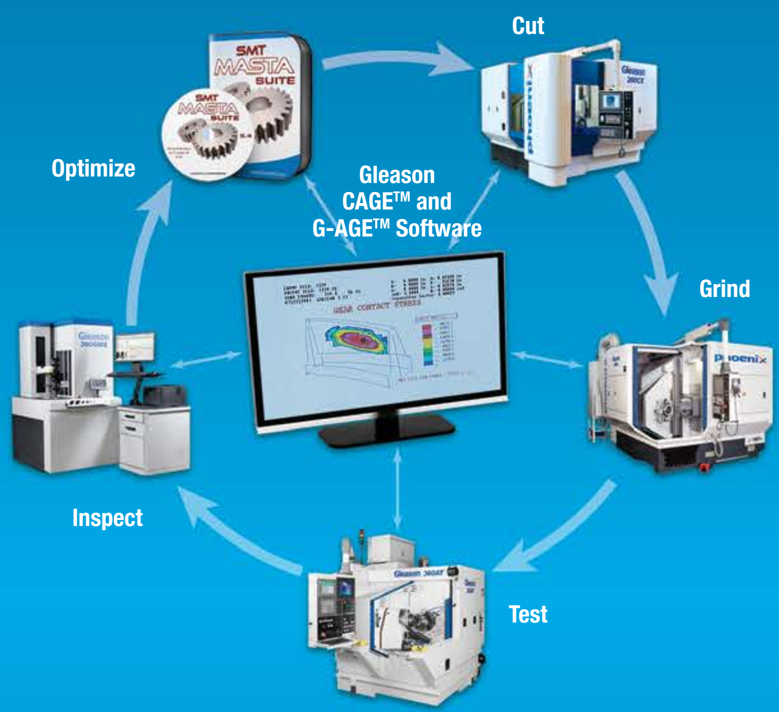

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QUESTION

I must confess I sometimes find myself a bit dazed when discussing lubrication issues with either staff or vendors. The terminology seems to be all over the lot, with some terms having double meanings. Can you help cut through the confusion?

Expert answer provided by Robert Errichello, Geartech, Inc. ***(geartech@mt.net)***

The following "primer" on tribology nomenclature should help to clear the fog. It is an article by Douglas Godfrey that was published in the STLE magazine, *Lubrication Engineering*. And while it was first published in 1989, I believe in this case what was true then, holds true 25 years later.

TRIBOLOGY NOMENCLATURE

Discontinue use of "Extreme Pressure (EP);"Use "Antiscuff"

EP lubricants generally contain chemically active additives that coat or react with metal surfaces to form films that prevent scuffing. However, the term "EP" is not appropriate; some explain the term by saying it really means extreme temperature. Occasionally we see the ridiculous and self-contradictory term "mild, extreme pressure." High contact pressures are not always necessary to cause scuffing, nor is scuffing expected to occur under high contact pressures if metallurgy and lubricant choices are ideal. On the other hand, extreme pressures — such as 300,000 psi — exist in elastohydrodynamic lubrication where no controlling chemical reaction occurs. Antiscuff is my recommendation, which is based on function, rather than a particular mechanism or condition. Thus the definition could be simple: "An antiscuff lubricant is one that inhibits scuffing." This definition will help reduce the frequent confusion about the difference in EP and antiwear lubricants. The term parallels antiwear, which is a lubricant that reduces wear.

Discontinue "Film Strength"

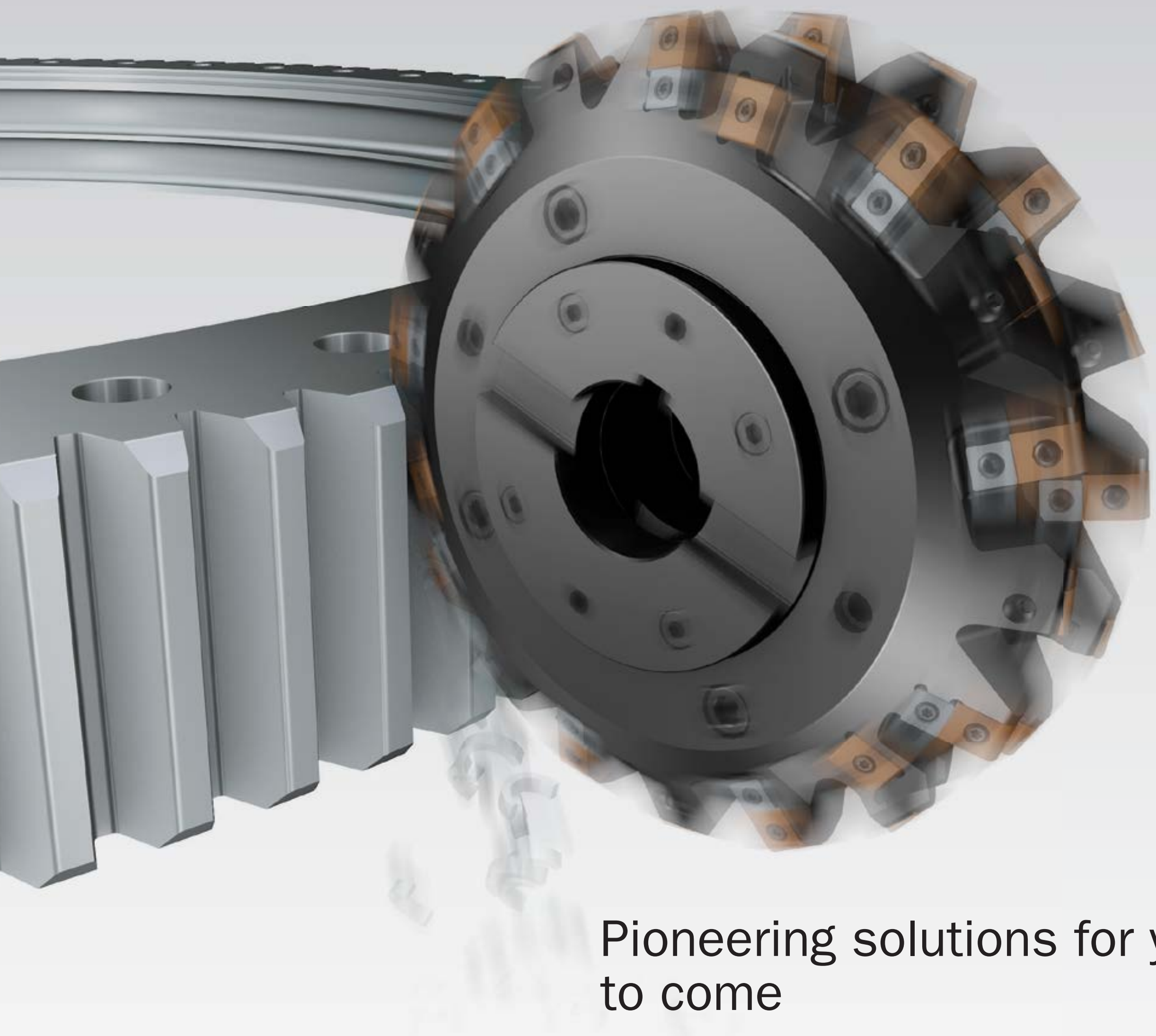
Years ago I used the term "film strength," but now I recommend against using it. A lubricant film may be "strong," but the meaning is not clear. Modern research shows that the important parameter of an oil film is its thickness in relation to the roughnesses of the rolling or sliding surfaces – i.e., the lambda factor. Also, the important properties of an antiscuff or antiwear solid surface film are physical; e.g., melting point, thickness, and hardness in relation to the metal underneath, shear strength, and tenacity.

Discontinue use of "Oiliness" and "Friction Modifier;" Use "Lubricity"

The term oiliness is extremely vague and does not even suggest the intended meaning of low friction or lubricity. Medicinal white oil is oily but a very poor boundary lubricant. So if one means that the oil has natural or synthetic friction-reducing properties, the term lubricity should be used, which could be defined as that property of a lubricant that reduces friction. A lubricant with fatty acid additives has lubricity. The term "friction modifier" means literally that the oil decreases or increases friction. Of course a decrease or reduction is what is usually meant, so let's say what we mean and use "friction reducer."

Discontinue use of "Saybolt Universal Seconds (SUS);" Use Centistoke, cSt

SUS, or SSU, or "seconds" is a viscosity value from a particular apparatus, under particular conditions, and is obsolete and not an internationally acceptable expression of viscosity. The centistoke is a fundamental viscosity for kinematic viscosity. Centipoise cP is the accepted unit for dynamic viscosity. The International Standard Organization's Viscosity Grades, ISO VG, may be used. The number corresponds to kinematic viscosity in centistoke at 40°C.



Discontinue "Thick" or "Thin" and "Heavy" or "Light;" Use High or Low Viscosity

Thick and thin, although very commonly used, are dimensional measurements, so, their use for oil film thickness is proper. However, it is imprecise, and careless for tribologists to use them to describe lubricant viscosity. Heavy and light indicate weight, mass, or relative density. Since lubricant viscosities are essentially independent of density, the use of heavy and light for viscosity are misleading and incorrect. Molecular weight and boiling range are related to lubricant viscosity. Similarly, we should not use "weight" following SAE for oil grade. The proper terminology is "SAE Grade," not, for example "30 weight."

Discontinue "Dry" Lubricant;" Use Solid Lubricant

"Dry" suggests the absence of water and should not be used for solid lubricants. Graphite and many solid polymers are dependent upon a little oil or water for effective lubrication. In contrast, molybdenum disulfide works best in a dry environment or in a vacuum. In tribology, let's reserve "dry" to mean the absence or very low concentrations of water.

Discontinue "Anti-Friction" Bearings; Use Rolling Element Bearings

Once in a while an author uses the old-fashioned term "anti-friction" for rolling element bearings. The term "anti-friction" originated because the start-up friction of rolling element bearings was lower than for sliding bearings. But currently this difference is less important, due to hydrostatic bearings, low shear strength surface films, and lubricity additives for sliding bearings. The amount of pure sliding that occurs in rolling element bearings could cause high start-up friction under high loads. Sealed, grease-lubricated, rolling element bearings can have considerable friction or resistance to rotation.

Discontinue "Mechanical Wear/ Chemical Wear"

"Mechanical Wear" and "Chemical Wear" are often used as the only two wear mechanisms; but, in my opinion, these are much too general and interrelated to be useful. For example, wear apparently due to mechanical conditions, (such as high load), can actually be a result of chemical factors (such as the rate of oxide film formation). Conversely, wear involving chemical reaction (such as corrosive wear), can be highly dependent upon physical or mechanical properties of the corrosion product. I recommend being specific on the wear mechanism involved.

Discontinue "Scoring;" Use Scuffing

In the U.S. gear industry, scoring is often used interchangeably with scuffing. Scuffing is used exclusively elsewhere in the world. The word scoring suggests scratching by a hard sharp tool, which is abrasion. Scoring, for scuffing, causes confusion, especially outside the U.S., and should not be used. The term scuffing should be used to indicate the metal transfer, tearing, and local welding involved.

The above article by Douglas Godfrey *was published in* STLE *magazine* Lubrication Engineering, *December 1989, pp. 750-751. It is reproduced here with minor editorial changes, including the following*:

- Antiscuff is used instead of Anti-scuff
- Antiwear is used instead of Anti-wear
- Rolling Element Bearings is used instead of Roller Bearings

Robert L. Errichello possesses over 40 years of industrial and classroom experience; heads up his own gear consulting firm—GEARTECH; and developed his proprietary GEARTECH software. Bob has been a consultant to the gear industry for the past 35 years and to over 40 wind turbine manufacturers, purchasers, operators and researchers. He has taught courses in material science, fracture mechanics, vibration and machine design at San Francisco State University and the University of California, Berkeley. He's presented numerous seminars to professional societies, technical schools and the gear, bearing, and lubrication industries, and his AGMA Gear Failure Analysis seminar is sold out every session. In his "spare" time Bob is a member of several AGMA committees, including the AGMA Gear Rating Committee, AGMA Nomenclature Committee, AGMA/AWEA Wind Turbine Committee, ASM International, ASME Power Transmission and Gearing Committee, STLE, NREL GRC, and the Montana Society of Engineers. A prolific author, Bob has published over 70 articles on design, analysis, and application of gears, and is the author of three widely-used computer programs for the design and analysis of gears. He is a longtime technical editor for *GEAR TECHNOLOGY* and STLE Tribology Transactions. He is recipient of the AGMA TDEC Award, the AGMA E.P. Connell Award, the AGMA Lifetime Achievement Award, the STLE Wilbur Deutch Memorial Award, and the AWEA Technical Achievement Award.

Table 1 Tribology nomenclature

Preferred term	Discontinued term	Application
Antiscuff	Extreme pressure (EP)	Antiscuff additive Antiscuff lubricant
None	Film strength	None
Lubricity	Oiliness Friction modifier	Lubricity additive
Centistoke (cSt)	Saybolt universal seconds SUS or SSU	Kinematic viscosity (the official SI unit for kinematic viscosity is m^2/s. Industry uses the unit centistoke (cSt) or mm^2/s).
Solid lubricant	Dry lubricant	Coatings to reduce friction and wear such as graphite, molybdenum disulfide, or soft metals.
High viscosity Low viscosity	Thick lubricant Thin lubricant Heavy lubricant Light lubricant	ISO viscosity grade
Rolling element bearing	Anti-friction bearing	Ball or roller bearings
Adhesive wear Abrasive wear Hertzian fatigue	Mechanical wear	Failure modes involving primarily mechanical mechanisms
Corrosion Fretting corrosion	Chemical wear	Failure modes involving primarily chemical or electrochemical reactions

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1. Publication Title	2. Publication Number	3. Filing Date
GEAR TECHNOLOGY - JOURNAL OF GEAR MANUFACTURING	0743-6858	9-29-2014
4. Issue Frequency	5. Number of Issues Published Annually	6. Annual Subscription Price *(if any)*
MONTHLY - EXCEPT IN FEB., APR., OCT., DEC.	8	$70.00

7. Complete Mailing Address of Known Office of Publication *(Not printer) (Street, city, county, state, and ZIP+4®)*: 1840 JARVIS AVE., ELK GROVE VILLAGE, COOK COUNTY, IL 60007-2440

Contact Person: WILLIAM R. STOTT
Telephone *(Include area code)*: 847-437-6604

8. Complete Mailing Address of Headquarters or General Business Office of Publisher *(Not printer)*: 1840 JARVIS AVE., ELK GROVE VILLAGE, COOK COUNTY, IL 60007-2440

9. Full Names and Complete Mailing Addresses of Publisher, Editor, and Managing Editor *(Do not leave blank)*

Publisher *(Name and complete mailing address)*: MICHAEL GOLDSTEIN, 1840 JARVIS AVE., ELK GROVE VILLAGE, COOK COUNTY, IL 60007-2440

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14. Issue Date for Circulation Data Below: AUGUST 2014

15. Extent and Nature of Circulation			Average No. Copies Each Issue During Preceding 12 Months	No. Copies of Single Issue Published Nearest to Filing Date
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f. Total Distribution *(Sum of 15c and e)* ▶			12,092	11,702
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Less Energy Consumption with High-Efficiency Bevel Gears and their Usage in the U.S.

Dr. Hermann J. Stadtfeld

This presentation introduces a new procedure that — derived from exact calculations — aids in determining the parameters of the validation testing of spiral bevel and hypoid gears in single-reduction axles.

Introduction

The efficiency of a gearbox is the output energy divided by the input energy. It depends on a variety of factors. If the complete gearbox assembly in its operating environment is observed, then the following efficiency influencing factors have to be considered:

Gearset:

- Gear type (straight, spiral bevel, hypoid)
- Manufacturing process (face hobbing, face milling)
- Hard-finishing process (none, lapping, grinding)
- Gear quality and surface roughness
- Characteristic of surface texture
- Gear parameters (spiral angle, pressure angle, profile shift, depth proportion, cutter radius, hypoid offset)
- Contact topography (Ease-Off, motion error, tooth contact)

Gearbox:

- Housing design
- Bearings
- Seal rings
- Kind of lubrication (grease, oil sump, oil circulation)
- Intensity of lubrication present (oil level, volume of circulation)
- Lubrication type (viscosity, additives)
- Lubrication dynamics (oil churning)
- Deflection characteristic under load

Operating Conditions:

- Speed
- Torque
- Direction of rotation (drive or coast)
- Temperature (of gearbox)

Environment:

- Vibration
- Temperature (surrounding)
- Heat transfer properties due to convection, radiation and surrounding fluid movement (e.g. air)

If the gearset is in the center of attention of efficiency and its optimization, then some of the physical relationships that contribute to tooth mesh efficiency have to be observed. While the teeth of a gearset roll in mesh, the flank surfaces have contact zones which move through the allocated contact area. The contact zones start as lines which spread under load to slender ellipses. This contact condition requires the observation of several effects:

Contact Condition Effects

- Relative sliding between the surfaces
- Rolling velocity of one surface relative to the other
- Change of sliding and rolling velocity during the tooth mesh
- Surface texture, roughness and waviness
- Normal forces or normal line force distribution
- Kind of lubrication
- Lubrication gap geometry (reduced curvature in principal directions)
- Lubrication gap kinematics (change of curvature during a mesh)
- Heat transfer properties of gear members, lubrication and surrounding components

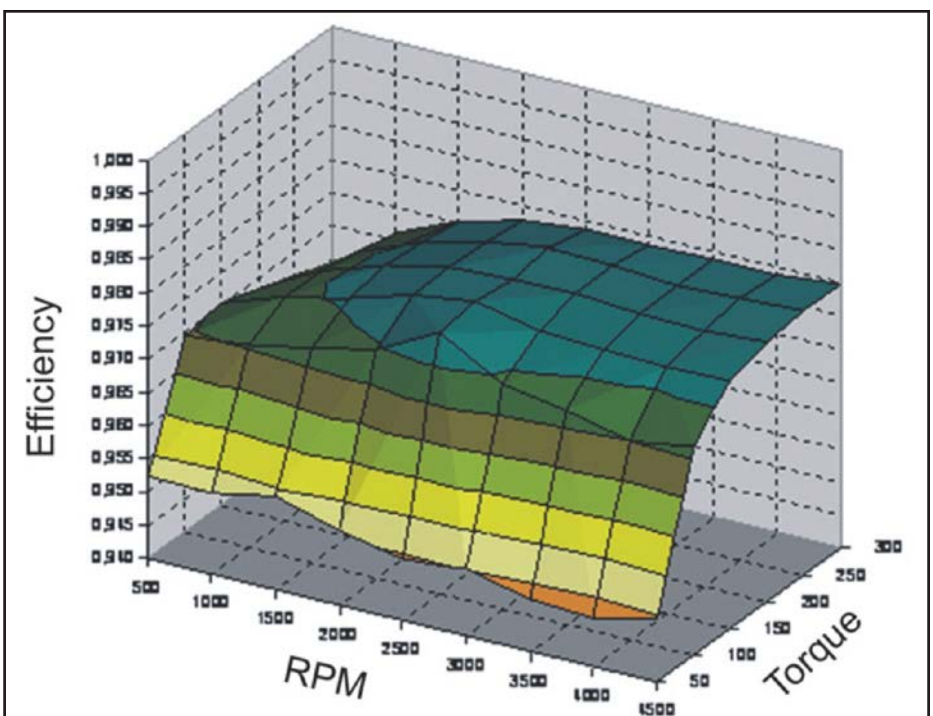

Figure 1 Efficiency characteristics versus speed and torque.

Theoretical analysis and practical test rig investigations helped to understand many of the relationships between gear design, manufacturing process, etc., to the power loss during the tooth mesh. A spiral bevel gearset, for example, has a higher efficiency than a straight bevel gearset and a hypoid gearset with moderate offset has an even higher efficiency. Bevel worm gear drives work on an efficiency level that is 10% and more below spiral bevel gears; however, it is higher than the efficiency of worm gear drives.

The investigations about efficiency and the efforts to improve gear efficiency are not based on one particular efficiency number, but an efficiency *map*. Figure 1 shows the efficiency vs. speed and torque. This typical chart shows there is less dependency from the speed than from the torque. The diagram shows that with low torque, the efficiency is independent from the speed. Doubling the speed means doubling the energy transmitted. If the efficiency remains constant during this speed increase, then the loss of energy in the tooth contact is doubled. Increasing the torque will also increase the efficiency for medium and high speeds, since the lubrication film has a high load-carrying capacity and the load increase will not increase the oil friction by the same amount.

The following sections will elaborate on the effects influencing the efficiency in spiral bevel and hypoid gears, and give hints and guidelines for high-efficiency gear design. The trend here in U.S. regarding the manufacture of more efficient gears is summarized in the last section of this paper.

Hydrodynamic Friction

To calculate the precise energy dissipation in the tooth mesh of a bevel gearset, the continuous tooth mesh is analyzed in a certain number of discrete roll positions. The friction factor of each discrete roll position changes, depending on surface conditions, surface kinematics and the dynamics of the lubricant. Also the constant change of the shape of the lubrication gap has an influence upon the elastohydrodynamic friction. The Stribeck curve (Fig. 2) is a graphical representation of the friction factor vs. the relative surface velocity of two mating surfaces in a hydrodynamic system. The shape of the Stribeck curve depends on the surface roughness, the reduced curvature and the contact force of the two mating surfaces in the contact zone considering a specific lubricant. The friction factor can be obtained from the Stribeck curve if the relative velocity is known.

The Stribeck curve in Figure 2 shows the conditions along the spectrum of relative velocities (solid body friction, boundary conditions and hydrodynamic friction). Efficiency calculation programs compute "points of the Stribeck curve"

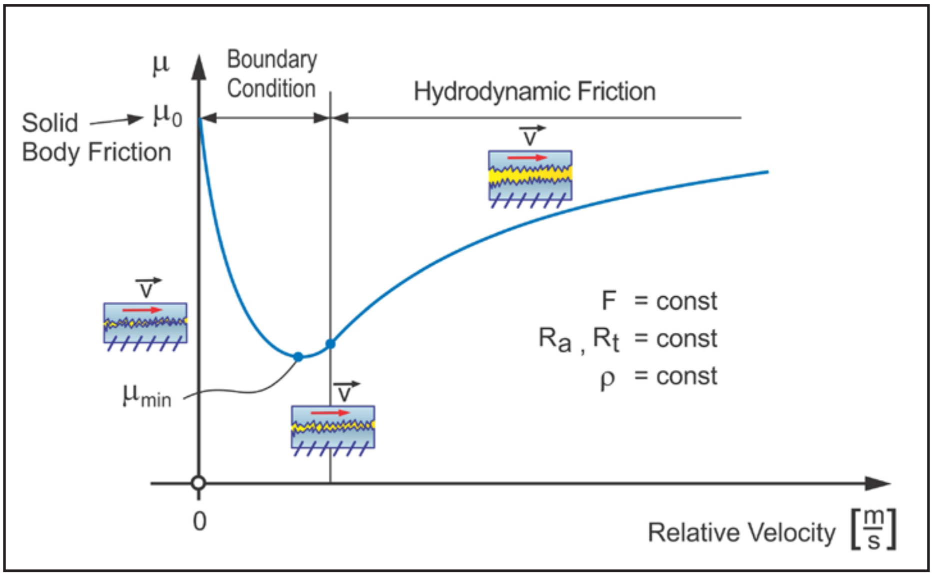

Figure 2 Stribeck curve (Ref. 1).

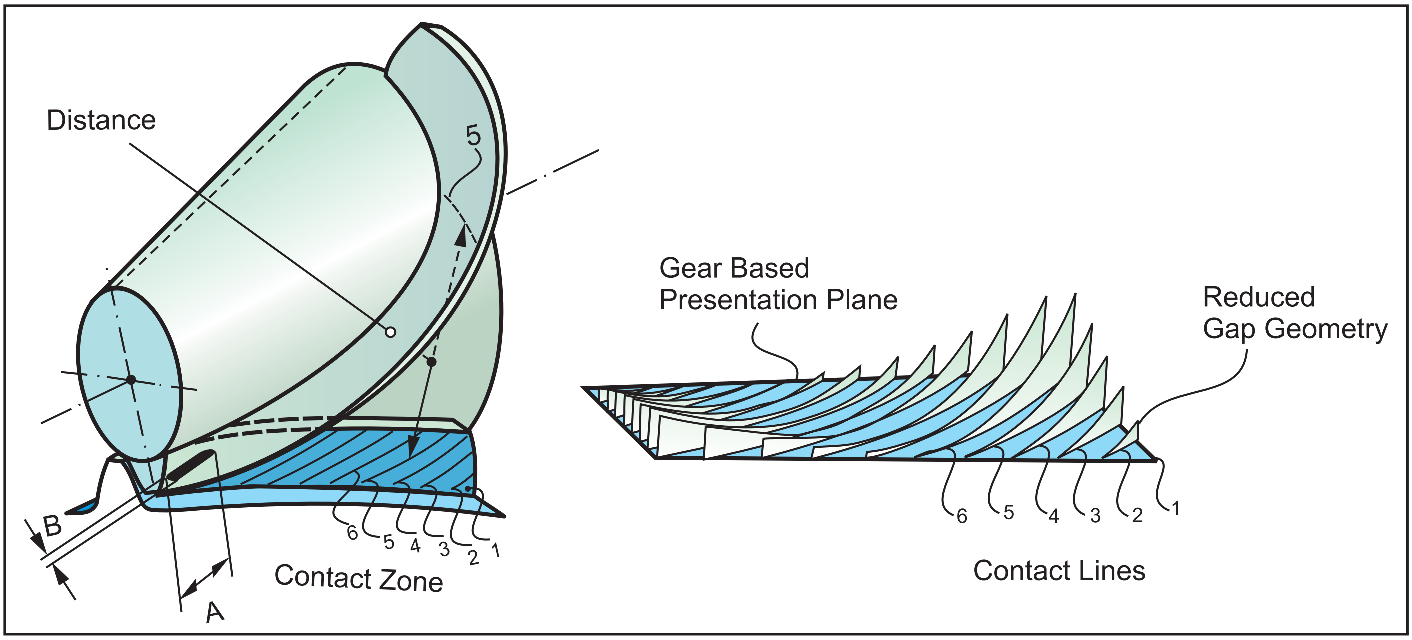

Figure 3 Contact gap and contact geometry aspects (Ref. 2).

with equations that consider the "Contact Condition Effects" listed above. The contact gap geometry and kinematic are next to surface roughness, lubrication properties and normal forces, the most important input for a friction factor calculation.

Contact Gap Analysis

The basis of a contact gap analysis in gears is the geometric and kinematic understanding of the interaction between the pinion and gear flank surfaces. Figure 3 shows on the left side a pinion flank rolling on a gear flank with a contact zone. The contact zone extends a distance along one pair of corresponding potential contact lines between pinion and gear. While the gearset rotates in mesh, the contact zone will move from its current location for example to the right. The surface curvatures between the two flanks are separated in two principal directions: one along the contact line, one along the path of contact (which is the direction from one contact line to the next).

The curvature in path of contact direction is some magnitudes larger than the curvature in contact line direction, which is reflected by A>>B. However, depending on both the angle of the contact lines and on the direction of the sliding and rolling velocities between both flanks, both directions, contact line direction and the direction perpendicular to that (the latter is not always identical with the path of contact direction) must be considered for hydrodynamic investigation. The right-side graphic in Figure 3 shows the reduced curvatures of 20 discrete contact lines, each in their contact position, plotted above the gear projection plane (contact line scan).

Figure 4 shows the sliding and rolling velocity vectors of a typical hypoid gearset for each path of contact point for the 20 discussed roll positions. Each vector is projected to the tangential plane at the point of origin of the vector. The velocity vectors are drawn inside the gear tooth projection plane. The points of origin of both rolling and sliding velocity vectors (dots) are grouped along the path of contact which is found as the connection of the minima of the individual lines in the contact line scan graphic (Fig. 4, right). An observer who is located in one particular path of contact point on the gear flank surface would notice a momentarily contacting pinion point sliding away in the direction and with the speed the sliding velocity vector represents. The observer could also notice (particularly at the pitch point in straight bevel and spiral bevel gears, where no sliding but only rolling occurs), that the solid body, connected to that point moved in a certain direction by rolling like a wheel rolls on a pavement. The direction of this rolling and the movement — accomplished by the rolling (per time unit) — are represented by the direction and magnitude of the rolling velocity vector. Another possibility to explain the definition of rolling and sliding velocity in bevel and hypoid gears is presented in Figure 5. Disk 1 on top rotates with ω_1 and is in contact with Disk 2 (bottom). The circumferential speed of Disk 1 is called the tangential velocity $V_{Tangential}$.

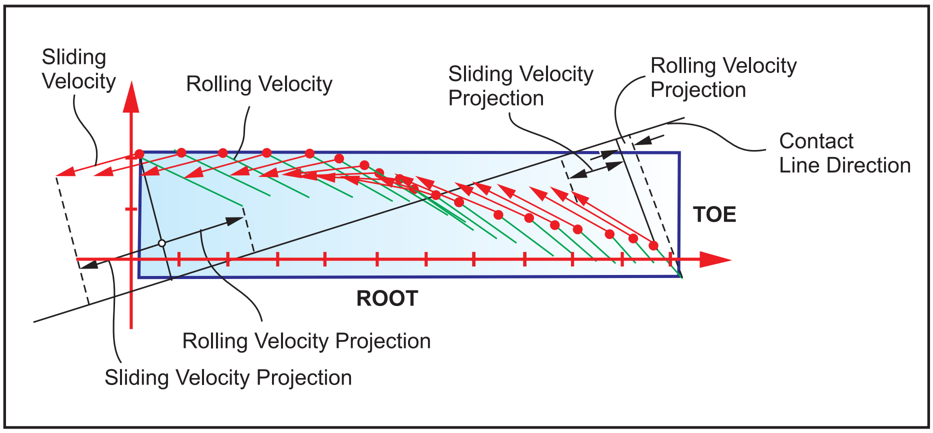

Figure 4 **Sliding and rolling velocities of a hypoid gearset along the path of contact (Ref. 2).**

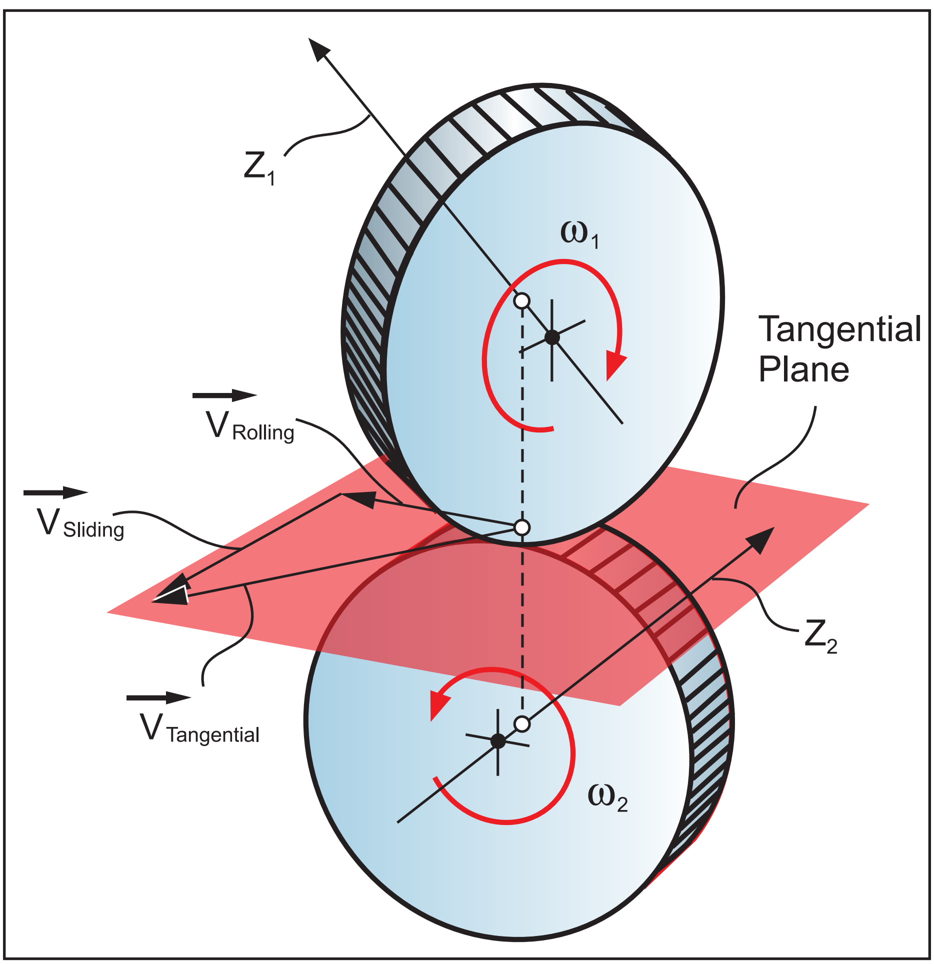

Figure 5 **Definition of sliding and rolling velocity.**

The component of $V_{Tangential}$, which points in axial direction of Disk 2 cannot rotate Disk 2; it only causes a sliding V_{Slide}. The component that points in tangential direction of Disk 2 V_{Roll} causes Disk 2 to rotate with ω_2; it is called the rolling velocity.

It is interesting that the rolling velocities have a relatively consistent direction, whereas the sliding velocities change their direction along the path of contact significantly. Figure 4 shows the average directions of the contact lines. The sliding and rolling velocities are projected in the contact line direction (example projections at the left and right side, Fig. 4). An analog projection in the direction perpendicular to the contact lines (not identical to the path of contact direction) allows two separate observations of the dynamics along the contact lines and perpendicular to them. The gap geometry change from contact line to contact line (Fig. 3, right) can be considered as an additional aspect. A single observation of the main direction appears unacceptable, given that sliding and rolling velocity have different directions and change along the path of contact significantly.

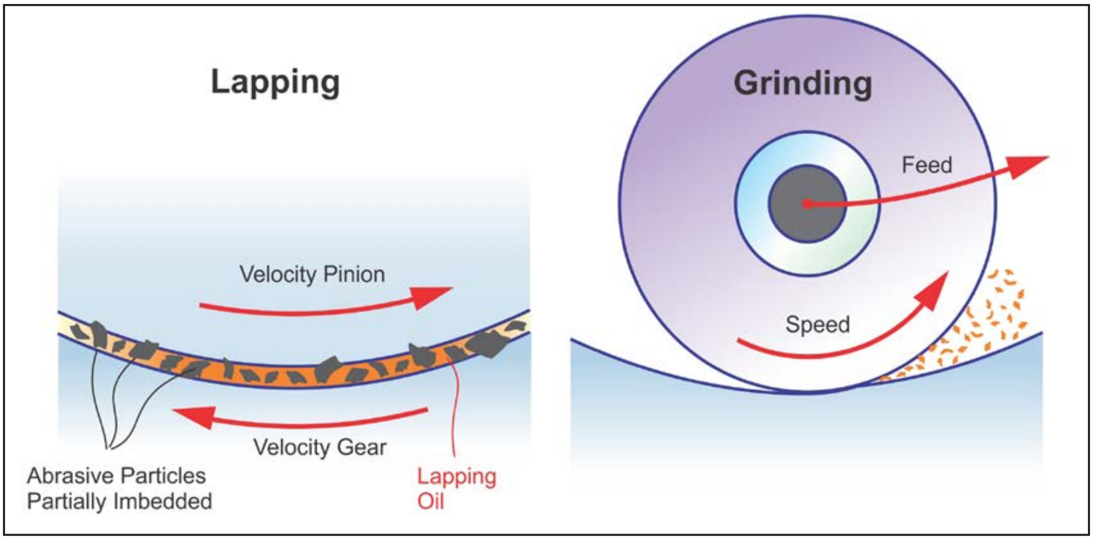

Figure 6 **Material removal mechanism: (left) lapping; (right) grinding.**

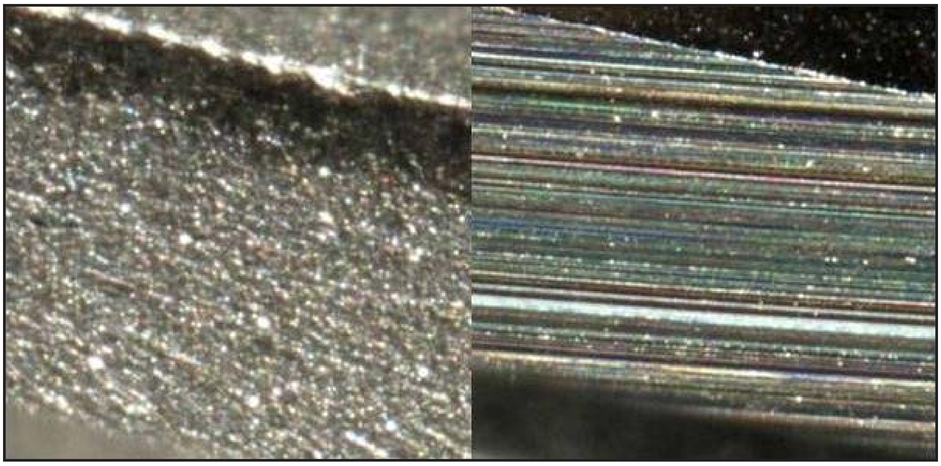

Figure 7 **Lapped surface: (left) ground surface; (right) 20x magnification.**

Manufacturing Process and Surface Finish

Bevel and hypoid gears for industrial applications are case-hardened and hard-finished after heat treatment by lapping, grinding or skiving. The chip removing mechanisms of lapping and grinding are quite different.

As demonstrated in Figure 6, (left), in lapping the abrasive grit is flooded with oil into the mesh between a gear and a pinion flank. The relative velocity would only roll the particles between the two surfaces and not lead to any significant material removal. The lapping torque is required in order to press the particles into the surface of one of the two members. If a particle is partially imbedded in the pinion flank, then the relative velocity and the force between the flanks will cause a material removal between this particle and the gear flank surface. Abrasive particles have to get partially imbedded in both mating flanks in order to assure a material removal on both members. Most particles are only slightly imbedded in the surface roughness of a flank and get flushed away after one flank contact ends and the next begins. However, it cannot be avoided that a certain percentage of particles penetrates partially into the surface and remains there after lapping. The surface roughness of lapped gears depends on the lapping grit size and the lapping torque.

Grinding is a cutting process with microscopically small, undefined and randomly distributed cutting edges (Fig. 6, right). The surface roughness of ground gears depends on the grit of the grinding wheel, the in-feed value and the dressing parameters. Independent from those factors, grinding will not leave any abrasive particles imbedded in the flank surfaces.

Since face hobbed gears (continuous index cutting) cannot be ground, but lap very well, and since face milled gears (single index cutting) can be ground but lap with certain obstacles, the common choices are the combinations "face hobbing – lapping" or "face milling – grinding." The surface finishes produced by the lapping and grinding processes are quite different. Lapped surfaces (left photo, Fig. 7) have a roughness of Ra below 0.5μm, but particles of the lapping grit are pressed into the surface (white spots in Fig. 7, left) where they remain in the later operation, which has a friction increasing effect. Ground surfaces have a surface roughness at or slightly above Ra = μ.5m, with striations that are parallel to the root line. The break-in during the first 1,000 miles of operation of a vehicle, for example, reduces the roughness to Ra values below 0.5μm and reduces the striations. Therefore, the grinding process has significant advantages regarding gear efficiency after the flank surfaces are polished due to the natural break-in. It can be stated that the highest surface finishes result in the highest efficiencies of gears. Super-finishing— after grinding— becomes interesting in cases where the best efficiency is required immediately.

The diagram in Figure 8 compares the efficiency of gears with no hard-finishing operation to lapping, skiving and grinding. It seems conclusive that gears with no hard-finishing show low efficiency, where lapping, skiving and grinding deliver gears with high efficiency. After reading the section above, it is also understandable that lapping has some disadvantage due to the remaining lapping grit and therefore delivers lower efficiency than skiving and grinding. Although the skived surface finish has low roughness and excellent potential for high efficiency, it appears that ground surfaces show, after the break-in, the optimal combination of low roughness and oil film-promoting surface texture than skiving. The general experience with modern power transmissions reveals a trend to a higher efficiency of ground gears.

Efficiency of Different Gear Types

High- and super-reduction hypoids (HRHs and SRHs) have been systematically tested with respect to efficiency (Ref. 3). Strategies for their optimization have been successfully developed and their limitations are well known. In the comparison with other types of angular gear drives (Fig. 9), the high or super reduction gearsets have the lowest efficiency. In spite of the analogy between cylindrical gears and straight bevel gears, the straight bevel gear efficiency is slightly below that of spur gears, and even a bit more below spiral bevel gears — provided that gear quality and hard-finishing methods are comparable.

Face gears are generally below straight bevel gears in an efficiency comparison. Reasons are the low contact ratio and the large difference between operating pitch line and the pinion's nominal pitch line. The difference in efficiency between face hobbed and face milled spiral bevel and hypoid gears seems surprising at first view. Test rig investigations of face hobbed-lapped and face milled-lapped hypoid gearsets have been conducted. It was assured that spiral angle, pressure angle and tooth contact between the sample gearsets were identical at mid face of pinion and gear. Other basic design parameters like offset, cutter radius curvature at mid-face, and of course number of teeth, facewidth and module have also been matched as closely as possible. The test gearsets have been lapped to a similar contact size and location. However, the results of an efficiency map show at medium to high torque and speed between 0.5 to 1% lower efficiency of the face hobbed gearset (Ref. 4). It was noticed that the face hobbed gearset operated at about 20°F higher temperature. The developed hydrodynamic friction calculation is unable to capture the efficiency lowering effect of face hobbed gears. This indicated that some effect is not considered in the friction factor calculation. Today, it is supposed that the flank twist of face hobbed teeth is the reason for the efficiency reduction and causes increased friction factors. Figure 10, left top, the natural twist of a face hobbed gear flank. Since the mating pinion flank has the same amount of

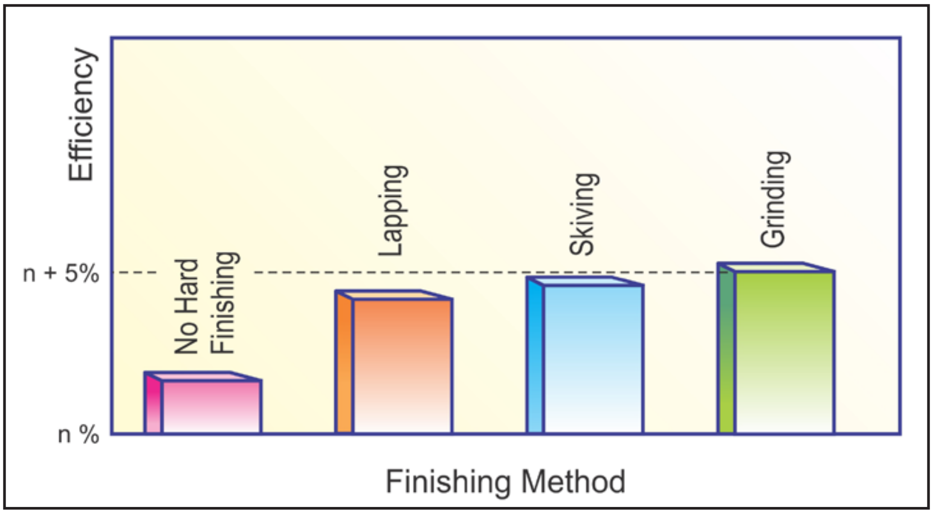

Figure 8 Quantitative comparison of hard-finishing influence with efficiency.

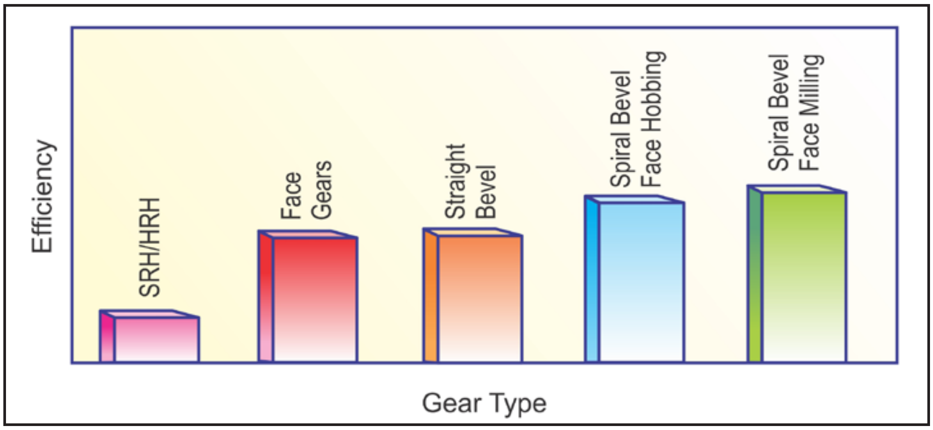

Figure 9 Quantitative comparison of different gear type efficiency.

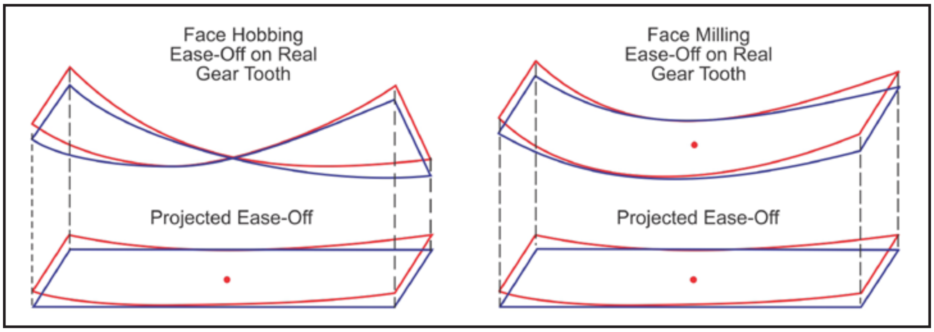

Figure 10 Contact topography: (left) face hobbing; (right) face milling.

twist, the Ease-Off calculation and projection filters out the entire twist. The result is the Ease-Off (left side bottom, Fig. 10). This Ease-Off is identical to the face milled version (Fig. 10, bottom right) which has no flank twist (Fig. 10, top-right). It can be concluded that a contact gap, moving along the facewidth of a twisted flank pair, introduces a different dynamic to the lubricant that has a negative influence on its efficiency, resulting in a different Stribeck curve. The existence and quantification of this relationship has to be verified in future test rig investigations.

The flank twist of face hobbed gears depends on the cutter head size and the number of blade groups. Many blade groups and small cutter diameter result in high amounts of twist. The advantage of the twist is the higher forgiveness of tolerances and housing deflections under load, which means smaller contact movements due to the twisted teeth.

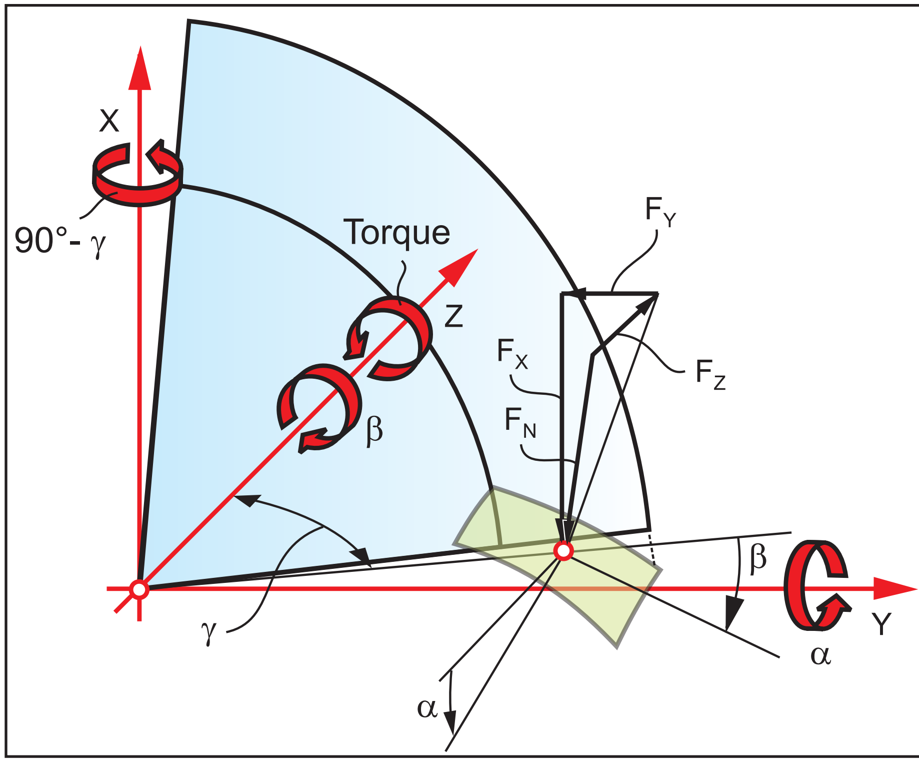

Figure 11 Bearing reaction load calculation.

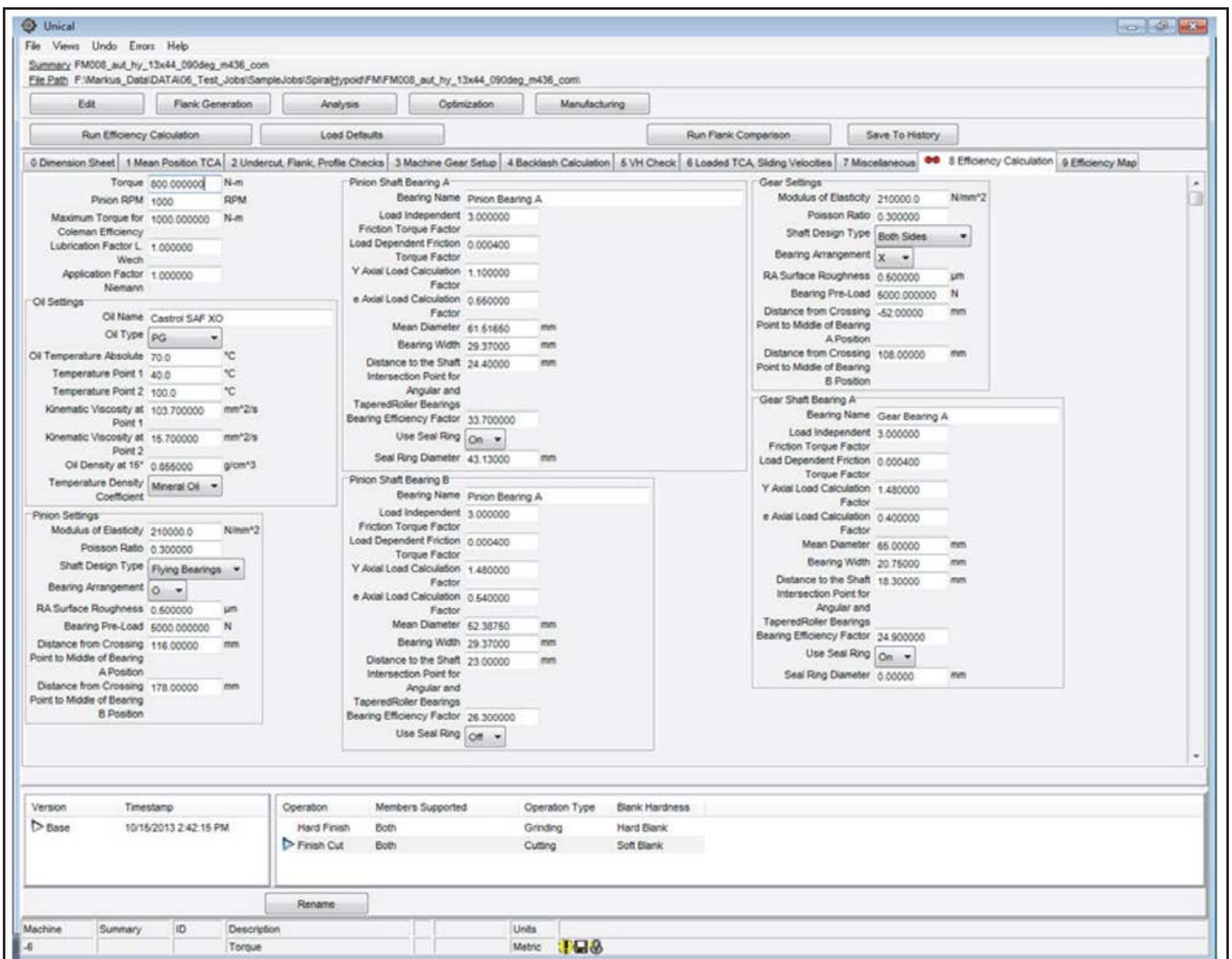

Figure 12 UNICAL efficiency calculation interface.

Contact Forces Depending on Gear Parameters

The normal force F_N, (Fig. 11) is multiplied with the friction factor in order to compute the friction force. Friction-force-times-velocity results in the energy loss that is subtracted from the input energy in order to gain the percentage of energy left for the output shaft. This percentage number is identical to the efficiency. The Gleason efficiency software calculates the normal forces, the velocities and friction factors in 20 discrete roll positions (only one shown in Fig. 11) and uses a numerical integration to gain realistic efficiency values for bevel gearsets (Ref. 5). Multiple teeth in mesh according to the actual load sharing is considered in the Gleason efficiency calculation.

In Figure 11, the force F_X times the radius is equal the torque. Differences between the direction of F_X and F_N, due to the spiral angle, cause F_N to become larger than F_X. The result is a larger friction force and higher bearing forces — without any visible benefit. However, the face contact ratio depends on a spiral angle and reduces the load-per-tooth. The two effects of F_N larger than F_X and individual F_N lower due to a favorable load sharing, lead to an efficiency optimal spiral angle for every gearset. Efficiency optimal values also exist for the pressure angle, the cutter radius, the offset and other parameters.

Efficiency Calculation Software

Gleason developed an efficiency calculation software that considers all the aspects in gearset efficiency as described in the previous sections (Ref. 4). The software can also compute the energy losses in the surrounding of the gearset caused by bearings and seal rings. Figure 12 shows the input interface of the *UNICAL Efficiency* module.

In order to generate graphical efficiency maps, *UNICAL* accepts a range of torques and rpms as well as a number of increments in order to generate an ASCII file with a matrix, which can directly be imported into *Excel*.

Summary

The different sections of this paper gave the reader hints and explanations that favor grinding (over lapping), face milling over face hobbing, and recommended the reader a small hypoid offset vs. no offset for highest efficiency. This preselection is often not possible and doesn't always apply. It seems equally important to offer some quantitative hints that may help to select efficiency-optimal gear parameters.

The following list includes the major gear parameters of an automotive gearset that was the basis of a parameter variation that delivered the efficiency dependency diagrams shown in Figure 13:

Basic Gearset Data

- Ratio: 13 × 43
- Face Module: 4.4 mm
- Ring Gear OD: 196 mm
- Facewidth: 33 mm
- Spiral Angle Gear: 31°
- Included Pressure Angle: 40°
- Hypoid Offset: 29 mm

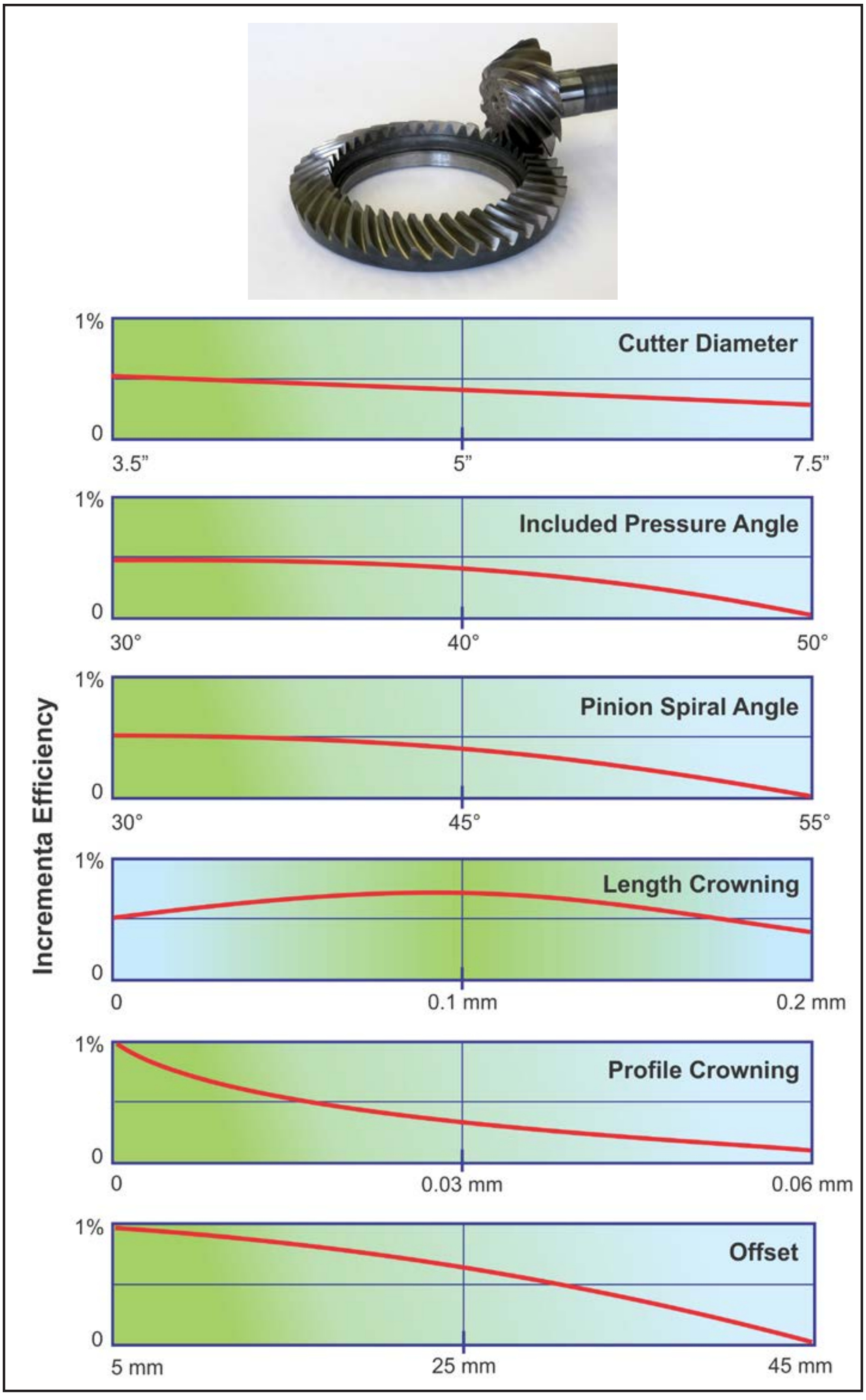

Figure 13 Efficiency influence on test hypoid gearset.

The tables in Figure 13 cover cutter diameter, pressure angle, spiral angle, length crowning, profile crowning and hypoid offset. In many cases, variation of certain parameters is not an option. However, if the gear engineer conducts a total observation of all parameter influences regarding strength and efficiency, it is often possible to find a way to higher efficiency with equal strength. The trends in the diagrams in Figure 13 are results of test rig efficiency measurements on an automotive hypoid gearset, for average operating conditions (Ref. 4).

Based on the statements in this paper, the highest efficiency is achieved with a face milled ground hypoid gearset with a small offset, a low pressure angle, low spiral angle, a length crowning which is 3% of the facewidth and a profile crowning which is very small (or zero). In order to maximize the efficiency, this gearset should be cut with a small cutter diameter (e.g. ratio involute outer cone 0.75) and show a surface finish with an Ra = 0.5 mm or below.

Trend in Efficient Gear Manufacturing in the U.S.

The trend in the U.S. regarding efficiency optimization is significant. The U.S. Government supports manufacturers with grants that have plans to increase the operation efficiency of their products. In many cases those grants are related to geartrains in vehicles, marine and aerospace applications as well as energy producing (or converting) equipment.

The U.S. automotive industry is preparing for smaller vehicles with advanced, energy saving technologies. The customer in the U.S. still likes to buy SUVs, pickup trucks and rear wheel-drive fun or muscle cars. The automobile producer will still build those lucrative vehicles and uses the additional profits to develop fuel saving technology. As the number of sold large SUVs, trucks and fun cars reduces per year, the smaller cars are built more fuel efficient and the larger cars are equipped with many sophisticated features. This is a well-planned preparation for the sophisticated and fuel efficient cars of tomorrow (Ref. 6).

The low popularity of diesel cars is mostly based on the high diesel tax in the U.S. Certain customers are interested in diesel vehicles with their high gas mileage and their high torque; they regret that Diesel-powered cars are not yet widely commercially available. Many people have a critical but educated opinion about hybrid cars. Combustion engine, plus electrical motor and generator, plus the additional weight and space of the batteries results in complex and expensive systems that require more energy to build and yet have the environmental headache regarding the toxic batteries. The maintenance cost of hybrid vehicles is a multiple of that which non-hybrids require after five years of service. Experts announced that the market in the U.S. and Europe will be saturated with 20% hybrid vehicles in the long term (Ref. 7). The other cars will be small with an increase of manual shift transmissions and mild hybrid features like shift indicator and automatic engine shutoff at traffic lights, etc. The percentage of diesel vehicles will increase as soon as the lawmakers set a new direction with modern emission regulations and adequate diesel taxes.

The speed reduction of a prime mover to the wheels or to propellers is inefficient, with slow running electric motors and electronic control units. The required speed reduction for fast-running small-size motors with a high efficiency rating shows a trend to more gears with high efficiency and high power density in most industries, and particularly in the personal transportation sector. The inefficiency of slow-running prime movers and, in particular, electric motors electric motors—at least as they are built today—is is a physical law which will only be overcome with fundamentally different designs that utilize other physical effects. Since this is not in sight for the coming decades, gears with the highest efficiency will maintain a high demand and the manufacturers that can make them will be very successful.

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Dr. Hermann J. Stadtfeld received in 1978 his B.S. and in 1982 his M.S. in mechanical engineering at the Technical University in Aachen, Germany; upon receiving his Doctorate, he remained as a research scientist at the University's Machine Tool Laboratory. In 1987, he accepted the position of head of engineering and R&D of the Bevel Gear Machine Tool Division of Oerlikon Buehrle AG in Zurich and, in 1992, returned to academia as visiting professor at the Rochester Institute of Technology. Dr. Stadtfeld returned to the commercial workplace in 1994—joining The Gleason Works—also in Rochester—first as director of R&D, and, in 1996, as vice president R&D. During a three-year hiatus (2002-2005) from Gleason, he established a gear research company in Germany while simultaneously accepting a professorship to teach gear technology courses at the University of Ilmenau. Stadtfeld subsequently returned to the Gleason Corporation in 2005, where he currently holds the position of vice president, bevel gear technology and R&D. A prolific author (and frequent contributor to Gear Technology), Dr. Stadtfeld has published more than 200 technical papers and 10 books on bevel gear technology; he also controls more than 50 international patents on gear design, gear process, tools and machinery.

Micropitting of Large Gearboxes: Influence of Geometry and Operating Conditions

Dr.-Ing. Khashayar Nazifi and Prof. I.R. Dr.-Ing. Wolfgang Predki

The focus of the following presentation is two-fold: 1) on tests of new geometric variants; and 2) on to-date, non-investigated operating (environmental) conditions. By variation of non-investigated geometric parameters and operation conditions the understanding of micropitting formation is improved. Thereby it is essential to ensure existent calculation methods and match them to results of the comparison between large gearbox tests and standard gearbox test runs to allow a safe forecast of wear due to micropitting in the future.

Introduction

Micropitting is the word used to describe the modified and dull-grey appearance of case-hardened gear flanks. In particular, the areas of negative specific sliding from engagement, beginning with (Fig. 1, left picture, line A), up to the pitch point (Fig. 1, left picture, line C) are susceptible to micropitting.

Numerous, small material chunks fallen from the surface are detectable by microscope in these grey areas (Fig. 1, middle). A further zooming of the area of interest (Fig. 1, right) shows directed edges of the pitting due to sliding and friction forces over these damaged surfaces. Because of this geometry the edges create shades when the light impacts in one certain direction — from pitch circle to dedendum — and the dedendum of the flank appears dull-grey.

With an increasing number of revolutions these material breakouts can develop along the path of contact and into the material depth — detectable as profile form deviations — especially in the dedendum area of gear flanks. Figure 2 (left) shows these deviations caused by wear in an exaggerated illustration.

Observations often show that excessive pitting initiates in or at the edge of micropitting areas (Fig. 2, right). There are at least as many cases with no pitting appearance and stopping micropitting growth.

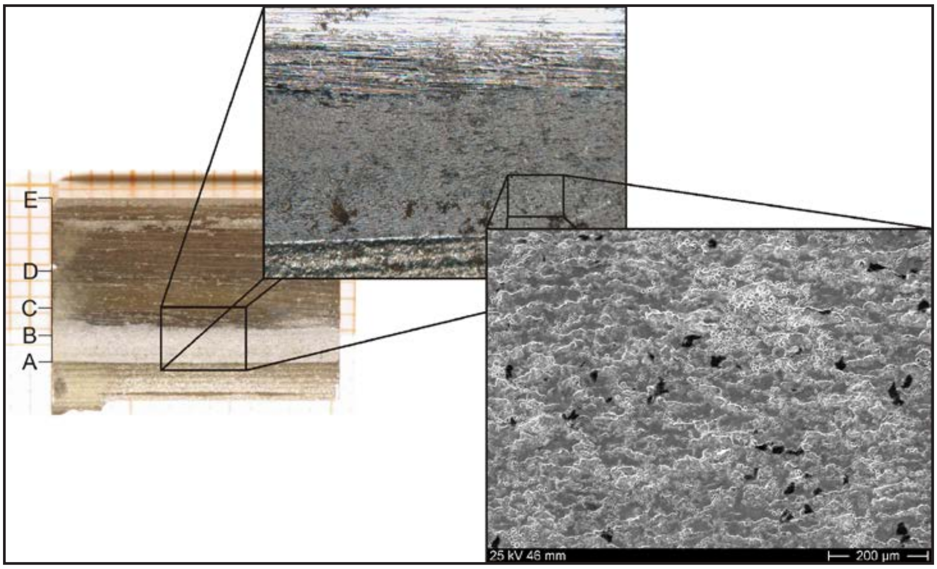

Figure 1 Micropitting on gear flank with different zoom factors.

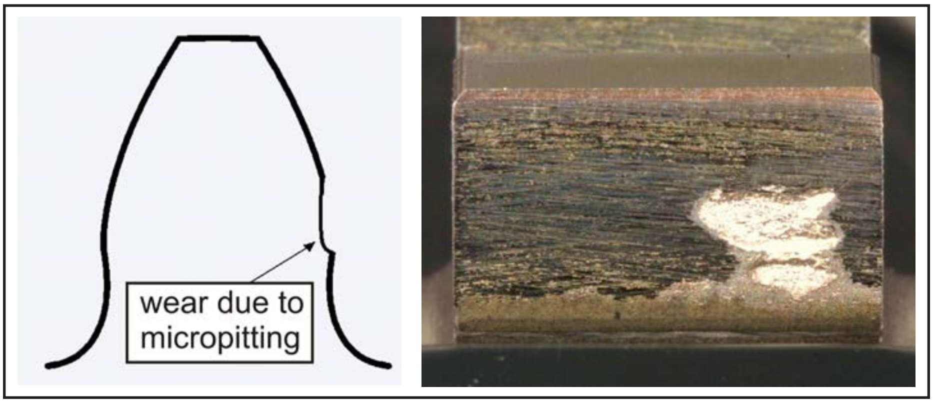

Figure 2 Micropitting (left) deviations on gear flank; pitting (right) caused by micropitting.

Since the early 1980s, investigations of the micropitting carrying capacity of gears have been carried out. These investigations were mainly centered on gears with small modules up to 10 mm. Starting with Haske (Ref. 1) and Lützig (Refs. 2-3), the Ruhr-University Bochum began test runs with gears module 22 mm. The investigations of the small gears lead to a calculation formula for local prediction of profile form deviations due to micropitting wear described in FVA Project 259 I (Ref. 4). First comparisons between calculation and test bench results (Refs, 2-3) show deviations when applied on large modules of 22 mm. Further investigations (Ref. 5) of large gears as described in this paper shall lead to a better understanding of micropitting wear and profile form deviations. To achieve this goal, new geo-

This paper was first presented at the 2013 VDI International Conference on Gears, Technical University of Munich, Garching, Germany, and is reprinted here with VDI permission.

metrical and operational parameters are considered. In order to determine size effects, test runs are carried out on test benches of two different sizes.

Test Benches

The largest spur gear test bench in the world at a research facility is the one at the Ruhr-Universität Bochum. It is specially made for tests on large gearbox teething. The key parameters of the test bench are shown in Table 1.

The test bench is devised as a back-to-back arrangement, making it only necessary to compensate the losses deriving from the bearings, seals and gears as driving power (Fig. 3). The wheel shaft of a spur gearbox is driven over a one-staged, adjustment gearbox by a variable speed electrical motor. This so-called power return gearbox is connected to a second spur gearbox that contains the testing gearset. The torque measurement system is applied to the connecting shaft of the big wheels. The back-to-back connection is closed by the shaft linking the pinions of the spur gearboxes using a hydraulic bracing unit. The bracing unit consists of a hydraulic turning motor that receives hydraulic lubricant through a rotary feed-through. The change of load level and direction is controlled by a proportional and way valve. The valves are controlled via computer, allowing an exact adjustment of the applied torque in operation. Therefore, load collectives and change of torque direction are possible.

The lubrication systems of the test and of the power return gearbox work separately and have their own lubrication tank. The lubricant injection systems are equipped with temperature-regulated cooling water valves and heat exchangers. Furthermore, extra cooling devices keep the room temperature at a constant level. The lubrication system of the test gearbox has additional immersion heaters that heat the lubricant to the desired test temperature before test start. The tank is filled with 600 l of the test lubricant; from there the lubricant is pumped with a flow rate of 180 l/min to the injection nozzles within the gearbox housing. The lubricant is injected into starting and ending mesh via flat fan nozzles. More injection nozzles are directed to the bearings for lubrication.

Table 1 Test bench parameters

Centre distance	a	447 mm
Maximum cycling power	P_{cyc}	6 MW
Maximum brace torque	T_2	114 kNm
Power of electrical drive	P_{Drive}	240 kW
Load appliance	back-to-back with controlled hydraulic bracing unit	

Several measurement systems with torque, temperature and vibration sensors serve to document the operating condition for further test evaluation. Furthermore, a facility of this size needs intensive monitoring to be able to shut down the test bench automatically in case of damaged bearings or gears.

Test Scheme

Overall there are eight test runs with module 22 mm, and two with module 16 mm gears carried out on the large test bench. Due to the much lower running costs of the small test bench and production costs of small gearsets, a higher number of test runs have been carried out on the small test bench. Therefore 17 test runs with module 4.5 mm and four with module 3.27 mm are made to investigate the size influence on the one hand, and explore non-investigated parameters on the other. Besides the module ratio of nearly five, both gear sizes have almost similar geometry. This leads to a comparable Hertzian contact stress distribution along the path of contact. All other operating conditions have been kept constant to all test runs, as there are lubricant, lubrication temperature $\vartheta = 90°C$, circumferential speed $v_t = 8.3$ m/s and minimal lubricant film thickness. In order to achieve distinguishable results, the damage load stage against micropitting of the lubricant is chosen low — = 8. The test gears of the large test bench have an arithmetical mean roughness of the flanks that ranges between Ra = 0.1 µm up to 0.7 µm, and long linear tip reliefs beginning at the points of single engagement that are between $C_a = 50$ µm and 100 µm. For the test runs on the small test bench, the aritmetical mean roughness of the flanks is adjusted in order to achieve the same minimal lubricant film thickness as on the large test bench; the tip reliefs of the small gears are chosen for the same Hertzian contact stress on the pitch circle as for the large gears. The low costs for small gears enable variants of the profile shift and tip relief investigations, in addition to the size-effect test runs.

Table 2 shows the investigated parameters on the large gearbox. Earlier investigations have shown the major influence of the arithmetical mean roughness on the appearance of micropitting. New production technologies such as super finishing enable a reduction in the

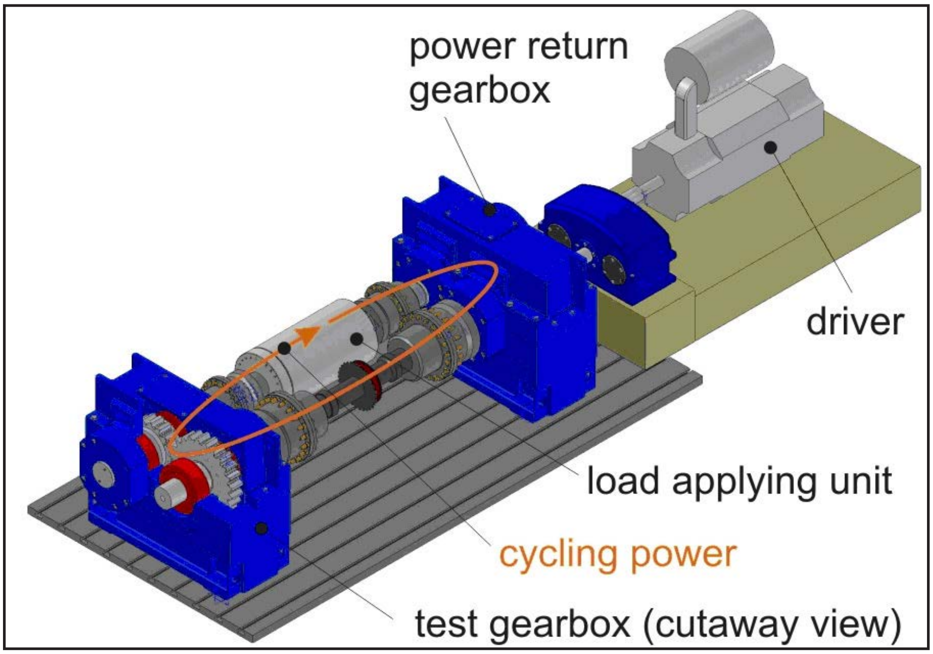

Figure 3 Big gearbox test bench.

surface roughness of gear teeth down to an arithmetic mean roughness of Ra = 0.1 µm — and even lower. For the large gearbox two gearsets have undergone this treatment and started the test runs with Ra = 0.1 µm and Ra = 0.3 µm.

Investigations to date have focused on the gear engagement within the regular contact zone; pre-engagement due to mesh interference has not been taken into account. The idea that the lubricant is wiped off the tooth surface by mesh interference must be verified by one experiment with extremely tip-edge-rounded gears on the last 2-5% of the path-of-contact.

All existing test results on gear micropitting have been carried out on gears with modules up to $m_n = 10$ mm (Ref. 4) and on the described large gearbox with module $m_n = 22$ mm (Refs. 1, 2). To close this module gap in the investigations, one gearset with module $m_n = 16$ mm is used in the test runs. The geometry is designed to achieve similar sliding velocities along the path-of- contact.

The profile shift of the regular C gears is designed for equal specific sliding velocities in the dedendum of the test gears. Typical gears in most applications have increased profile shifts around $x_1 = 0.4$ and higher. One gearset is designed with a profile shift of $x_1 = 0.5$ to account for typical applications.

For generating energy with wind or water turbines, high torques with low speeds are transformed to low torques with high speeds. Within the used gearboxes the big wheel drives the pinion. This operating condition is not common to all other gearbox applications and is not yet investigated. One test run has thus far been carried out to ascertain the influences on micropitting.

Gearboxes are open breathing systems. During operation air within the gearbox heats up and its volume increases and excess air is pressed out. On production stops the air cools down again, the air volume decreases, and wet air from outside is sucked into the gearbox. Water condenses on the interior of the housing, runs down the walls, and attains the lubricant. Contamination with 500 ppm water within the lubricant of one test run has to show the effect on micropitting appearance.

Test Results

The size comparison tests show that the profile form deviations deriving from mesh interference have a more significant impact on larger module than on smaller module gears. This can be explained by the fact that in order to receive equal Hertzian contact stresses at the pitch circle for geometrically similar gears, the line load increases in proportion to the module. Therefore the deformation of the gears increases proportionately to the module and creates higher profile form deviations. Conversely, observations show that the profile form deviations caused by micropitting do not increase by the module. Even the morphology of micropitting does not change significantly between different module sizes like crack width, length, angle to surface and/or distance between cracks.

Moreover, it can be stated that gear flank pitting does not grow out of the micropitting area. In fact, pitting develops at the transition of the micropitting area to the undamaged flank as a result of the unworkable geometry. The reasons for this disadvantageous geometry can be, apart from micropitting wear, shaving marks due to mesh interference or unfavorably chosen profile modifications. If wear on the gear flanks is unavoidable, the profile form deviations caused by the wear have to be directed by profile modifications to have the least effect on pitting occurrence.

Figure 4 shows the flank of a superfinished gearset with arithmetical mean roughness of Ra = 0.12 µm within an endurance test run. At left, in the figure, the flank can be seen shortly before the pitting failure. Except for the shaving line in the dedendum nothing else can be observed on the flank. After the next run of the endurance test the whole flank is failed due to massive pitting, as shown on the right side.

Figure 5 shows that the minimum radius of curvature r_{min} of a rougher gear flank moves with increasing load cycles towards the flank and therefore the region with highest contact stresses moves along the flank as well; a low surface roughness avoids this movement along the path of contact. Hereby the material is highly loaded at the same position and pitting occurs. Test runs with gears possessing flanks with arithmetical surface roughness between Ra = 0.1 µm and 1.0 µm show that, with increasing micropitting areas, the pitting-free lifespan can be increased. In contradiction to this effect, stagnating micropitting areas that only grow into the material create higher-profile form deformations, and therefore reduce the minimum radius of curvature r_{min} and decrease the pitting-free lifespan.

Tip relief and tip-edge-rounding have proven to be a proper method to reduce mesh interference. Tip-edge-rounding can be applied purposefully by grinding or as a side effect of other finishing technology. A relation between the duration of the superfinishing procedure and the

Table 2 Overview of investigated parameters on large gearbox

Investigated parameters	Standard as defined in [1], [2]	Variation
Arithmetic mean roughness	0.8 µm	0.1 µm – 0.3 µm
Tip edge roundness	20 µm	250 µm
Module	22 mm	16 mm
Profile shift	$x_1 = 0.18$	$x_1 = 0.5$
Driving gear	Pinion	Large wheel
Water contamination	0 ppm	500 ppm

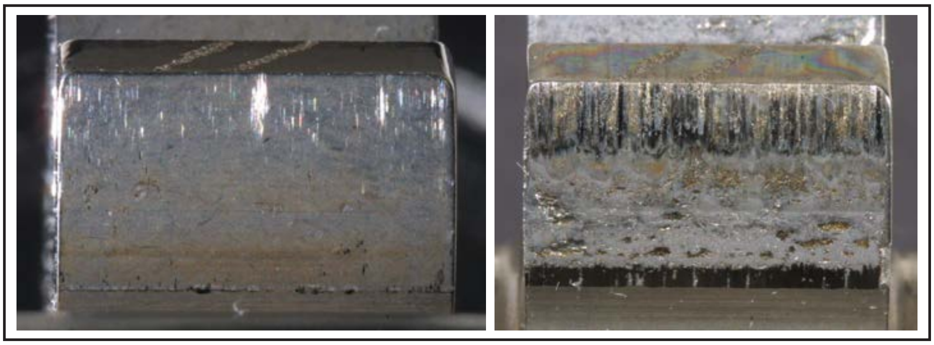

Figure 4 Gear flank $m_n = 4.5$ mm, $Ra = 0.12$ µm. (Left) $N = 33.3 \cdot 10^6$; (right) $N = 43.7 \cdot 10^6$.

tip-edge-roundness has been observed within the investigations. The superfinishing process is continuously optimized towards higher contour accuracy of the flanks so that very fine surfaces can be achieved with shorter process times. These optimizations lead to less roundness of the tip edges and the positive side effect declines.

Aside from the reduction of shaving due to mesh interference, the tip-edge-roundness leads to better lubrication of the flank at start-of-contact. This can be observed with gears of module $m_n = 4.5$ mm and grinded tip-edge-roundness. Although the mesh interference effect of these gears is not so pronounced on the large gearsets, the test results show a higher resistance to micropitting and fewer profile form deviations.

Without considering the mesh interference, the correlation between arithmetical mean roughness and profile form deviations had been lost for gears with low tip relief in the former project (Ref. 2). By the newly gained knowledge about mesh interference and the resulting damages, the old results can be re-evaluated. With the re-evaluation the correlation between arithmetical mean roughness and profile form deviations can be reconstructed again; it shows that with increasing flank roughness the profile form deviations caused by micropitting grow for small as well as for large gears.

The influence of arithmetical mean roughness on micropitting creation is demonstrated for large gears featuring flanks with very low roughness of Ra = 0.1 µm. Chemically accelerated vibratory-finished gears show very small micropitting areas due to the very low surface roughness. Test runs with gears module $m_n = 22$ mm have shown that an arithmetical mean roughness of Ra = 0.3 µm is completely sufficient for suppressing micropitting. The results of gearsets with practical profile shifts on large and standard test benches show congruently the influence of specific sliding velocities on micropitting development. By increasing the positive profile shift on the pinion, the amount of specific sliding velocities in the dedendum of the pinion is reduced. This area of the flanks shows — compared to the regular C gears — very small micropitting. As a consequence of the fix center distance of the test bench gearboxes, the profile shift sum must be kept constant. As a result of this boundary condition extreme, negative profile shifted big wheels occur with high amounts of negative specific gliding velocities in the dedendum. This is now the place where large micropitting areas can be observed after the test runs.

Test runs with a driving wheel have illustrated that the driving direction has an influence on the resulting profile form deviations. The micropitting-driven profile form deviations are a function of sliding velocities and surface roughness of the flanks, and both values are not affected by changing from driving pinion to driving wheel.

Profile form deviations do not have different causes, yet these deviations appear not separately on the flank and lay on each other. This is what is meant by superposition. Essential for mesh interference is the stiffness in the outer point of single engagement. Is the driving direction changed the outer point of single engagement swaps from point D on the path of engagement to point B. The regular C gear is much stiffer in point B than in point D. Therefore the resulting profile form deviation is lower for driving wheels than for driving pinions. As expected, the place of maximum profile deviation is not the dedendum of the pinion but rather the dedendum of the wheel. The tip-edge shows by entering the engagement with the sharp corner towards the mating flank (Fig. 6, left) and shaves over it. Leaving engagement, the obtuse corner is pulled over the mating flank (Fig. 6, right). Therefore the shaving at pre-engagement is rated as more damaging than at post-engagement.

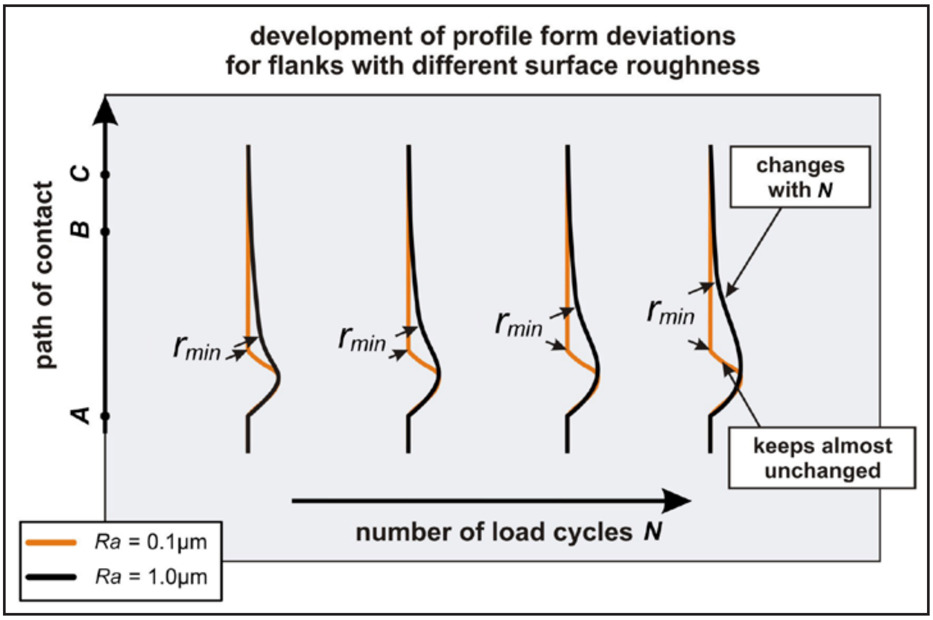

Figure 5 Development of profile form deviations for flanks with different surface roughness.

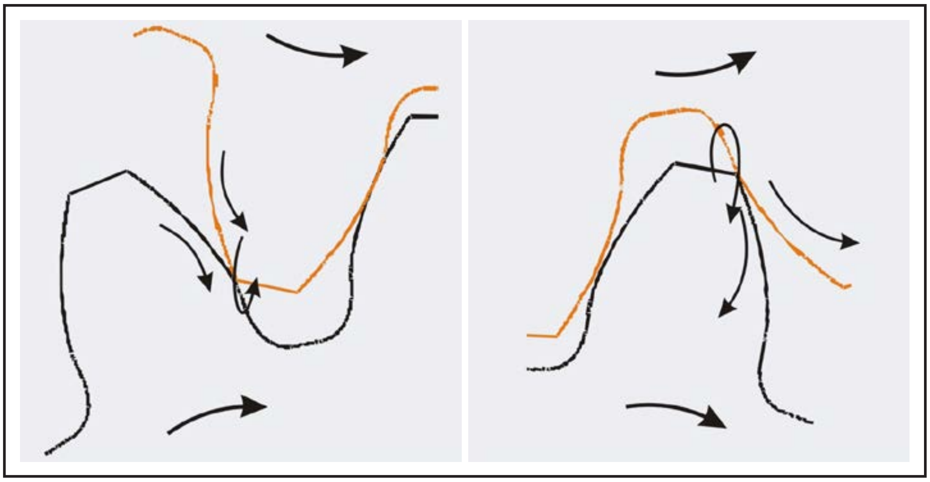

Figure 6 Kinematics of gear teeth: (left) at pre-engagement; (right) at post-engagement.

The lubricant used for test runs appears to be relatively impervious to water contamination, and the micropitting carrying capacity is unchanged. The water quantity used in the test runs is W = 500 ppm, although there is a dependency between contamination duration and wear amount.

On the first flank the reaction duration of additive and water is probably too short, and no negative influence can be observed. On the second flank the wear increases. This flank has been exposed to the contaminated lubricant as working as well as the non-working flank. Pre-tests with lubricants used in wind turbine gearboxes show vastly differing reactions to water contamination. With dependency on the used additives, the wear on the flank increases. Two different cases have to be considered in the water contamination of lubricants:

1. Water is completely insolvent in lubricant.
2. An oversaturated lubricant with free water molecules is given.

In the case of solved water in lubricant, the reaction between water and additives is critical. The pre-tests have shown that oxidation on flanks is not critical respective to wear.

Calculation Results

Within project FVA 259 I (Ref. 4) a new approach for the calculation of micropitting-caused wear is shown. This method considers different local lubrication conditions, loads along the tooth profile, micropitting carrying capacity of the lubricant, and profile modifications. In order to calculate wear for a gearbox, the operating conditions of the regarded gearbox (index „GF“) are compared to the operating conditions of the standard gearbox (index „GFT“). The calculation formula is adjusted with the knowledge that micropitting wear does not grow with module size. The old calculation method is enhanced by the ratio of investigated module to standard module as shown in Figure 7. Figure 8 shows a comparison between test results, i.e., previous calculation method vs. enhanced calculation. As can be seen, the result is a very good fit.

$$f_{fm}(Y)=f_{fm,GFT}\cdot\left(\frac{\zeta_{GF}(Y)}{\zeta_{GFT}}\right)\cdot\left(\frac{b_{H,GF}(Y)}{b_{H,GFT}}\right)\cdot\left(\frac{p_{H,GF}(Y)}{p_{H,GFT}}\right)^{0.25}\cdot\left(\frac{\lambda_{GF}(Y)}{T_{\lambda}\cdot\lambda_{GFT}}\right)^{-1.25}\cdot\left(\frac{N_{GF}}{N_{GFT}}\right)^{0.25}\cdot\left(\frac{m_{GF}}{m_{GFT}}\right)^{-1}\cdot C$$

Figure 7 New formula for calculating micropitting-caused wear.

Summary

- By virtue of detailed analysis, profile form deviations detected in test runs are cause-determined.
- Having this knowledge enables study of each deviation and cause on its own.
- It can thus be shown that micropitting morphology is very similar between different module sizes.
- Deviations caused by micropitting are not relative to module, and deviations caused by mesh interference are relative to module.
- Moreover, the influence of micropitting and, in particular, the influence of flank geometry on pitting occurrence is shown to be related to high local Hertzian stresses.

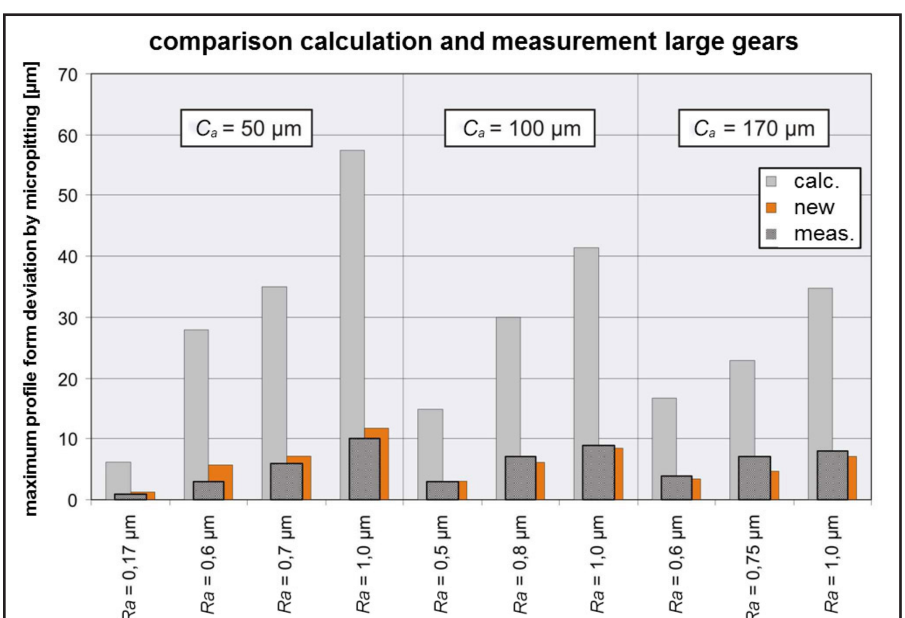

Figure 8 Comparison between test results; old calculation and new method.

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Until his retirement in 2012, **Prof. Dr.-Ing. Wolfgang Predki** served with distinction as Head of Chair for Mechanical Components, Industrial- and Automotive Power Transmission (LMGK) at Ruhr-University Bochum since 1992.Upon receiving his doctorate in 1982, Predki began work at the former Flender AG. His last position was as Head of Engineering, where he was responsible for worm, standard-helical, and planetary gears. In his 20 years as a professor Predki supervised many dissertations, published countless reports, and headed the DIN and FVA working groups for worm gears.

Simulation of Deviations in Hobbing and Generation Grinding

Günther Gravel

The hobbing and generation grinding production processes are complex due to tool geometry and kinematics. Expert knowledge and extensive testing are required for a clear attribution of cause to workpiece deviations. A newly developed software tool now makes it possible to simulate the cutting procedure of the tool and superimpose systematic deviations on it. The performance of the simulation software is illustrated here with practical examples. The new simulation tool allows the user to accurately predict the effect of errors. With this knowledge, the user can design and operate optimal, robust gearing processes.

Introduction

The continuous machining of tooth flanks by a rolling motion process has long been a standard practice for manufacturing cost-effective gearing with high accuracy. This process is used for soft- and hard-machining by hobbing and generation grinding. The tool has the shape of a worm that is interrupted by gashes with hobs. Both tool and workpiece operate in a kinematic coupling with versatile motion options. In Figure 1 the possible influence categories are listed as possible reasons for deviations discovered in the scope of measuring a workpiece.

The tool may have deviations when it is new, or due to wear and damage. It can be set up in the machine incorrectly, thus indicating run-out deviations. The cutting process on the tooth flank is controlled by technology parameters such as feed rate and infeed; foreseeable deviations resulting from this are not only feed markings but also deviations in chip shape formation. Not surprising, given that the machine tool must implement and synchronize the different movements at a high precision. Here deviations also result from the control processes, deformation or position errors of the axes. The user therefore must deal with a complicated scenario of fault possibilities, and is pleased when he can assign the root cause of the fault to a category in order to then pursue out further checks or changes to the parameters.

With this in mind, simulation software now exists that mirrors the effects of typical faults stemming from hobbing and generation grinding to the workpiece, and aids the user when searching for the cause. The following article presents the layout and function of this software in practical examples. Implementation requires only a simple operation and a quick and accurate calculation. With just a slight interpretation of the results, the simulation has been integrated in an analysis tool for gear measurement. The simulation results are represented in the same manner as the results of a gear measurement. Effort expended for development is reduced considerably by using the numerous calculation and output routines of the analysis software.

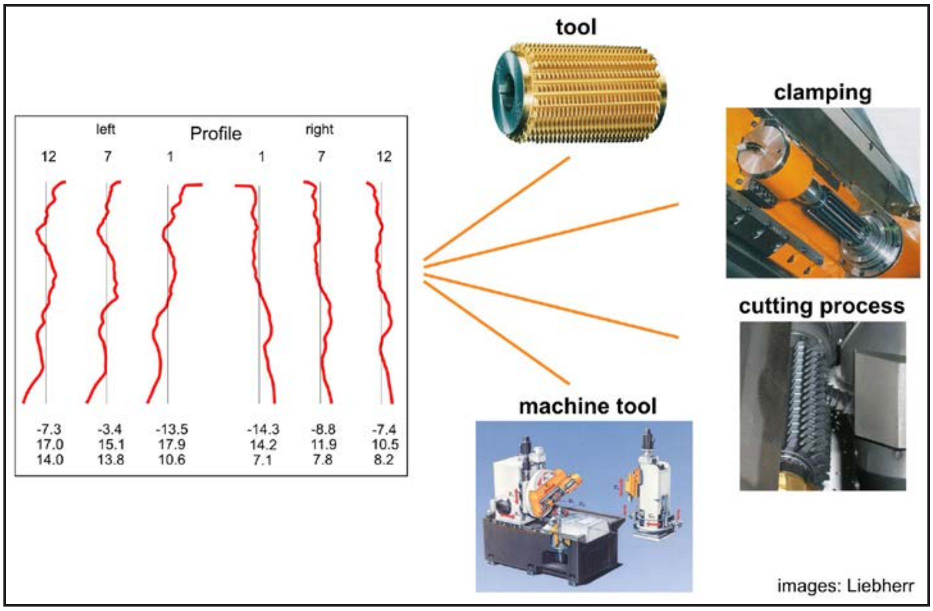

Figure 1 Causes of deviations.

Layout of the Simulation Software

This simulation software provides representation of a rolling production by a worm-shaped tool. The only difference when considering hobs vs. grinding worms is that with hobs, the number of cutting edges is clearly determined, whereas with grinding worms the number is theoretically infinite but can still be effectively approximated in suitable quantity. As several deviations — such as the profile cut markings — only occur when hobbing and hobs are compared with grinding worms relatively easy to measure on gear measurement devices, only examples of hobbing shall be considered in the following; all possibilities of the software described here also apply to generation grinding.

The fundamental basis of the calculation is the consideration of points on the surface of the workpiece and the descrip-

This paper was first presented at the 2013 VDI International Conference on Gears, Technical University of Munich, Garching, Germany, and is reprinted here with VDI permission.

tion of the tool cutting edge as a sequence of points. These points are equipped with possibilities for movement that adhere to defined dependencies. The workpiece points are treated as measuring points of a gear measurement that can then be used to calculate deviations using the conventional procedures of measuring technology. The tool cutting edges each have a cutting contour and description for the position of this contour. In their basic state these position parameters define the position of the cutting edge on the spiral-shaped tool body. All movements can only be implemented by changing these position parameters; in this way it is easy to represent many tool errors as position changes.

The possibility of moving the workpiece is only a rotation in the *Z* axis that is coupled with the tool rotation. The tool carries out an axial feed per rotation in the direction of the workpiece axis. The position of the tool in the direction of the tool axis is determined by the shift position. In this regard a diagonal shifting permits a movement during processing. The radial position of the tool to the workpiece axis is determined by the addendum modification. A movement during the machining is also possible here, for example, to generate a flank modification; the tool is rotated around the swiveling angle from the horizontal position that is determined from the helix angle of the workpiece gearing and the lead angle of the tool worm.

Indeed, in the course of simulation every single workpiece point is provided with an allowance and considered accordingly as to which cutting edge makes contact with it, and in which position. During cutting, the allowance is reduced to the clearance to the cutting edge (Fig. 3). On the measuring point considered here, the enlarged deviation curve of all measuring points is reduced rapidly, as with the removal of chips.

The implementation of the procedure described here is sufficient for an exact simulation, but leads to a response time that is impracticable when each point of the tool contour of every tool tooth meets in relation to each workpiece point in any possible position. For smooth performance, numerous guidelines have been implemented that in effect limit the tool teeth and cutting zones to the actually effective ones; in doing so, these rules also consider possible tool errors.

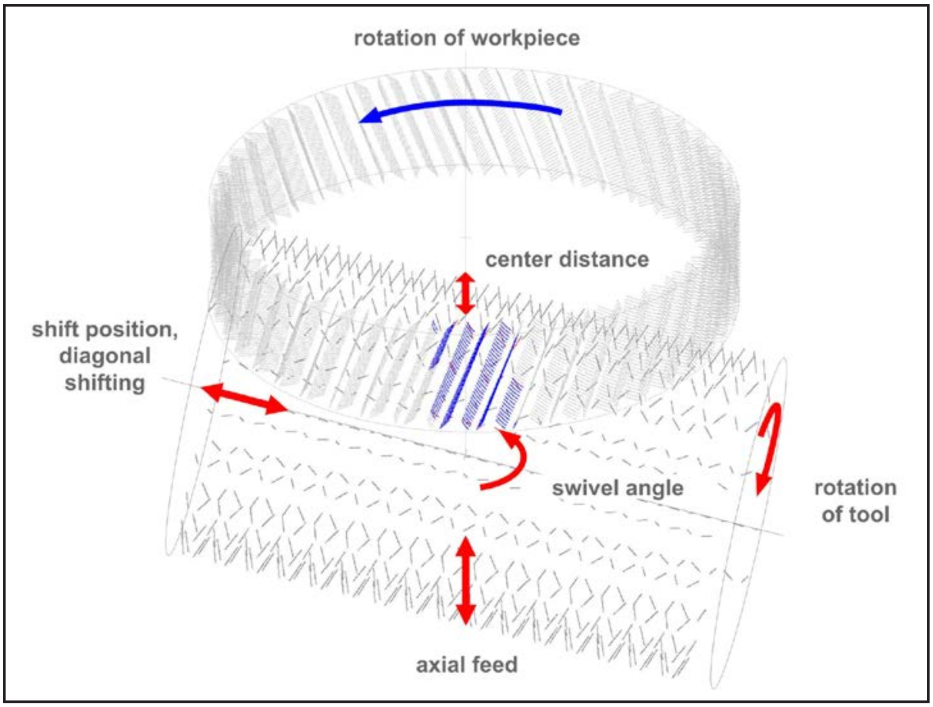

Figure 2 **Description of the kinematics.**

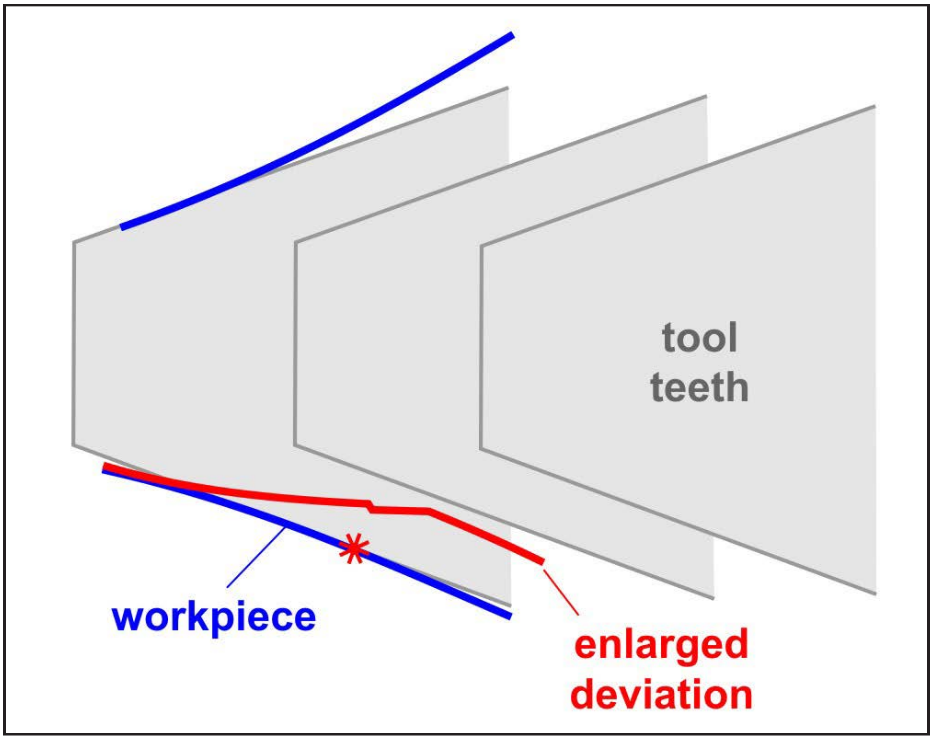

Figure 3 **Calculation of cutting.**

Simulation Results with Error-Free Processing

Figure 4 shows the results of the hobbing simulation of a workpiece; an error-free processing is carried out with a relatively high axial feed. Profile cuts and curves of the tooth trace on the right and left tooth flanks in the diagram — as well as pitch points on all teeth — are specified as measuring points according to a standard measurement on three distributed teeth. The markings of the axial feed arise on the tooth trace; the distance of the tips is equivalent with the feed rate. The crowning of the tooth trace results from the set-point specification of a crowned flank modification.

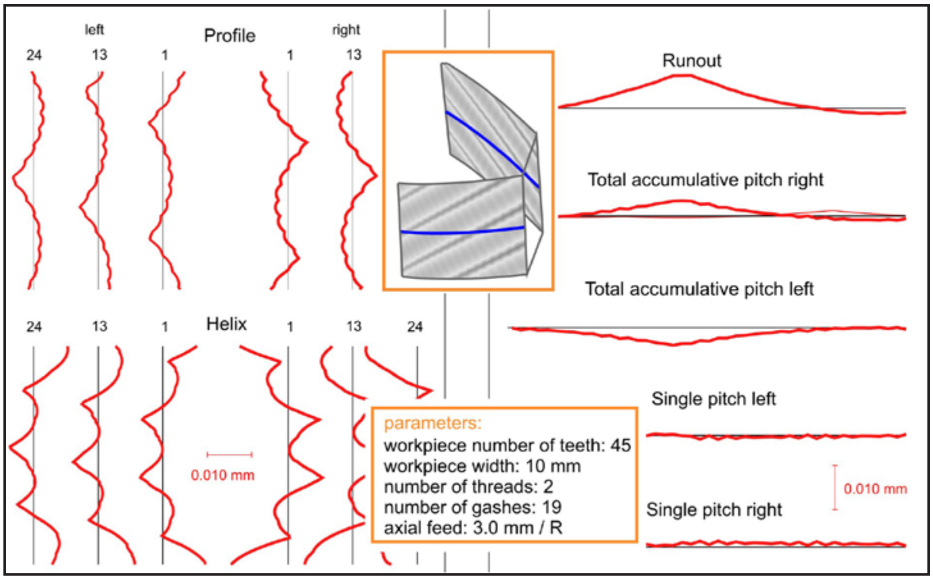

Figure 4 Standard measurement.

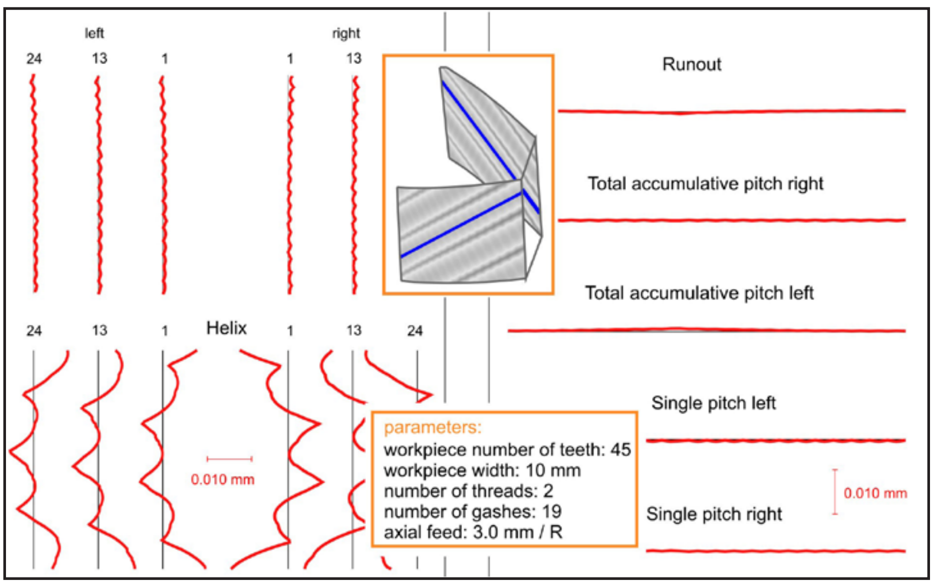

Figure 5 Measurement in the spiral of feed.

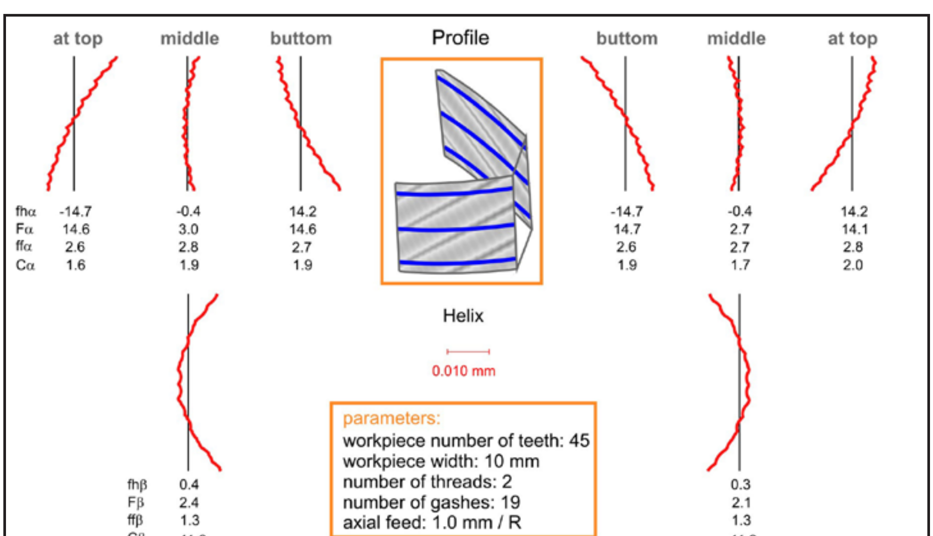

Figure 6 Measurement of twist.

The 3D topography of a tooth is represented in the middle of Figure 4. An obliquely running ripple results over the tooth flank due to the axial feed. A typical profile measurement (blue line) is carried out in the transverse section and cuts this ripple effect, which also results in a ripple in the profile of the same amplitude. Moreover, the profile indicates a finer, higher-frequency ripple. These deviations result from the generating cuts after the cutting sequence of the individual cutting edges. They can be clearly seen due to the relatively small number of gashes-per-thread of this tool. As the ripples also move from tooth to tooth due to the axial feed, the pitch variation also indicates irregularities, depending on where the individual pitch point is located between peak and valley.

The deviation in form generated by the axial feed reflects the quality of the workpiece; but with regard to the manufacturing assessment, do not allow support statement about the accuracy of the profile generation or positional deviation of the gear teeth (radial run-out and pitch variation). It is therefore common on gear measurement devices to do a measurement in the spiral feed. With the profile and pitch measurements, the measuring probe then always scans in the base of the ripple (Fig. 5). The measuring points can also be distributed in this way in the simulation so that the deviations from the axial feed disappear and only the generating cut deviation remains in the profile.

As the position of the measuring points on the tooth flank can be freely selected, it is also possible to generate three profile cuts — common when measuring the twist. Figure 6 shows the deviations when using a considerably smaller axial feed during the simulation. The crowned contour of the tooth trace is generated by a correction of the axial distance during machining. As the tool is inclined by the swiveling angle, and thus does not only cut in the transverse section level of the workpiece, a tilting of the profile with changing signs results at the top and bottom that is designated as twist. Using the calculation of the standard characteristic values, the twist can also be output numerically. In practical tests, a good match with the values calculated is observed.

Figure 7 shows the results of the simulation of many more profile cuts as a color-coded representation of the deviations. On the figure's left side, error-free processing was done with a high axial feed and without crowned tooth trace. On the right side of the figure a positional deviation of the tool has also been specified in the form of a wobble. Whereas the right tooth flank of the workpiece shows almost no changes, the left tooth flank shows significant deviation patterns that can also be recognized visually on the tooth flanks of the manufactured gear. If the measurement diameter of a tooth trace measurement is modified here (displacement of a vertical cutting line to the outside or inside), then the form of the deviation curves can modify significantly. This effect is comprehensible only by means of a topographical representation. In this way the user of the simulation software is also able to analyze surface effects of the machining.

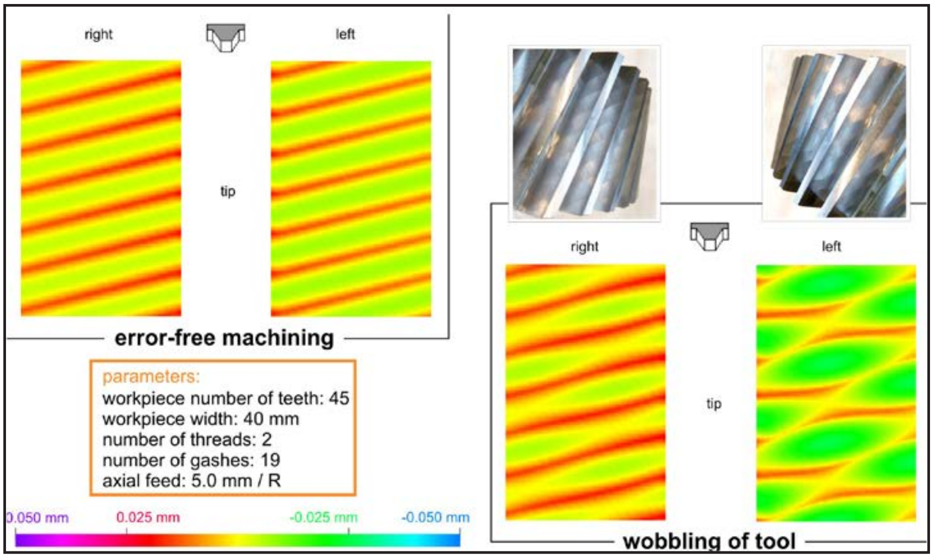

Figure 7 Simulation of many sections and topography presentation.

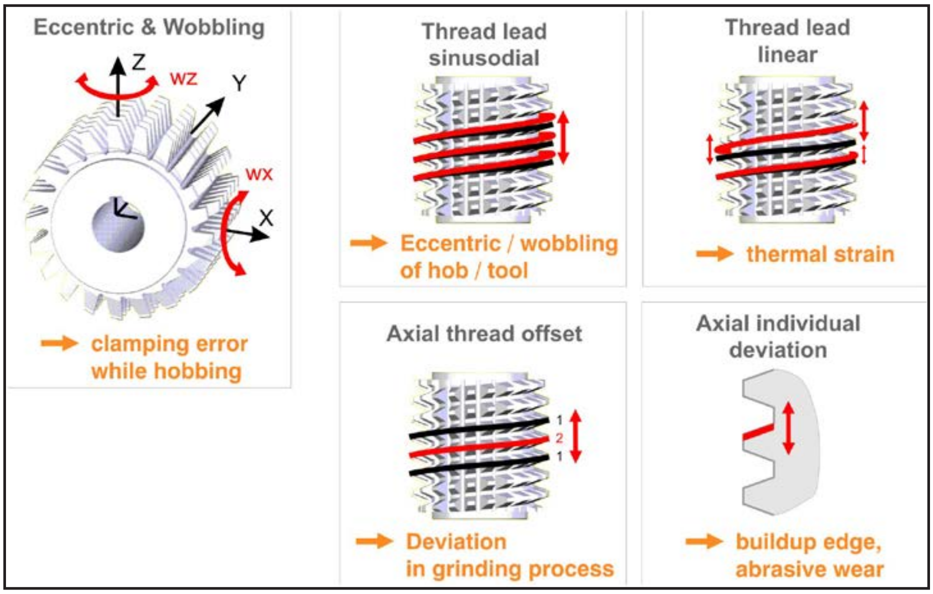

Figure 8 Simulation of tool and clamping errors.

Consideration of Tool and Clamping Errors

In addition to error-free machining the cutting can be simulated using a defective tool. Figure 8 shows the possible tool errors that can easily be generated, as well as overlapped by a few mouse clicks. Corresponding to the clamping error in the hobbing or grinding machine, the tool can run wobbly or eccentrically — which is described on the reference collar by radial and axial run-out deviations. The tool can have a sinus-shaped thread lead deviation if the hob or grinding worm does not run to the reference collars, and a linear thread lead deviation if temperature expansion should occur. With multi-start tools, one thread can be axially displaced with respect to the others; after all, by specifying a deviation on a single cutting tooth, the effects of buildup edge, wear, or cutouts can be easily assessed upon the quality of a toothed gear manufactured in this way.

A hob has been purposely clamped eccentrically and a toothed gear has been machined with it to check the accuracy of the simulation. Figure 9 shows the results measured in blue that are compared with the red ones of the simulation results. The concentricity variation on the main and counter bearings, and their angular position to the machine axis have been modified in the simulation step by step until the test settings — determined with a dial indicator — have been reached. The deviations — in the form of the measurement and calculation — correspond very well with one another.

It is obvious that not only typical, systemic errors must be considered in the simulation, but also the actual errors for each individual cutting edge, as they can be determined by measurement of the tool on a gear measurement device.

Figure 10 shows the measurement of a double-start hob; the profile deviation of the cutting edge, and the axial deviation of each tooth are transferred via an interface and used for the simulation. The differences of the deviation on the left and right tool flanks — and on the threads between one another — lead to different profile and flank deviations on the workpiece that, at this ratio of workpiece teeth to the thread number, are the same on every-second gear tooth. In this calculation a diagonal feed rate of the tool has been entered that leads to a situation in which not all of the same tool teeth are active in the entire tooth trace. The result is greater deviations in form in this area — according to the hob deviations. The combination of simulation with hob measurement unleashes the possibility of predicting with great precision and detail the quality a hob-processed workpiece can attain in the most favorable circumstance. Clamping errors can then be overlapped here in the simulation as well.

Summary

- A new software tool is presented that provides high accuracy simulation of typical errors in the production of toothed gears by hobbing and generation grinding.
- This software enables consideration of any points on the tooth flank and represents all results in the form of a gear measurement familiar to the user.
- A 3D consideration of the twisting and of the topographical deviation pattern becomes possible.
- Comparison of the measured deviation on faulty components with the simulation results displays harmonious agreement. This provides users and planners of hobbing and generation grinder processes in construction and production with a high-performance tool that supports them in the dimensioning of processes and tools, and when looking for root cause deviations.
- With the option to edit the process parameters quickly and easily, the understanding of these complex machining processes and their influence categories is increased significantly.

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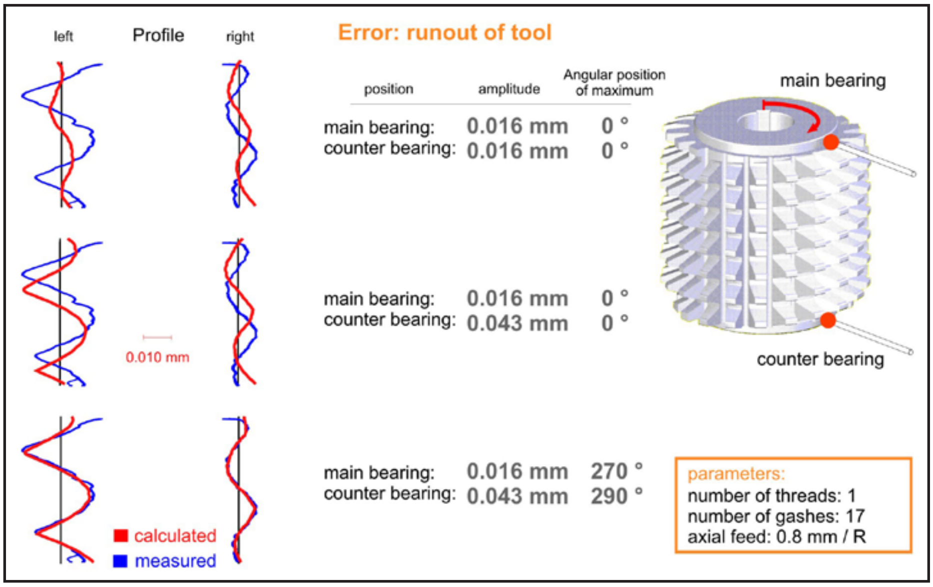


Figure 9 Comparison of measured and calculated profile deviations.

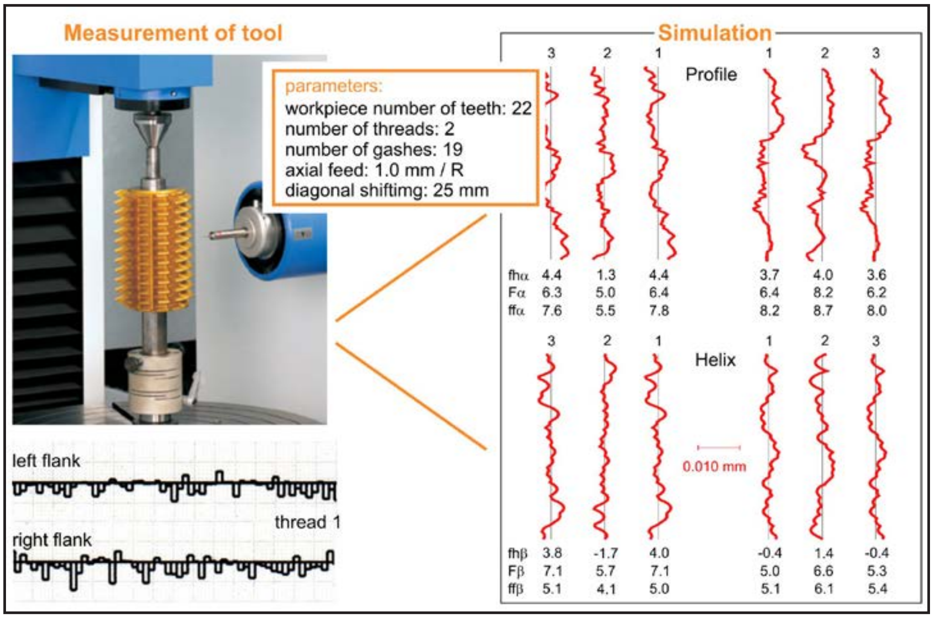


Figure 10 Prediction of workpiece quality from a tool measurement.

Günther Gravel is professor for production engineering at the Hamburg University of Applied Sciences. He is the head of the Institute for Production Engineering. For more than 20 years, Dr. Gravel has studied the measurement of gears. He is now developing software for the analysis of gear measurement and for the simulation of errors in gear manufacturing processes; in fact the software mentioned in this article is part of a software deviation analysis suite. This software can be used to visualize deviations, simulate errors, calculate corrections for the manufacturing process, and evaluate ripples on a gear surface. It has been developed in cooperation with Liebherr and Klingelnberg and is available with all Klingelnberg measuring machines. For questions and practical applications contact *'www.klingelnberg.com'*.

On the Move with Circle Gear

PERSONNEL CHANGES AND EXPANSION HIGHLIGHT CICERO, ILLINOIS GEAR MANUFACTURER

Michael McKernin was recently appointed president of Circle Gear and Machine Company in Cicero, Illinois. He follows in the footsteps of Albert Knez Sr. the company's current CEO and former president of over 30 years. McKernin has held various positions within the company across engineering and sales disciplines during his 25+ years.

McKernin's efforts have been recognized by Charlotte Knez Schmidt and Albert Knez Jr, third generation members of the founding family and current company executives. "Mike has certainly been busy in his new position. Since his appointment, we have relocated our Quality Reducer Division, re-tooled our manufacturing capability and purchased the building directly adjacent to the main works, increasing our total manufacturing space to over 121,000 square feet" said Mrs. Schmidt.

"Acquiring the 77,000 square foot building located next door to Circle Gear earlier this year, allowed us to better utilize manufacturing and engineering resources, while improving overall service to our customer base. Quality Reducer Service (QRS) formerly of LaGrange, Illinois, moved to the Cicero location in March of 2014. QRS and Circle Gear will now be together under one roof," said McKernin.

QRS specializes in the inspection, overhaul and rebuilding of industrial gearboxes. They have long been supported by the manufacturing and engineering expertise of Circle Gear. In addition to QRS, the expanded facility will house two recent machine purchases, a Gleason Model 463 with aircraft quality hypoid/spiral bevel gear tooth capabilities and the Luren LFG-8040 vertical profile gear grinder.

"Much of our sustained growth over the past two years has been in spiral bevel/hypoid product line," McKernin added. "Bevel gear tooth grinding is a logical extension of that product line."

"The addition of **Paul Campion** as general manager of operations opened the door to significant growth in our bevel department. Paul's reputation and expertise are well known in the gear industry. His leadership and 30+ years of experience have been catalysts for growth not only in bevels but across the full range of our product offering," stated McKernin.

McKernin also noted that the versatility, increased production and consistent quality achieved from the new Luren Tooth Grinder were cause to obsolete other machines. "The timing couldn't have been better," McKernin said, "given our recent growth, this machine has allowed Circle Gear to remap our manufacturing footprint and reclaim much needed floor space, while helping to expand throughput in our plant."

A key component for McKernin is to make these changes as seamless as possible for their customers. "The cornerstone of our business model has always included shortened lead-times and breakdown service. The productivity gains and improved workflow from our increased machine capacity and floor space have allowed us to keep customers happy and coming back for more," McKernin said.

Circle Gear, a family owned and operated company since 1951, is an ISO 9001:2008 registered company and a proud member of AGMA (*www.circlegear.com*).

Matthew Cane

RECEIVES AGMA FOUNDATION SCHOLARSHIP

Born and raised in the Chicago area, **Matthew Cane** made the decision to return to school after some trying times during the recession. "I graduated with honors from McHenry County College with my Associates degree in Applied Science – Manufacturing Management, and several certificates including Manufacturing Design Technology," Cane said.

He's currently attending Southern Illinois University (SIU) on the weekends to obtain his Bachelor's degree in Industrial Technology, and working full time as a quality coordinator and tool design engineer at Star SU, LLC.

Cane said a healthy dose of curiosity regarding how things work and how they're made helped him become interested in manufacturing and engineering. "I can't tell you how many broken appliances I took apart as a kid just to see how they worked, but I can tell you I'm a lot better at putting them back together—and there are a lot less parts left over."

Before going to school, Cane took some online certification courses through AGMA. He read in a newsletter about the AGMA Foundation Scholarship and applied once he transferred to SIU. Recipients of the 2014 AGMA Foundation Scholarship included Cane, Ryan Hall and Tyler O'Brien.

"The scholarship is helping to bring advanced education within reach. Everything I've learned, I've been able to directly apply to what I do on a daily basis. While I've had a fairly broad range of experiences within Star SU, my academic pursuits have given me broad experiences in manufacturing. For example, I've been able to go on tours to local heat treat facilities and get to know their process beyond what I would be exposed to in my day to day professional capacity," Cane said.

Cane has been able to draw on all these experiences to further his career in manufacturing. "I've had exposure to so much of the value chain having worked my way up, whether it's shipping and receiving, resharpening tools on a CNC machine, designing cutting tools, or visiting customers and seeing and troubleshooting the application side. Each experience is another piece of the puzzle, and so much of manufacturing is just trying to see the whole picture, to improve a process or product, remove waste, or fix a defect. Learning the upstream and downstream operations is what provides the perspective to be able to solve those challenges," Cane said.

In the future, Cane would like to become more involved with some of Star SU's major automotive projects. "I look forward to continuing to grow in that direction and I'd also like to pursue a graduate degree down the line as well. I'm interested in learning the business management aspects in addition to the technical information I'm learning and applying now," Cane said.

He also has this advice for students interested in pursuing a career in the gear industry: "Take the time to understand the whole process. I understand a lot more about hobbing or shaving a gear because I resharpened and designed those tools. Rake, lead, indexing, etc. are more than just values on an inspection chart, and there are a variety of variables that come together to produce a gear. Understanding as much as you can about those variables is what leads you to control the process and get consistent results."

Getting involved in AGMA is also a good idea. "There are several reasons for my involvement," Cane adds. "I've learned valuable information as a student in AGMA courses, and now they are supporting my degree in Industrial Technology. They also set quality standards I reference in my designs, host technical and networking meetings, and while I love attending IMTS, the AGMA Gear Expo is specific to the gear industry."

The AGMA Foundation offers $5,000 scholarships to assist undergraduate and graduate level engineering students whose programs focus on gear technology and gear research. For additional information, visit *www.agma.org.*

ITAMCO

DONATES CMM TO PLYMOUTH HIGH SCHOOL

ITAMCO (Indiana Technology and Manufacturing Companies) has donated a Zeiss Coordinate Measuring Machine (CMM) to the Precision Tool Manufacturing Training Program for high school students. The donation was announced at IMTS 2014. The new machine is evidence

of ITAMCO's continuing support for the program that Mark Neidig, purchasing manager at ITAMCO, proposed to the Plymouth School Corporation superintendent in 2013.

The new machine will be added to the inventory of precision machining tools housed in the ITAMCO Manufacturing Center on the Plymouth High School's campus in north central Indiana. In addition to ITAMCO's $100,000 initial donation and ongoing technical assistance, the North Central Area Vocational Cooperative (NCAVC) and Ivy Tech are active contributors. NCAVC contributed funds to purchase equipment and the program's trainer is an Ivy Tech employee. Students receive high school credits and Ivy Tech college credits.

ITAMCO provides open gearing and precision machining services and, like many manufacturers, needs highly skilled employees to operate their technologically advanced CNC equipment. Neidig said that he initiated the program because the ITAMCO team wants to encourage high school students to enter rewarding careers in manufacturing. "We need to keep the USA at the forefront of innovative manufacturing, but we obviously have selfish motivations as well. We need skilled workers in our own facilities," said Neidig.

The ITAMCO staff donated a Zeiss DuraMax CMM because it's a world-class machine like the Zeiss CMM machines they use on their own shop floor. The DuraMax replaces the limitations of manual measuring tools with CNC accuracy and flexibility. "Our facility is better equipped than a typical machine shop and we want participants in the training program to be prepared to work on a plant floor like ours," said Neidig. Zeiss generously discounted the price of the machine, contributed 12 educational licenses for their *Calypso* software for the DuraMax, and provided training for the manufacturing center's instructor. The *Calypso* software enables users to create a measuring plan without programming code or text editing.

After only one year of operation, the training program has success stories. Thirteen students have taken Precision Machining I and four were seniors. Three of these seniors are now working at ITAMCO after graduation and one of the ITAMCO employees is continuing his education at Ivy Tech. The fourth student is also working for a local manufacturer. "The companies were pleased with our students' training because they were prepared to work on the shop floor," said Scott Kaser, the instructor for the Precision Tool Manufacturing Training Program and a certified CNC Machinist. "I was just like these kids. I didn't want to go to college but I wanted a good paying job. I like working with them and I enjoy our partnerships with local companies that want to hire them," he added.

LiuGong

WINS DISTINGUISHED AWARD AT BEI ASIA

Creative Group Pte Ltd. held the BEI Asia Awards for the second year running – the first award for enterprises in the Built Environment Industry (BEI) in the Ritz-Carlton Millenia Singapore, Grand Ballroom. With the highest financial turnover and number of years in the industry, LiuGong was awarded the Distinguished Award of the BEI Asia Awards. Dr. Vivian Balakrishnan, minister for environment and water resources, attended the awards event as the guest of honor. Joseph Wong, vice president of LiuGong, was invited to attend the event.

BEI is a pioneer in the industry and the first of its kind in Singapore, the BEI Asia Awards recognize, reward, and honor the achievements of leading enterprises across Singapore's Built Environment Industry. The awards acknowledge both local and locally-based companies who have demonstrated excellence in establishing successful businesses while engaging in best business practices such as corporate social responsibility through sustainable efforts.

"As one of the leading construction equipment manufacturers in the world, LiuGong has been honored with quite a few notable Chinese awards, such as the national quality award, but this is our first such award outside of China. To be awarded this honor from BEI is very special to LiuGong," said Wong. "This recognition will spur us on to continue our pursuit of excellence in the manufacturing of construction equipment placing technology, quality and environmental performance in the forefront of our global pursuits."

Hexagon Metrology

ACQUIRES VERO SOFTWARE

Vero Software is a UK-based software company with a strong brand and proven customer satisfaction track record. Their software aids the design and manufacturing process with solutions for programming and controlling machine tools, addressing the rising challenge of achieving manufacturing efficiencies with high-quality output.

Several well-known brands in Vero Software's portfolio include Alphacam, Cabinet Vision, Edgecam, Radan, SURFCAM, VISI, and WorkNC. The company has large market coverage with offices in the U.K., Germany, Italy, France, Japan, USA, Brazil, Netherlands, China, Korea, Spain and India supplying products to more than 45 countries through its wholly owned subsidiaries and reseller network.

The acquisition strengthens Hexagon's software offerings, providing the means to close the gap of making quality data fully actionable by extending the reach of the newly developed MMS (metrology planning software) to include *CAM* (manufacturing planning software).

"Together with its unique suite of manufacturing software solutions, Vero Software has the expertise, knowledge and resources to deliver even higher levels of productivity to our customers," said Hexagon President and CEO Ola Rollén. "Leveraging our global footprint, the synergies from our combined technologies will advance our strategy, supporting the growing need to integrate all data and processes across the manufacturing lifecycle."

Vero Software will be fully consolidated as of August 2014 (closing being subject to regulatory approval) and will positively contribute to Hexagon's earnings. The company's turnover for 2013 amounted to approximately 80 million EUR.

TorqTek

EXPANDS NORTH CHARLESTON FACILITY

TorqTek Design and Manufacturing, LLC, a supplier of timing gears to automotive manufacturers, is expanding its North Charleston facility. The $12 million investment is expected to create 50 new jobs.

Founded in 1995 as a joint venture of Getrag Gears of North America and Cummins Inc., the company was renamed TorqTek in January 2012 as part of a management buyout. The company is currently expanding to meet motorbike contract demands for industry leaders Harley Davidson and BMW. After exploring options in neighboring states, TorqTek chose to expand its facility in North Charleston for proximate access to its existing and prospective customer base.

Governor Nikki Haley said, "TorqTek's decision to expand in North Charleston further strengthens their longstanding commitment to South Carolina as part of our vibrant automotive industry. We applaud their $12 million investment and the creation of 50 new jobs in Charleston County."

TorqTek currently produces primarily timing gears for the automotive market but has been currently awarded with contracts for transmission components and complete transmission assemblies.

At launch, the new operations will be housed in approximately 100,000 square feet located at 4500 Leeds Avenue in North Charleston with no additional space required. TorqTek employs approximately 138 workers and anticipates hiring 50 associates in the coming months.

ASME

ANNOUNCES POWER TRANSMISSION AND GEARING CONFERENCE

The ASME 2015 Power Transmission and Gearing Conference is an integral part of the ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conferences (2015 IDETC/CIE). This event will take place in Boston, Massachusetts, August, 2-5 2015 (www.asmeconferences.org).

The 2015 IDETC/CIE conference is the flagship international meeting for design engineering. The Power Transmission and Gearing Committee organizes an international conference every four years. This event is a premier meeting for the power transmission and gearing technologists. This meeting provides a forum to exchange ideas and become familiar with the latest research findings, new concepts, and applications that address critical design engineering issues.

Authors, presenters, and attendees are invited to participate in this event to expand cooperation, understanding, and promotion of research, development, and application of knowledge in the many disciplines having influence on power transmission and gearing performance. Dissemination of knowledge by presenting research results, new developments, and novel concepts at the ASME Power Transmission and Gearing Conference will serve as the foundation upon which the conference program will be developed. Topics sought include but are not limited to:

- Gear Geometry
- Gear Analysis, Materials, Fatigue
- Gear Dynamics and Noise
- Gearbox Design, Reliability, and Diagnostics
- Gear Manufacturing
- Lubrication and Efficiency
- Engineered Surfaces and Wear
- Bearings, Clutches, Couplings, and Splines
- Transmission Systems Including Novel Concepts

LES ENGRENAGES LYONNAISE

IGC 2014 a venue where gearing and cutting-edge find common ground

Jack McGuinn, Senior Editor

Soon upon setting down in this beautiful, former (43 B.C.) Roman Colony that is now the City of Lyon, I was careening to my hotel, Mach I-plastered to the back seat of a sleek, shiny-black Mercedes taxi, when I realized I was staring at — zut alors? — *cornfields!* Acres upon acres of them. As if the plane had been diabolically diverted to — Iowa? I'm in Dubuque? Not Lyon? Mon Dieu!

What was this — inverted culture shock? (In fact, no; I'll be frank: I, your intrepid "foreign correspondent" — and here it is — *who has never before slipped the protective bosom of his Homeland's shores* — would never associate cornfields with France. Why? you may ask. French movies are reason enough for me. Pick one: *The 400 Blows*; *The Artist*; *Diabolique*; *Breathless* —not one single cornrow in sight. So I'm copping to personal ignorance here — fin — end of story.

Moving on, things were much more as anticipated at the International Gear Conference 2014, a three-days-of-gears affair convened near the final days August (26—28) in Lyon, Villeurbanne, France (and this seems as good a place as any to dispense with the full moniker and to roll out my unofficial — since none other exists — conference acronym — *IGC 2014*). Approximately 270 attendees from at least 27 countries witnessed proceedings that showcased (at latest count) 120 presentations of technical work addressing, in some capacity, just about every aspect of gearing known to God, man, woman and child. Equally impressive was the representation of leading manufacturing entities, universities and research facilities on hand in support and sponsorship of the conference presenters.

Making IGC 2014 financially feasible were the sponsorships of KiSSsoft, SKF, Romax, Safran, Eurocopter, CETIM and Carnot Institute I@L. Conspicuous by their absence: no U.S. commercial sponsorship; no sign of AGMA, either (but they attended the two-day, conference-organized ISO technical meetings that immediately followed the conference).

And isn't that *always* the way with these rodeos? Show up. *Who cares? Don't* show up? Attention *will* be paid. But the Americans get a pass on this one. There was no U.S. involvement of any kind — excepting presenters — according to INSA Lyon Professor Philippe Velex, distinguished chairman of IGC 2014 because, he said:

"We didn't ask them."

Velex did not elaborate, but in later remarks said that "We did not contact any because a) we were not that sure that the conference was going to be a success with a large international audience; and b) we already had a number of European sponsors and no room left for additional booths. He also stated that U.S. sponsorships would be solicited for the next conference, tentatively slated for 2018. So there is *plenty* of time to work that out.

Meanwhile, he would certainly be loath to admit it, but Professor Velex was in just about every conceivable way *the* face and voice of the IGC 2014 — from delivering the conference opening remarks; to chaperoning several busloads of presenters and attendees to Paul Bocuse's phantasmagoric L'Abbaye De Collonges — truly a culinary Bread & Circus extravaganza that had eyes popping and jaws agape — when they weren't busy chewing; to conferring the Best Paper Award; to delivering the conference's closing comments. (I must add here that at some point the Professor's unflappable demeanor through all of this somehow recalled for me an image of that certain Frenchman with the taciturn yet wry-and-edgy personality that a duelist back in the day would have found appealing when in need of a second to watch his back — quite literally — while his life and family fortune (or simply a gambling debt) were on the line. (*Ed.'s Note*: *We cannot speak for the Professor, but doubt he is currently available for such extracurricular activity*.)

For the record, however, Velex wanted to make one thing crystal clear: "It really was teamwork with significant contributions from the members of the organiz-

Dr. Ulrich Kissling (left) making a point with an unidentified gear industry colleague at IGC 2014 (photo IGC).

ing committee and other colleagues from the lab."

Returning to the question, one eager to elaborate on the U.S no-show issue was Dr. Stephen P. Radzevich, principal engineer-gear transmission, Apex Tool Group, LLC — *and* a presenter as well — at IGC 2014: "Yes, I was surprised with that. No U.S. sponsor participation indicates a lack of interest by the U.S. gear industry in the latest achievements in the field of gear research, design, production, inspection, etc."

The other shoe dropping, rhetorically at least, was Dr. Alex Kapelevich of AKGears LLC (also a presenter) left wondering — whither AGMA?

"I don't know why AGMA has not sponsored this conference. It usually is a sponsor of the VDI/TUM conferences in Munich."

But this very enthusiastic 2014 gathering was certainly not lacking for collectively elite, *academic* sponsorship — and leadership — of the highest international order. And on a state level as well, with the French-based institutions that comprise the country's historical bedrock of scholarship, learning and engineering research: INSA Lyon; The National Center for Scientific Research; LaMCoS; The Technical Centre for Mechanical Industry (CETIM); Ingenierie@Lyon; and ECAM Lyon.


The "Class" of IGC 2014—Presenters and Attendees (photo IGC).

Asked to comment on the general quality of the papers presented, Kapelevich said IGC 2014 was a "typical, engineering university-organized conference, similar to the VDI/TUM conferences in Munich (but smaller), and many other such gear conferences outside of the U.S. There were more professors and PhD students than engineers, like me.

"As a result, many qualification papers were presented. Some of them did not look very practical to me, though I've found a few presented papers quite interesting."

Responding to the same question, Radzevich also gave mixed reviews, first acknowledging what he termed the "newest accomplishments in the field of gearing" while lamenting the dearth of presentations addressing what for him are obviously critical — and under-researched — gearing subjects.

"The papers presented reflect the newest accomplishments in the field of gearing — that is, in gear theory; gear design and manufacture; gear inspection; testing; and so forth," he said. "These papers should be recognized as the best available (for now).

"In the meantime, most of the efforts need to be focused on high-power-density gearing (HPD), high-RPM gearing, and low-tooth-count (LTC) gearing. As for the immediate future, HPD, high-RPM, and LTC gearing will get wider application in the industry."

While certainly not a consensus, put these two responses together, check out the Abstracts (*http://int-gear-conf14.sciencesconf.org*) when they become available, and it is clear that those attending this conference hoping to return home armed with solutions on how to make gears better, faster, and cheaper stood as much chance of that happening as McDonald's does of opening a franchise in Paris. (*They what!?* Never mind).

IGC 2014, after all, was a venue for gear brains — young and not-so-young — to present their — and "what if" may be putting it too glibly — doctoral theses and commercially supported work to an international audience eager to hear something new. This was not a Gear Expo Fall Technical Conference — this was a Gear Expo Fall Technical Conference on Absinthe. "Green Fairy" references notwithstanding, the attendees at this three-day think tank seemed to soak it up. The gear theory, that is. More than one was heard to comment that it was refreshing to hear new ideas and design approaches, to be privy to some down-the-road thinking that they're not challenged with very often. Make no mistake — much of what was heard and seen in Lyon may never translate to the factory floor; many of the papers presented here might never again see publication. Buy many attendees seemed grateful that at least the presenters had their "day in court" before their peers, if you will — an opportunity to put their work out there — maybe for the first time — and to see what becomes of it.

And along of course with the funding it takes to stage such an event as IGC 2014, those grateful attendees should also tip their chapeaux to the cited consortium of French academic institutions that was so helpful in providing a nurturing and welcoming environment that aided considerably in making IGC 2014 a success. And those who came away dissatisfied with the proceedings — or the general direction of the content of the presentations, at any rate — should remember this: the plain truth is that the program notes were quite clear as to what IGC 2014 was about, and it certainly wasn't "back-to-basics":

"*The main objective of this conference is to provide a forum for the most recent advances addressing the challenges in modern, mechanical transmissions.*"

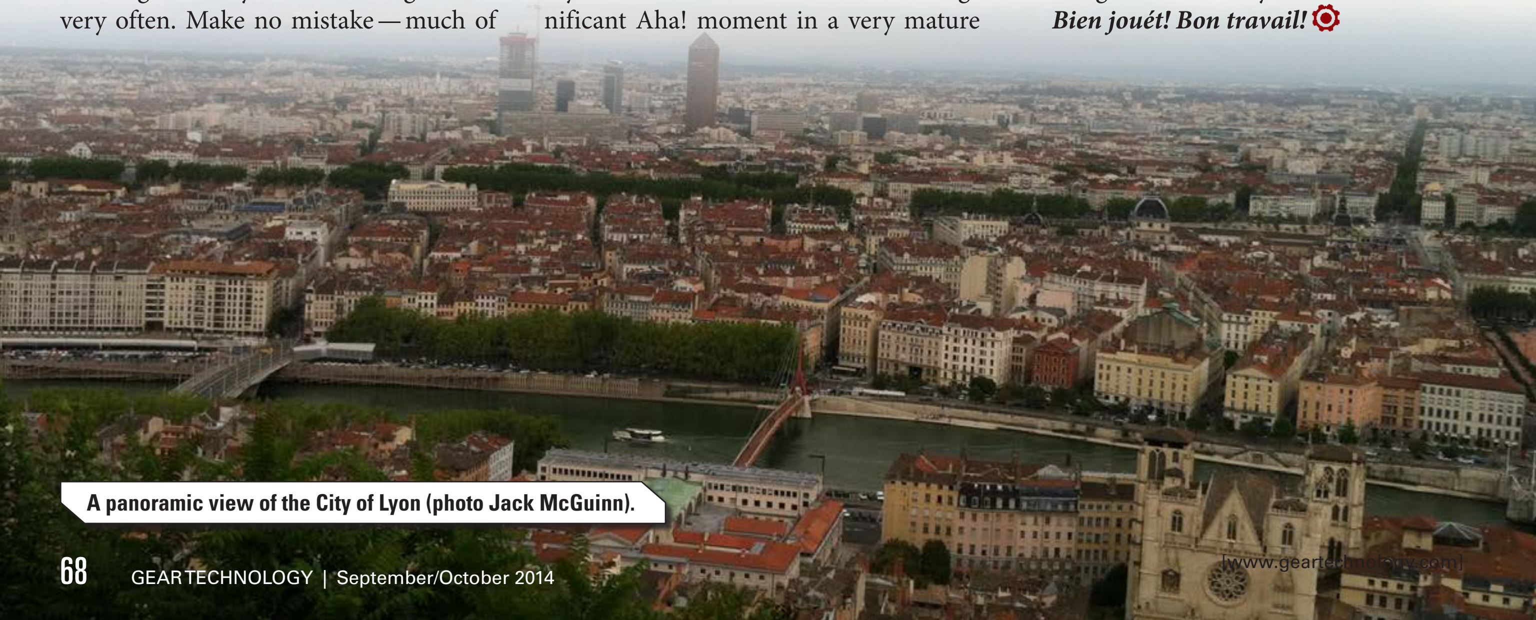
A last word on "success." As made clear throughout this account, the majority of work presented at IGC 2014 dealt with "the future" of gearing — whatever that might be. Who can say from where the next watershed, significant Aha! moment in a very mature industry will come? From which sector? Machinery? Materials? Design? Something not yet imagined?

What matters is that collegial gatherings like IGC 2014 serve a very important need in our slim but — as we well appreciate — critical niche in the planet's transmission of power. Is it not even remotely possible that there were papers presented here — initially dismissed here in Lyon— whose relevance may not yet be appreciated for years to come? I am not an engineer — an engineer of words, *maybe* — but I do know a bit about wonderful things being wrought — not in steel — before their "time." One example: do some research on the life of Vincent Willem Van Gogh.

So to all of the dedicated people responsible for the realization of IGC 2014 — and IGC 2018, n'est-ce pas? — we, as should the entire international gear community, bid them:

Bien jouét! Bon travail!

Prof. Dr. Bernd-Robert Höhn, center, delivered the first of the conference's plenary presentations — on high-ratio transmissions (photo IGC).



A panoramic view of the City of Lyon (photo Jack McGuinn).

October 27–30—Gear Dynamics and Gear Noise Course. Ohio State University. The Gear Dynamics and Gear Noise Short Course has been offered for 35 years and is considered extremely valuable for gear designers and noise specialists who encounter gear noise and transmission design problems. Attendees will learn how to design gears to minimize the major excitations of gear noise: transmission error, dynamic friction forces and shuttling forces. Fundamentals of gear noise generation and gear noise measurement will be covered along with topics on gear rattle, transmission dynamics and housing acoustics. This four-day course includes extensive demonstrations of specialized gear analysis software in addition to the demonstrations of many Ohio State gear test rigs. A unique feature of the course is the interactive workshop session (on Day 3) that invites attendees to discuss their specific gear and transmission noise concerns. The round table discussions on Day 4 are intended to foster interactive problem solving discussions on a variety of topics. Cost is $1,950 per person. For more information, visit *www.nvhgear.org*.

October 27–30—PTC Asia 2014. Shanghai New International Expo Center, Shanghai. Sponsored by Deutsche Messe Worldwide, along with the China Hydraulics, Pneumatics & Seals Association and the China General Machine Components Industry Association, PTC Asia focuses on fluid power; mechanical components, including gears, bearings, chain & belt transmissions, couplings, brakes, and similar components. The AGMA Pavilion will feature AGMA member exhibitors. The 2013 event attracted 1,500 exhibitors and more than 77,000 attendees. The show is co-located with CeMAT Asia (material handling show), ComVac Asia (compressed air and vacuum technology) and Industrial Supply Asia (trade fair for industrial subcontracting and light construction). For more information, visit *www.ptc-asia.com/EN/*.

October 28–30—The Assembly Show. Donald E. Stephens Convention Center, Rosemont, IL. Focused exclusively on assembly technology, equipment and products, visitors will find the latest advances in custom automated assembly solutions, robotics, screwdriving, adhesives, dispensing, plastics assembly, conveyors, fasteners, packaging, workstations, welding, vision systems and more. The target audience includes corporate management, manufacturing engineers, design engineers and purchasing personnel. For more information, visit *www.theassemblyshow.com*.

October 30–November 4—JIMTOF. Tokyo Big Sight (Tokyo International Exhibition Center). The 27th Japan International Machine Tool Fair will feature approximately 5,000 booths covering 45,000 square meters of exhibit space. Exhibitor categories include machine tools (both metal cutting and metal forming); machine tool accessories; cutting tools; grinding wheels & abrasives; gears and gear devices; fluid power; inspection equipment; controls; and related tools and equipment. Among the gear machine tool manufacturers will be Affolter, Gleason, Hamai, Kashifuji, Klingelnberg, Luren Precision, Mitsubishi, Reishauer, and many others. For more information, visit *www.jimtof.org*.

November 5–7—Detailed Gear Design—Beyond Simple Service Factors. Hyatt Place, Las Vegas. This class, taught by Raymond Drago of Drive System Technology, will provide gear engineers, gear designers and application engineers with: a basic introduction to gear theory and standardization; practical considerations and limitations associated with the application of standard AGMA/ISO durability rating analyses; investigation of the differences in stress states among the various surface durability failure modes, including pitting, spalling, case crushing and subcase fatigue; extended load capacity analysis techniques; consideration of friction in the calculation of surface compressive stresses; and much more. The course is designed for gear engineers, gear designers, application engineers, and others who are responsible for interpreting gear design or who want to better understand all aspects of gear design. AGMA members: $1,395 for first registrant from a company, $1,195 for additional registrants. Non-members: $1,895 for first registrant, $1,695 for additional registrants. For more information, visit *www.agma.org*.

November 11–13—FABTECH. Georgia World Congress Center, Atlanta. FABTECH is North America's largest metal forming, fabricating, welding and finishing event, with 1,400 exhibitors and 27,000 attendees expected. Registration is free until November 7. After that, the cost is $50. For more information, visit *www.fabtechexpo.com*.

November 14–20—ASME 2014 IMECE. Montreal, Quebec. The annual ASME International Mechanical Engineering Congress and Exposition (IMECE) is the premier global conference that focuses on today's technical challenges, research updates and breakthrough innovations that are shaping the future of engineering. The Congress convenes engineers, academics, scientists and technologists of all disciplines for the purposes of exploring solutions to global challenges and for the advancement of engineering excellence worldwide. Engineers have long contributed to human progress by solving complex challenges on a global scale. Many of these challenges are found in developing and emerging markets, particularly as they relate to critical infrastructures, such as access to energy, clean water, effective sanitation and healthcare. For more information, visit *www.asmeconfernces.org*.

December 8–11—Gleason Cutting Tools Gear School. Loves Park, IL. This comprehensive 3½ day program is a blend of shop time and classroom study. A coordinated series of lectures is presented by engineering, productions, inspection and sales staff members averaging 27 years' experience. It's an ideal course for those seeking to understand the fundamentals of involute gear geometry, nomenclature, manufacturing and inspection. Training groups are kept small so that individual concerns may be fully addressed. Students are welcome to bring sample gear prints and inspection charts for discussions about interpretation. Shop tours and demonstrations are conducted to visually enhance the understanding of classroom discussions. $895 per person includes handbook and all materials, one group dinner and all lunches. For more information, visit *www.gleason.com*.

CORRECTION

In the July issue the technical paper—"Loaded Behavior of Gears Made of Fiber-Reinforced PA6"—was printed omitting the name of one of its co-authors—Laurent Chazeau. *Gear Technology* regrets the error, with apologies to the author.

From Bauhaus to Gearbox?

Faithful Addendum readers are well aware of its intent: to provide gear-related humor; whimsy; information; history; outside-the-box thinking — and whatnot.

Here's a serving of whatnot.

Arguably the city of Chicago's most compelling, dynamic period — early 1930s -1960 — is dramatically evoked in Thomas Dyja's 2013 book, *THE THIRD COAST — When Chicago Built the American Dream*.

What might make that period of particular — if somewhat offbeat — interest to Addendum readers is the fact that Chicago at the beginning of that time found itself a safe haven for German intellectual emigrés escaping to America after the Gestapo in 1933 had shut down the Bauhaus school of art and design in Weimar, celebrated for its form follows function approach — especially to architectural design.

But you thought this was a *gear* magazine — not *Architectural Digest*. But stay with us here. Berlin architect Walter Gropius (1883-1969) founded Bauhaus in 1919 with the ultimate aim of merging creative imagination with practical craftsmanship, art and *technology*. What's more, Bauhaus courses taught students to focus on the productivity of design.

This got us to thinking — some might say wool-gathering — whether there were a strain of Bauhaus DNA to be found in the make-up of mechanical engineers — i.e., gear designers and engineers.

Today, back in Germany where it belongs, (renamed in 1996) Bauhaus-Universität Weimar actually includes a chair in the field of *process engineering* — bringing it that much closer to our world of gears. Examples of discrete product processes include the casting, molding, forging and surface finishing of the component piece parts of end products or of the end products themselves.

While we think the above indicates a linkage between Bauhaus theory and gear world reality, we decided to bring in some back-up. We called upon Dr. Hermann J. Stadtfeld, vice president, bevel gear technology, R&D, Gleason Corp. Here's his impartial, clear-eyed response to this question: *Have any of the design principles of Bauhaus design theory found their way into gear design — even in subtle ways?*

"The University of Ilmenau in Germany, where I teach my gear class each year, is only a few miles away from Weimar. Weimar was, in the 1800s, until WWII, one of the significant European centers of intellectual thinking and creation; e.g., (German writer and statesman Johann Wolfgang von) Goethe worked there. Still today, there is the Bauhaus School of Design. For people that like the modern Neo-Classic architecture — such as the Gleason Headquarters at 1000 University Avenue in Rochester, NY — the Bauhaus movement was a scary step further into modern, simplistic design.

"However, the Bauhaus style established a synergy between form and function; i.e. — no pedestals or ornaments which don't contribute to the strength of a building or to its functionality are acceptable in Bauhaus creations. As such, it is a very technical- and engineering-dominated style to architect a building. Bauhaus architects are more engineers than artists.

"This particular school of thinking was adopted by engineers in designing of gearboxes, castings for machine components, etc.

"If you study 1700 to 1900 mechanical constructions, you will notice on gearboxes and also machine tools those pedestals and even ornaments in order to design a more esthetic creation. This part of the Bauhaus movement can be found in mechanical structures that often are the surroundings of gears.

"However, two points have to be made:

"Engineering thinking went through a general evolution between 1850 and 1930. None of the Bauhaus teachings found their way into mechanical engineering, but they were part of the same trend in the scene of creatively engaged professionals in Central Europe.

"The function-oriented thinking at this time did not have any influence on gear design, because by the 1700s gear design was already strictly function-oriented, with involutes and rounded root fillets; with face width and tooth thickness as a result of the required torque transmission.

"This would even allow the reverse conclusion, which is that the general trend — *which also led to Bauhaus* — was a result of mechanical designs like gears, internal combustion engines, electrical generators and motors — which from the beginning had been function-oriented."

Thus I believe the case is made that blurs the distinction between the "theoretical" world of Bauhaus and the "real" world of the gear designer/engineer. And that is why some would say:

In every good gear designer/engineer burns the soul of an artist.

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