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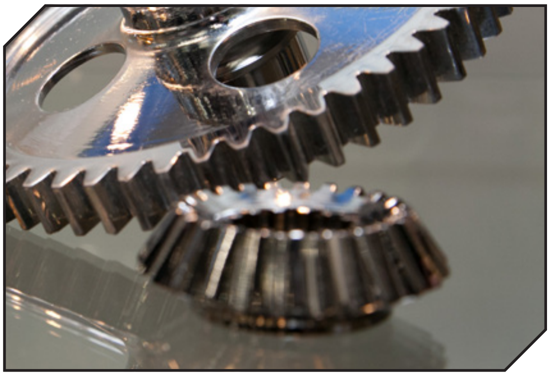

features

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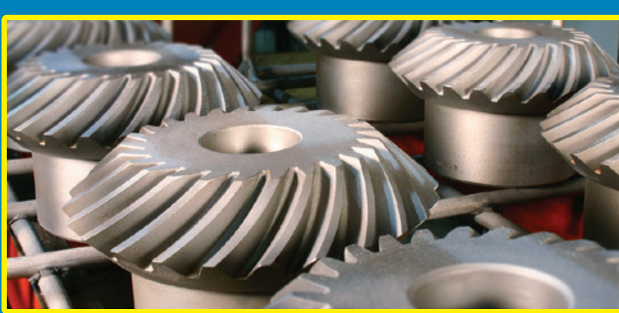

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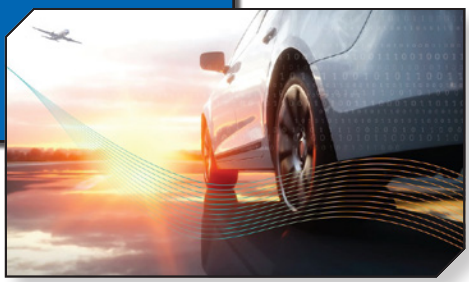
E-Mobility Fluids with ExxonMobil

Today's industrial customers expect gear oils to perform in harsher environments than ever before. Learn how synthetic base stocks can help meet those demands in this online webinar:

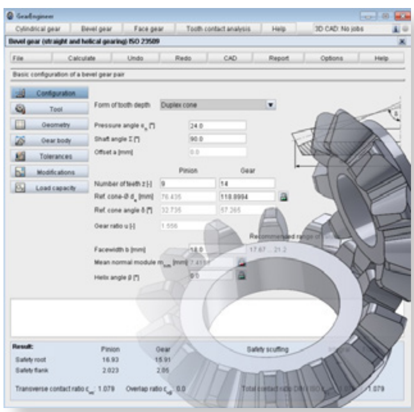
www.geartechnology.com/videos/E-Mobility-Fluids-with-ExxonMobil-/



5-Axis Milling with GearEngineer Software

This video shows the advantages and possibilities of 5-Axis Milling of Gears (cylindrical gears, bevel gears and spiral bevel gears), workflow with special software GearEngineer from GWJ Technology:

www.geartechnology.com/videos/GWJ-Technology-Provides-5-Axis-Milling-of-Gears-with-GearEngineer-Software--/



Gleason 685Q Process Controlled Quenching Machine

Gleason's 685Q Process Controlled Quenching Machine for production quenching of bevel and cylindrical gears, including aerospace, automotive, truck and tractor main drive gears up to 685 mm in diameter. Learn more here:

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Michael Goldstein founded Gear Technology in 1984 and served as Publisher and Editor-in-Chief from 1984 through 2019. Thanks to his efforts, the Michael Goldstein Gear Technology Library, the largest collection of gear knowledge available anywhere, will remain a free and open resource for the gear industry. More than 36 years' worth of technical articles can be found online at *www.geartechnology.com*. Michael continues working with the magazine in a consulting role and can be reached via e-mail at *michael@geartechnology.com*.

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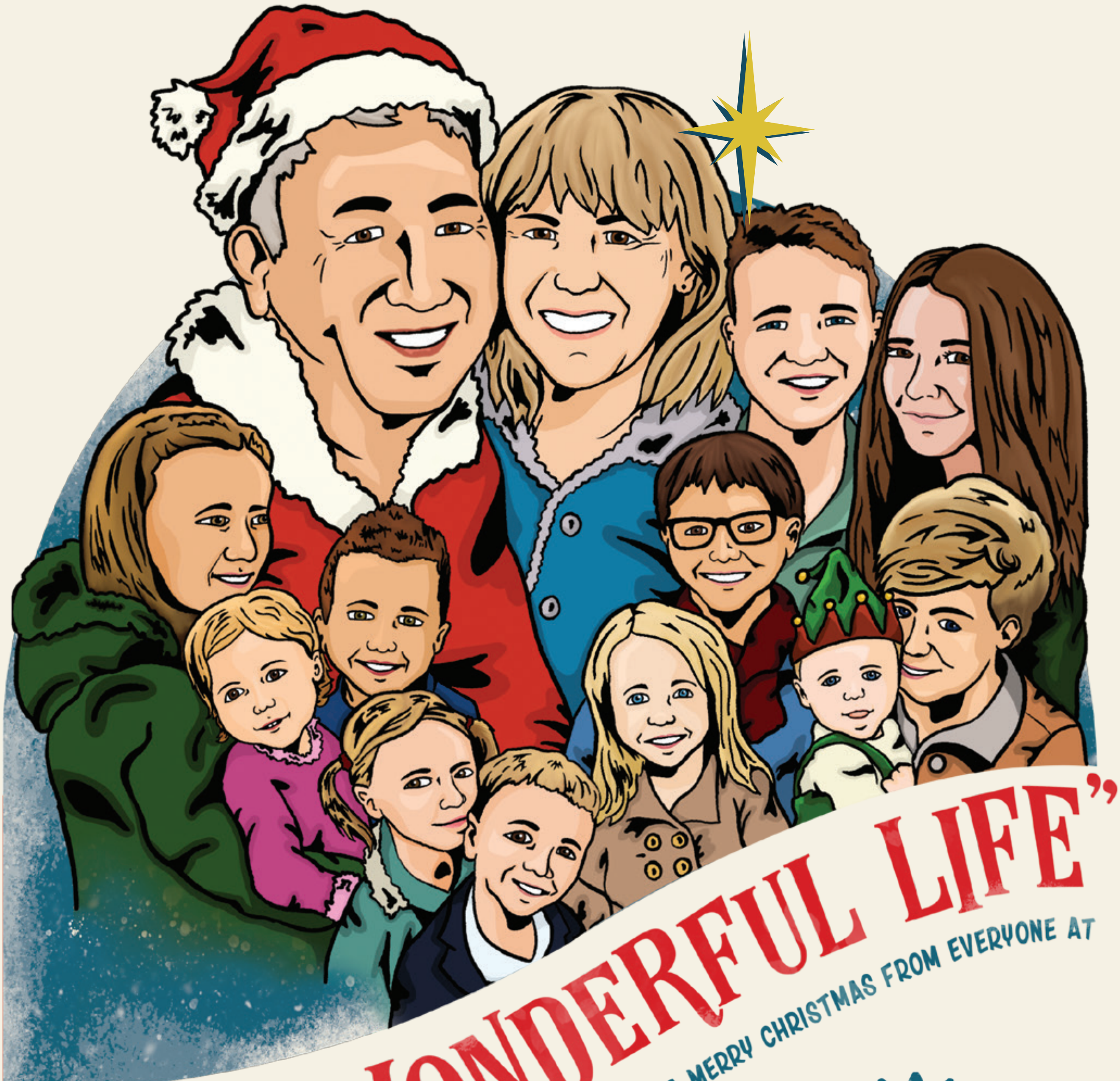

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LEGENDARY RELIABILITY

The Digital Evolution

Publisher & Editor-in-Chief
Randy Stott

Digital communications have been a big part of what we do here at *Gear Technology* since we launched *geartechnology.com* way back in 1996. We were trailblazers back then, venturing off into the great unknown that was the World Wide Web.

Over the years, our digital offerings have evolved. In 2003, we launched the digital version of *Gear Technology.* Shortly thereafter, we created the *Michael Goldstein Gear Technology Library*, the complete digital archive of every article we've ever published. We tagged articles with keywords and created an online searchable database to help you find articles on the subjects you were looking for, whether it was profile shift, elastohydrodynamic lubrication, bending fatigue or what have you. In 2009, we launched our e-mail newsletters, and in 2014 we launched the blog.

Over those same years, the digital landscape itself has changed, with the introductions of Google (1998), LinkedIn (2003), Facebook (2004), Youtube (2005), Twitter (2006), Instagram (2010), TikTok (2018) and so on. We've participated in many of these small revolutions (and continue to do so).

Many print-centric publishers have struggled with these changes. It used to be very expensive to create content. The costs of printing and mailing created a high bar for entry. Not so anymore, because anyone can create content and put it out there for the world to see. And today the distribution of content is controlled by algorithms and the whims of the audience itself via individual consumers' ability to like, upvote, share and so forth.

We've been very fortunate to hang on to our print-centric mindset, because our content is not so easily produced. Not just anybody can talk about the technical aspects of gear engineering. Plus, much of what we produce — like our technical articles — doesn't easily lend itself to the popular digital formats. You can't present a technical research paper in a podcast, for example.

So we're not doing away with the print publication — or the PDF replicas of it — anytime soon. But we *ARE* continuing to evolve with the times. In fact, we've been working hard over the past year — and investing in technology — to help us continue that evolution.

In 2022, you'll see some of those changes, starting with the launch of our new website. The new *geartechnology.com* will come with some important features, such as increased integration of video and social media, as well as our completely revamped online buyer's guide. You'll also begin to see content that's individually customized based on what's most relevant to what you do.

More importantly, we're committed to creating content with a digital-first mindset wherever that makes sense. We're creating videos for *Gear Technology TV* and sharing them on social media (see *www.geartechnology.com/tv/)*. We've significantly increased the topics we plan to cover in our e-mail newsletter, to the point where you should be seeing original content on gear-relevant topics every week (but only if you subscribe. In fact, here's a preview of what you can expect from the newsletter over the coming weeks:

- January 5 – Cutting Tools
- January 12 – Big Gears
- January 19 – Fine-Pitch Gears
- January 26 – Lubrication
- February 2 – Automation
- February 9 – Heat Treating

More than ever, it's extremely important that we know best how to reach you. Maybe your physical address and/or e-mail address have changed. So I urge you to renew your subscription today. Just go to *www.geartechnology.com/subscribe.htm* to sign up for the products you want and specify how you want them. That includes the printed copy, the digital edition, or both. It includes *Gear Technology* magazine, the e-mail newsletter and our other e-mail offerings. The choice is yours.

But no matter how you want to receive our content, we look forward to serving you for many more years to come.

Liebherr

PRESENTS LATEST E-MOBILITY TECHNOLOGIES

New drive technologies in electric mobility are changing the requirements for gears and therefore also for ~~of~~ the quality of the tooth flank surface~~s~~. Manufacturers of gears have to adapt their manufacturing process accordingly. It's good to be able to rely on a technology partner with expertise covering the entire range of production processes and technologies, which enables them to find suitable solutions even for special challenges.

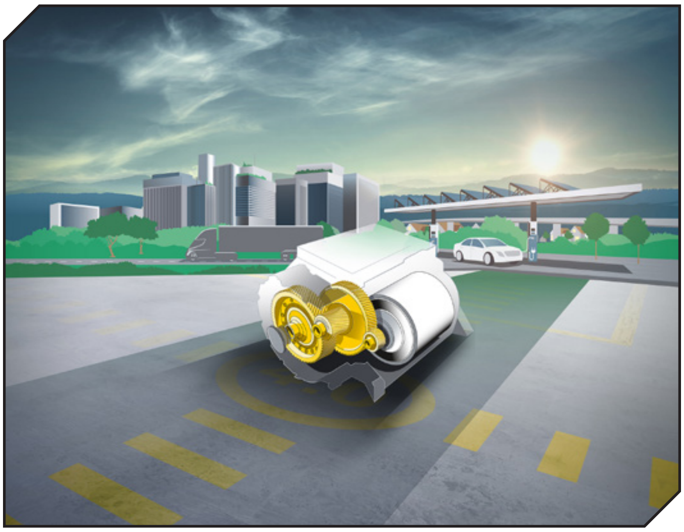


Illustration courtesy of Liebherr.

E-mobility is changing the entire drivetrain in cars, which also changes the demands made of gear components. One of the most important topics is the reduction of noise emissions from the drivetrain while driving. In order to minimize installation space, many parts of the gearbox are manufactured using a lightweight or compact design. At the same time, gear components must become increasingly robust and long-lasting in order to withstand the considerable stress caused by the higher engine RPM.

Process and technology expertise from Liebherr

This results in high quality demands on the tooth flank surfaces, which in turn brings about growing demands on the gear cutting process. Liebherr-Verzahntechnik GmbH has addressed this issue and refined and optimized various technological solutions for e-gearboxes. "We know about the challenges that manufacturers and suppliers must master in terms of quality and process reliability", explains Dr. Andreas Mehr, who is responsible for the technology applications of gear grinding and shaping. "We apply our expertise both in the process depth and in the range of technologies. This means that we can advise and assist customers comprehensively in order to find the optimal solution for them and their application."

Processes and methods

On the process side, generating grinding with dressing-free CBN grinding worms, for example, ensures a high degree of process reliability. During the hard gear finishing, the gears can be precision-ground and polished, which further improves the surface roughness. Tools with small outside diameters machine collision-critical gears with limited tool overrun.

Methods for tooth lead modification are available for the tooth flank topology. For example, topologically error-free grinding with targeted end relief (GER) optimizes the load-bearing capacity. In order to reduce noise emissions, a targeted waviness can be applied to the tooth flank (Noise Excitation Optimization), or the diagonal amount during finishing can be increased in order to distribute the ghost line structure stochastically (Silent Shift Grinding).

Tool material: CBN grinding worms

The more topological modifications are necessary, the more it pays off to think about the tool material: CBN tools can be an economical alternative here. For many applications, grinding with corundum grinding worms is a good solution which, however, reaches its limits when grinding with high topological demands because of the dressing effort required. Dressing-free CBN grinding worms from Liebherr's own production offer a number of advantages: high process reliability due to the long tool life, the avoidance of error sources during dressing, easy tool handling, and considerably reduced measurement and testing effort. For a topology with GER modification, for example, CBN grinding performs much better than corundum grinding with regard to the unit costs. Extremely fine surfaces with an Rz roughness factor of under three micrometers can also be achieved in this way.

Clamping solutions for small components

The challenge when producing gear parts for e-bikes is often in the intricate measurements and small modules. To manufacture these components in a high quality, the grinding process and clamping technology must be fast and extremely precise. Special clamping solutions ensure that even small and collision-critical components, such as drive shafts with a module of 0.6 mm in a gear quality of DIN 1-4, can be machined without difficulty.

E-Bike

Generating grinding example of a drive gear for an e-drive with dressing-free CBN.

Machine concept: economic efficiency and reproducibility

The exclusive Liebherr machine concept provides optimal concentricity and the highest possible reproducibility with a one-table solution — for the controlled and continual manufacturing of parts with quality requirements in the micrometer range, this is a technologically indispensable advantage. Particularly for smaller and medium batch sizes, which frequently occur in manufacturing for e-mobility, this concept is also particularly economical, since the short setup times enable a fast production start.

At eye level with the customer

"We see ourselves not only as product providers but as partners and solution providers", Dr. Andreas Mehr emphasizes. "We take the customer with us on the journey by offering advice and pointing out plausible alternatives so that he can finally make the decision that is best for him." For this purpose, Liebherr has a number of test machines on which all the process parameters for the production of specific parts can be tested and designed, including the tool, the design or measuring software, grinding methods or process parameters, tooth flank modifications or other settings.

The only limits are those set by physics

For example, in one customer's gearbox, noise was emitted despite adherence to the required specifications. Liebherr addressed this issue in an intensive discussion with the customer under strict time pressure. On the test machines, a number of variants for the corresponding component were ground and tested. It was revealed that the cause lay in further parameters outside the grinding process and that the gearbox had to be designed differently. On the basis of these results, the customer was able to optimize its processes accordingly. Noise emissions were significantly reduced, achieving a satisfactory solution within the limits of what is physically possible.

"It was possible to maintain the narrow timeframe because Liebherr has bundled the complete technology and expertise", recalls Dr. Andreas Mehr, who explains further: "Often, there is no 'right or wrong'. Rather, the choice of the optimal process depends on the specific requirements and parameters. At this point, we want to support our customers by honestly weighing up the pros and cons of one method or another."

www.liebherr.com

Helios Gear

EXPANDS GEAR CUTTING TOOL SOLUTIONS

For nearly all gear cutting applications, Helios now offers a solution for consumable cutting tools. Gear manufacturers benefit from Helios's addition of power skiving cutting tools, broaches, the latest PVD (physical vapor deposition) coatings, and improved resharpening services to its current line of gear cutting tools, which includes hobs, shaper cutters, milling cutters, and custom-engineered options. Significantly, Helios continues to offer delivery times on built-to-order tools as quick as four weeks. Said David Harroun, Helios vice-president, "gear manufacturers have access to Helios's world-class cutting tools delivered built-to-order extremely quickly and backed by both expert engineers and reconditioning services."

Helios now offers gear manufacturers engineered power skiving tools. These tools can be used on power skiving machines for a highly productive gear cutting operation compared to traditional methods such as shaping. Helios power skiving tools are available in contemporary powdered metal high-speed

steel and high-performance carbide, designed to optimize each application's geometry, workpiece material, and available machine spindle speeds. When used on a Helios Neo Power Skiving (NEOPS) machine, gear manufactures benefit from a profitably productive combination of quickly delivered, engineered tools and an affordable machine tool platform.

Also new to the Helios line of gear cutting tools are broaches offered in high-performance materials (including carbide) and the latest PVD coatings. Backed by Oerlikon Balzers, Helios offers Altensa coatings, which is the latest generation of aluminum chromium nitride coating engineered specifically for demanding gear cutting application. This coating offers up to 30% increased performance compared to the previous generation. Gear manufacturers that need the most from their cutting tools should speak with the Helios engineering team about this and other options to achieve higher levels of performance.

Helios continues to offer other cutting tool options, too, including hobs, shaper cutters, milling cutters, and uniquely engineered tools for special applications. Helios tools are offered in high-speed steel and carbide with a variety of coating options. Gear manufacturers also rely on Helios expert resharpening service, which has been improved with new optimization for quick turnarounds. Lastly, while supply chain disruption continues to impact gear manufacturers with delays and inconsistency, Helios leads the industry with reliable, short lead times on cutting tools. Gear manufacturers trust Helios for high quality, low cost, fast delivery cutting tool solutions — all backed by a dedicated team of tool engineers to support and ensure each application is profitably productive.

Heliosgearproducts.com

Chiron Group

INTRODUCES TWIN SPINDLE VMC

In response to the automotive and aerospace industries demand for dynamic, precise, and highly productive complete machining processes for their larger structural parts, the Chiron Group introduced the DZ 28 twin-spindle vertical machining centers featuring 1,200 mm spindle clearance and tool magazine with space for up to 60 tools.

"With the 28 Series, we are addressing new customers and workpieces," said Kristoffer Siegmann, head of global account management automotive at Chiron Group. "Previously, only single-spindle manufacturing could be used for components of this size, but the new DZ 28 twin-spindle machines permit considerably shorter cycle times — while delivering optimum part quality."

There are two versions of the twin-spindle machining center available: The DZ 28 P five-axis with pallet changer for high quantities and short cycle times, and the DZ 28 S five axis for direct loading.

This new machining center series can be flexibly configured to completely machine larger-sized structural parts which require maximum surface quality and dimensional accuracy, as well as high production rates and minimal downtime. Users will benefit from the machine's compact layout, available robot or gantry automation, and fully independent Z and X-direction spindles.

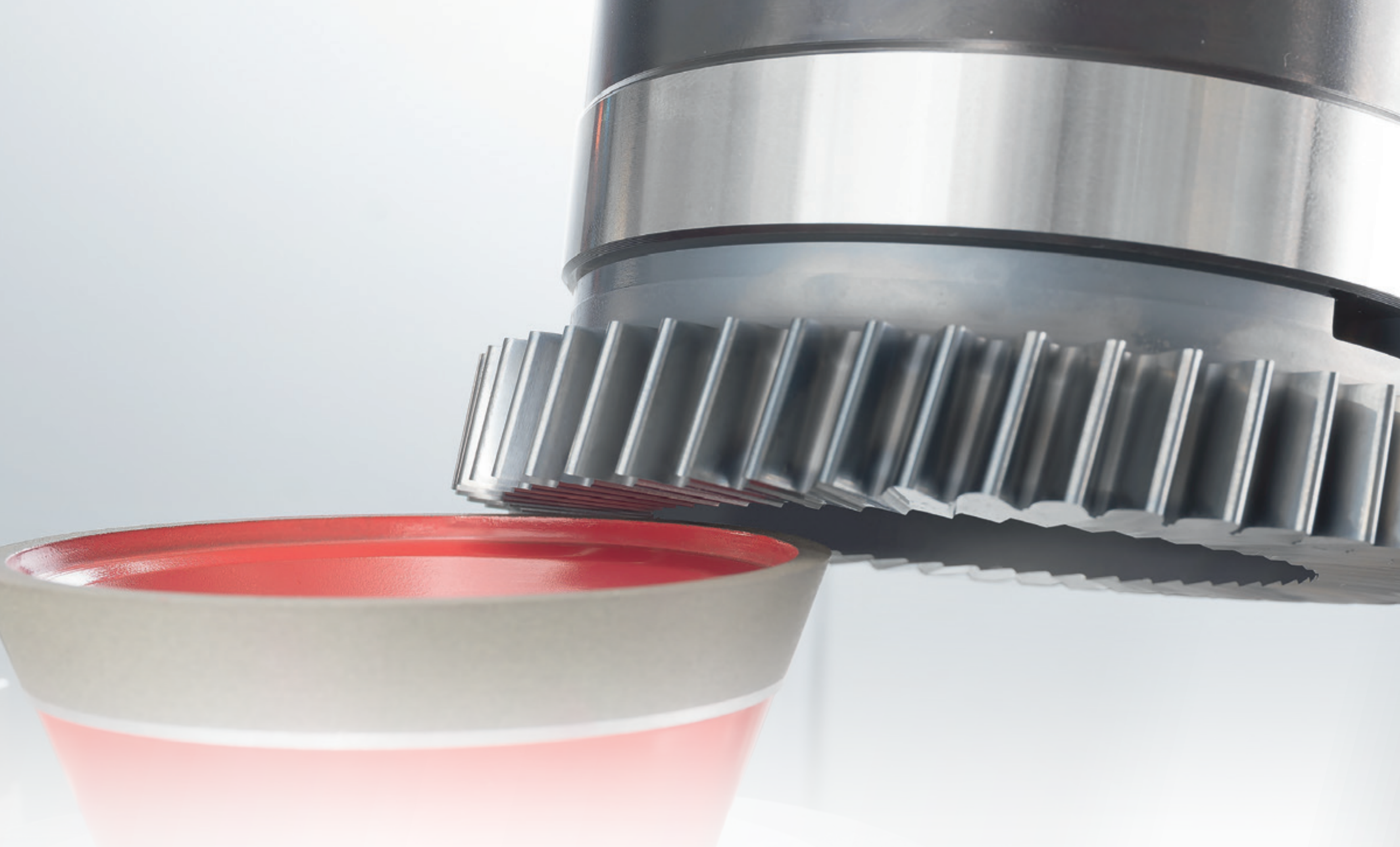
The DZ 28's design allows Chiron's characteristic speed and precision to be applied to more part families such as side beams, battery cases and housings for power electronics, as well as blades, blisks and impellers for engine and turbine building.

High axis acceleration and rapid traverse ensure more dynamic machining has previously been possible with workpiece dimensions in this range. The portal construction, rigid machine bed and active component cooling enable the required degree of precision on the workpiece.

A major advantage to the 28 Series, especially with large workpieces, is that operating and loading take place on separate sides. This means the operator has clear access to the working area and an unobstructed view into the machining process.

The DZ 28 is operated via Chiron's TouchLine, the established operating system from the Chiron SmartLine portfolio. A large display panel allows easy monitoring of the machine condition at all times and as with all of the Chiron Group's new series, the 28 Series is prepared for integration of all SmartLine modules. For example, this includes ProtectLine for preventive protection against machine crashes and ConditionLine for automatic condition monitoring of relevant machine components.

www.chironamerica.com



Consistent Quality with Reduced Cost

Resharpening of cutters for both soft cutting and hard finishing can now be fully automated on Gleason 300PS and 600PS vertical Power Skiving machines. Tool cost-per-piece is greatly reduced, and consistently high quality ensured.

gleason.com/ps-resharpening

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Total Gear Solutions Gleason

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GF Machining Solutions

HIGHLIGHTS EDM TECHNOLOGY AT EMO MILANO 2021

At EMO Milano 2021, GF Machining Solutions highlighted EDM technologies designed to help manufacturers increase productivity and accuracy. These die-sinking and wirecutting EDM machines — along with robust solutions that target the mold and die industry — provide operating precision, superb part quality and automated options.

The show marked the unveiling of the new AgieCharmilles CUT P Pro series of wire-cutting EDM machines designed for increased productivity, always available and ideal for every application with the largest technology database. The series includes the CUT P 350 Pro, the 550 Pro and the 800 Pro with robust designs and intuitive HMI as well as several automation options for lightsout operation.

At EMO Milano, GF Machining Solutions also announced the AgieCharmilles CUT X series of wire-cutting EDM machines, featuring new technologies that significantly increase operating precision. They are capable of holding extreme pitch positioning and contouring capabilities for superb part quality. The series includes the CUT X 350 and the CUT X 500 machines.

Particularly for mold makers in microelectronics, telecommunications, medical technology, connectors and optical systems, GF Machining Solutions demonstrated its AgieCharmilles FORM X 600 die-sinking EDM at EMO. The machine delivers positioning accuracy within 1 µm, and general machining accuracy on the workpiece down to 5 µm, combining speed and precision.

The new Uniqua human/machine interface (HMI), available for the CUT P Pro and the CUT X series, capitalizes on more than a century of EDM technology, with optimal functionality and ergonomics in a 19” vertical touchscreen, full keyboard and mouse. It is designed for every skill level, every approach and every user. For the utmost compatibility, Uniqua supports legacy file types from various EDM manufacturers. It also creates, imports, modifies and executes sequential (ISO-based) and object-oriented (dynamic) programs from previous versions of VISION and AC CUT. With offline and at-the-machine programming, ISO-based functionality and object-oriented programming, Uniqua provides a powerful graphic tool with integrated CAM and also ensures compatibility with major CAD/CAM programs.

With Intelligent Power Generator (IPG) technology, CUT P Pro series machines deliver surface finishes as smooth as Ra 0.08 µm and heighten accuracy with integrated thermal regulation that allow to achieve an accuracy of ±2µm.

Linear scales and rotary encoders form a double measuring system that protects the X, Y, Z, U and V axes. In the event of a collision, the system differentiates between the linear and the rotary encoder, and the energy absorber system automatically stops the axes without damage to machine or workpiece. This full protection applies at machine speeds of up to 3m/min.

www.gfms.com

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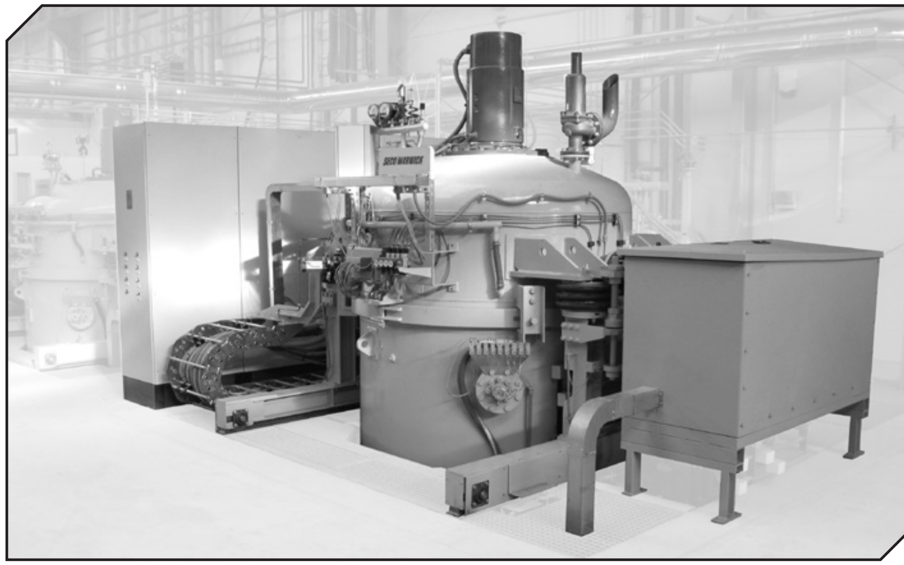
The Pit LPC is an advanced 21st century pit-type gas carburizing furnace for low pressure carburizing (LPC) of large parts or parts requiring deep case depths. As a modern alternative for atmosphere furnaces, the Pit LPC can reduce heat treating costs and improve production while improving the environment by operating in vacuum at higher temperatures than atmosphere furnaces can achieve. The Pit LPC also increases heat treater's production throughput without purchasing additional equipment, since a single Pit-LPC furnace is equivalent to the capacity of three atmosphere furnaces, and it can be reconfigured to fit into the space of an existing atmosphere furnace. Additionally, a single vacuum furnace provides more capability since it can handle gas carburizing on larger and longer workpieces.

Pit LPC is a state-of-the-art pit-type furnace solution meeting the most stringent environmental standards, while increasing worker safety through



All The Gear Cutting Tools You Will Ever Need Are Right Here

DTR is one of the world's largest producers.

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DTR is a world class supplier of the finest high performance long-life gear manufacturing tools, for small and large gear cutting applications. Established in 1976, we are one of the world's largest producers of cutting tools, shipping to over 20 countries.

DTR offers a full line of gear cutting tools including:

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- Shaper Cutters
- Milling Cutters
- Chamfering and Deburring Tools
- Broaches
- Master Gears

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PHONE: +82.32.814.1540
FAX: +82.32.814.5381

elimination of flammable and explosive atmospheres. High homogeneity of process parameters has a direct effect on the thickness of the carbonized layer and, as a result, on the quality of the processed workpieces. Plus, the unit can be reconfigured to the client's needs; SECO/VACUUM will adapt the Pit LPC furnace so that it can be installed in the old atmosphere furnace bay.

This LPC vacuum furnace is perfect for manufacturers carburizing large or long elements such as gears, bearings, drilling tools and other elements requiring thick case depths and it is a great furnace for companies who want to increase their production capacity without purchasing additional equipment (1 Pit LPC = 3 atmosphere furnaces), or save space by replacing three machines with one that fits into the same space as one.

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United Grinding

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On October 13–14, United Grinding North America opened its doors for Evolution to Revolution, a precision CNC grinding industry event filled with live machine demonstrations and technology innovations. Along with an 11-station display of part-production and automation solutions, the company also unveiled its Customer Oriented REvolution (C.O.R.E.) technology. Here are some highlights:

BLOHM PROFIMAT MC Aero

Creep Feed and Profile grinding have the reputation of a basic 3-axis machine producing a single part feature or operation. Five-axis systems, long popular in the Aerospace market, have adapted to more general production applications that require multiple features in various orientations, all with exacting tolerances and fine finish. In this session, you will learn how the five axis features of the BLOHM PROFIMAT MC Aero allow combining multiple grinding applications into a single set up, reducing setup, handling and

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production costs.

The BLOHM PROFIMAT MC Aero is the third generation of the highly successful MC platform that utilizes a moving column concept to provide a large and flexible workspace inside a compact machine envelope. This machine was originally designed for the aerospace industry, utilizing fixe-axis movements and super abrasives to deliver exacting tolerances on complex forms ground into difficult to machine material.

Since the introduction of the BLOHM PROFIMAT MC Aero in 1999, there are over 250 units installed worldwide, and has expanded to serve markets outside of the aviation industry, such as energy, machinery, and mold and die.

STUDER S33

STUDER technology excels at delivering flexibility and mastering unique configurations to achieve unique results. Attendees learned how the combination of hardware and software enables the STUDER S33 to use an ID wheel to grind the OD on a transmission shaft — and found out why that's the right way to tackle this difficult application.

STUDER S11

Manufacturers need to make every square foot of production space count toward optimal productivity. Attendees learned how the compact performance of the STUDER S11 and its optional configurations for match and edge grinding help manufacturers achieve that efficiency, demonstrating how the machine grinds a standard shaft with multiple ODs.

BLOHM PROFIMAT XT

Continuous dress creep feed (CDCF) grinding is a grinding process that's gaining popularity, especially among manufacturers that require high stock removal rate, high precision, AND fine surface finish quality. In this session, attendees learned about CDCF, and some of the applications where it excels, as well as a live demo of a CDCF rough pass, then a finish pass to see up-close-and-personally the material removal and surface finish that CDCF can deliver.

Grinding.com

WFL Millturn Technologies

INTRODUCES M20 MILLTURN MACHINING CENTER

WFL Millturn Technologies recently introduced the new M20 MILLTURN complete machining center.

Alongside gear skiving technology, there is clear trend toward automation and the integration of sensors. The latest solutions from WFL range from smart software to screw programming through to intelligent tools and clamping devices.

The M20 is available with a tailstock or counter spindle and features dynamic and powerful drives. The turning-boring-milling unit with integrated spindle motor and a B-axis with torque motor are entirely new features. The turning output of up to 44 kW means even hard-to-machine materials can be handled with ease. The milling spindle with up to 25 kW and 20,000 rpm is ideally equipped for all machining tasks. In terms of the tool system, there is the option of using HSK 63 or Capto C6.

The individual tool holder with B-axis on the lower slide is a real highlight. The upper and lower system can be used simultaneously, and both systems are supplied by a reliable and dynamic tool changer from a shared magazine. This allows even complex components to be machined with optimal efficiency.

The tool can be moved up to 100 mm below the turning center, so drill patterns with diameters of up to 200 mm can be produced on the face with a high level of precision and without turning the C-axis. Another key benefit of the machine is the possibility of easily integrating a wide range of automation options. Depending on the customer's requirements, articulated robots, gantry loaders or an integrated production cell with the associated peripheral equipment can be implemented. The newly integrated production cell 'intCELL' is fitted on the right-hand side of the machine and will also be presented to the public for the first time at EMO. The workpieces are supplied on a strip accumulator.

Furthermore, it is also possible to automatically switch the tool to the lower individual tool holder with B-axis. This makes it possible to set

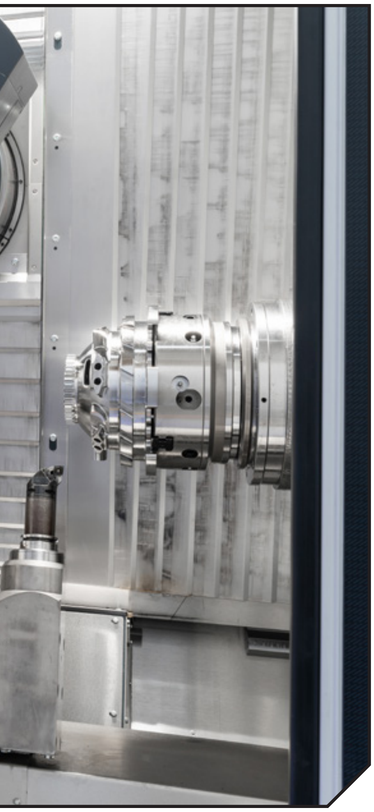
up the tools parallel to machining time and to automatically access the stock in the magazine. Stored tools can therefore be placed in the upper and lower tool holder. With the integrated loading concept, WFL has reduced the space requirement by 50% in comparison to a conventional produc-tion cell.

The M20's integrated loading feature is designed for chuck parts with a diameter of up to 300 mm and a workpiece weight of 15 kg. For shaft parts, a workpiece diameter of 100 mm and a workpiece length of 300 mm is possible.

The new operational data acquisition system is myWFL Cockpit. Machine and program states will be displayed according to chronological order, productivity and technical availability. You can view this on a web browser via the control system, either on a PC or a mobile device. This means that the user can always be well-informed about their machine productivity. Also new with myWFL Cockpit is the integration of the energy usage measurement device myWFL Energy which displays the current power and energy consumption data and that of each workpiece.

Another highlight of myWFL is the integrated condition monitoring cycle. When the cycle is running, the friction values of the axes and spindles, as well as the temperature in the milling spindle housing and the vibration or the rolling bearing condition value of the front milling spindle bearing are continuously recorded and stored on the control system. Using Condition Monitoring Viewer, it is possible to select the data of the various condition monitoring runs on the control system, graphically overlay them and analyze them according to time in this way. This allows for the early detection of possible malfunctions and minimizes unplanned downtimes.

www.wfl.at



Sandvik Coromant

LAUNCHES COROCUT QI

Sandvik Coromant has launched CoroCut QI, a range of internal and face grooving inserts designed for smaller diameters. Optimized to enable a lighter cutting action and reduced cutting forces, CoroCut QI ensures high process security, reliable grooving operations and precise chip evacuation, resulting in high surface quality grooves.

The addition of CoroCut QI completes the CoroCut Q platform, which already consists of CoroCut QD for parting off and CoroCut QF for secure face grooving. CoroCut QI provides a comprehensive selection of optimized tools for numerous parting and grooving applications, designed specifically for smaller diameters. All inserts fit both internal and face grooving tool holders, making it easier for users to select the right tool.

CoroCut QI is divided into internal grooving and face grooving application areas, and is an upgrade of the T-max

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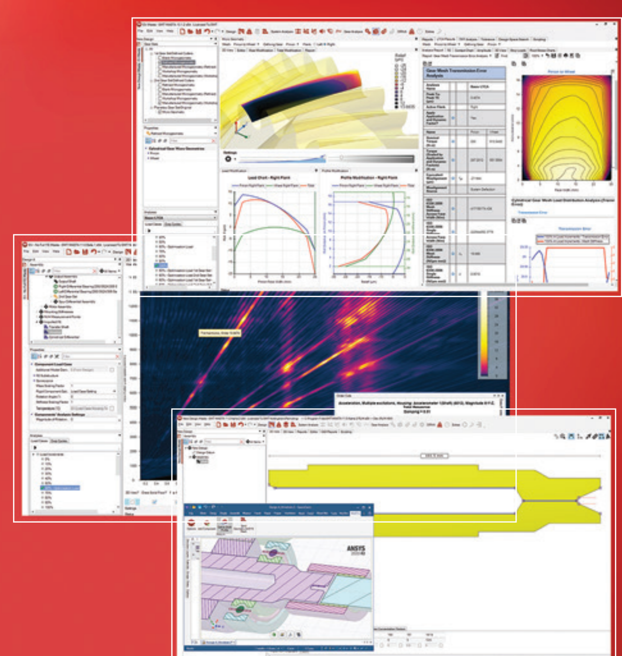

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Q-Cut 151.3 program. The improved design allows for greater chip control, a 10% productivity increase, 20% improved tool life aided by tighter edge-rounding tolerances and internal coolant for both internal and face grooving tools.

Key features of the CoroCut QI include an optimized tip seat angle for lighter cutting action and cutting forces that aid vibration-free machining, a rail insert seat for a stable and precise insert position ensuring minimal insert movement. In addition, screw-clamped tool holders ensure stability and high process security, and inserts with high edge line quality increase tool life and surface quality.

"Grooving can be a difficult technique to master," said Angélica González, product manager of the CoroCut Q platform at Sandvik Coromant. "Long overhangs, difficult chip evacuation and stuck chips are frequent problems when machining internal and face grooves. CoroCut QI has been developed to tackle these challenges to help achieve optimal results. Besides this, most CoroCut QI tools have internal coolant channels that deliver coolant directly to the cutting zone to enable efficient chip evacuation with minimum damage to the surface.

"The smaller the groove, the harder it is to machine. To combat this issue, CoroCut QI inserts are specifically designed for small diameters that require great precision. For example, the minimum hole diameter for internal grooving is between 12 and 60 millimeters (mm) with a cutting depth of two and eleven millimeters. Face grooving inserts can be used in a first cut diameter between 16 and 102 mm, with a cutting depth of 5.5 to 20 mm."

The insert geometries include -GF, a ground sharp insert for internal grooving, -TF with direct pressed geometry for face grooving and internal grooving and turning, and -RM, ideal for non-linear turning such as internal and face profiling.

"CoroCut QI is the upgrade to our previous grooving system," continued González. "In fact, performance tests compared with competing tools have demonstrated better process security and chip evacuation for a higher quality surface finish."

www.sandvik.coromant.com

Lowering the Temperature of Gear Oils with Performance Polymer Technology

Shubhamita Basu, Ph.D., North America Product Manager, Industrial Oils and
Carlos Nazario, North America Product Manager, Grease Additives

Companies that depend on industrial enclosed gears and open-gear systems are always searching for the best way to keep those systems lubricated while keeping the oil cooler. Higher operating temperatures can be detrimental for the quality of oil which can, in turn, cause gearbox durability issues. Reducing temperatures while maintaining adequate protection is paramount, as these gears are part of intricate operations that can cost significant time and money should they wear down or break.

While mineral oil-based fluids used to be the standard, operators are increasingly looking for the better protection offered by synthetic oils using Polyalphaolefin (PAO)-based formulations. PAO-based oils do perform well in these heavy-duty applications, but they can be significantly more expensive than their mineral oil counterparts. For lubricant manufacturers, the challenge is to create synthetic industrial gear oils (IGOs) and open gear lubricants (OGLs) that can offer the appropriate protection while keeping costs reasonable.

Tests performed on lubricants with performance polymers (PPs) have shown their ability to achieve both of those goals. In this article, we will examine the history of IGOs and OGLs, what a PP is, how lubricants with PPs perform under real-world conditions and what advantages they provide for IGO and OGL end users.

The History of Industrial Gear Oils and Open Gear Lubricants

Both IGOs and OGLs have undergone significant changes over the past 50 years. Engineering advancement has led to the development of much smaller enclosed gearboxes that are capable of producing higher power throughput compared to their mammoth forebears. These compact and more powerful gearboxes need a much smaller volume of IGOs leading to incomparable stress on the oil.

OGLs have also evolved significantly. Historically, OGLs were made of asphaltic bases without significant additive treatments, and there was no differentiation for OGLs based on end usage. Over time, OGLs have become more complex as scientists began to recognize that different open gear applications required different types of lubricants.

To address the shortcomings of conventional IGOs and OGLs in mineral oils, synthetic formulations are typically used. Using PPs can lead to the development of a new way to formulate synthetic IGOs and OGLs. In both cases, new and improved PPs offer specific advantages over traditional formulations.

What is a Performance Polymer?

PPs are a versatile class of polymers with unique architecture that offer superior thickening efficiencies, low traction coefficients and high shear stability. Depending on the end use applications, PPs can be used both as viscosity

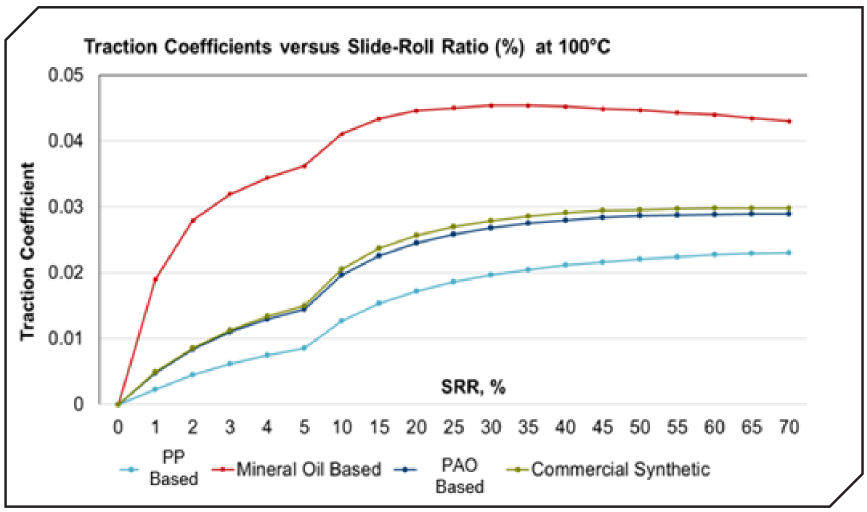


Figure 1 Traction Coefficient.

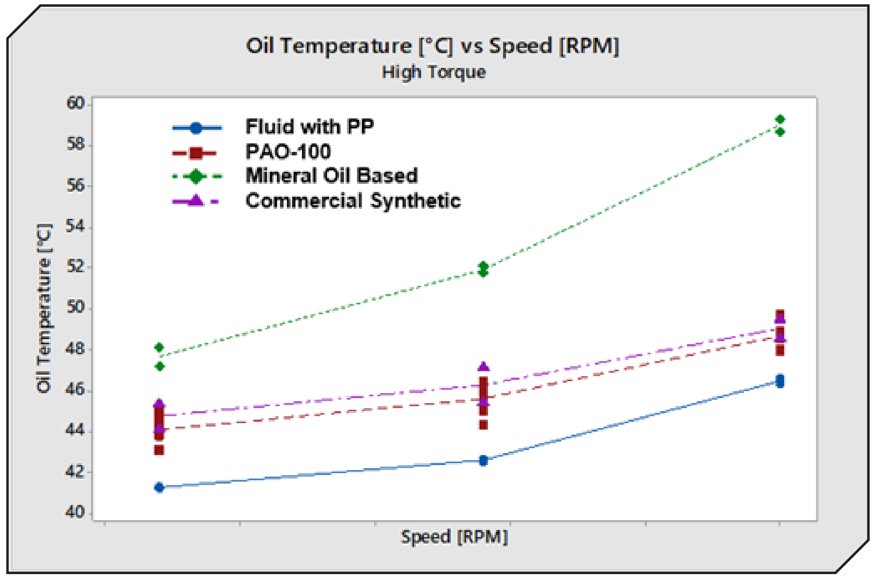


Figure 2 Temperature reduction by worm gear.

modifiers as well as base oils. They also exhibit excellent thermal and oxidative stability and can be used in incidental food contact applications and are NSF HX-1 certified.

The versatile nature of PPs allows them to be used with PAO base oils as well as with mineral oils. When added to more conventional base oils, PPs can elevate the performance of the resulting fluids by lowering the traction coefficients and operating temperatures while increasing overall energy efficiency—and these advantages are demonstrated in extensive statistically validated laboratory testing.

Experimental Design to Test PP in IGO Formulations

One of the greatest threats to industrial gear systems is the high temperatures under which they operate. After all, higher operating temperatures can cause durability issues and lead to poor film thickness in many applications. The goal of the laboratory test was to determine whether PPs could reduce temperatures enough to protect bearings while preventing micropitting and white etching cracks.

In the laboratory, four different fluids were tested:

- Mineral oil-based IGO.
- Commercial synthetic oil.
- Synthetic IGO with heavier PAO in PAO base oil.
- Synthetic IGO with a PP in PAO base oil.

Mineral oil-based IGO and the commercial IGO were the poor and good reference oils used in the study. Both of the test fluids—PP-based and conventional synthetic with heavier PAO—used the same performance IGO additive at 1.8% weight.

The four fluids were tested to measure their traction coefficients, temperature reduction and energy efficiency. Temperature reduction was measured using an in-house worm gear efficiency rig as well as an FZG rig.

What Do These Tests Reveal? The charts above showcase that IGOs

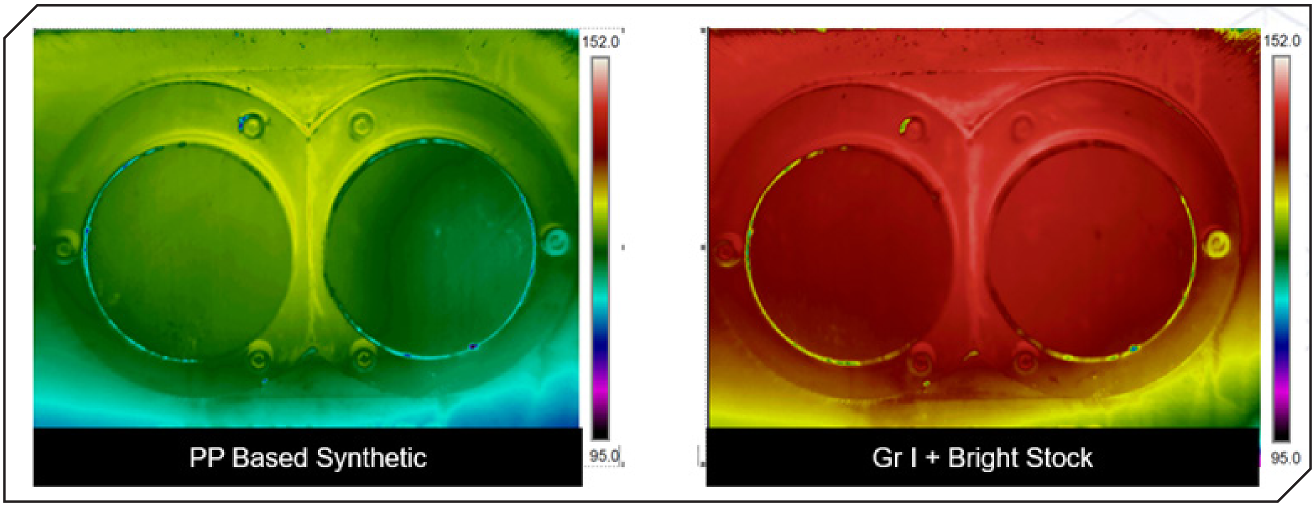


Figure 3 **Temperature reduction by FZG rig shows that IGO formulated with PP runs 17 °C cooler compared to conventional mineral oil-based formula.**

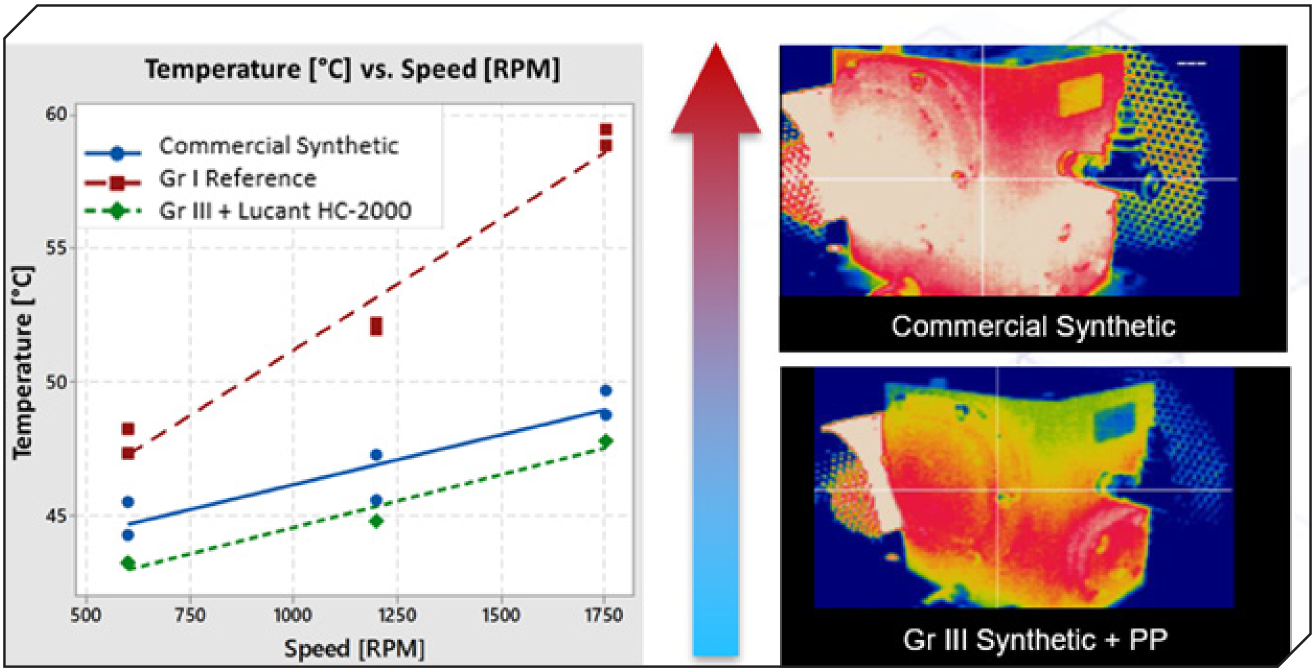


Figure 4 **Gr III Synthetic with PP vs. PAO Synthetic.**

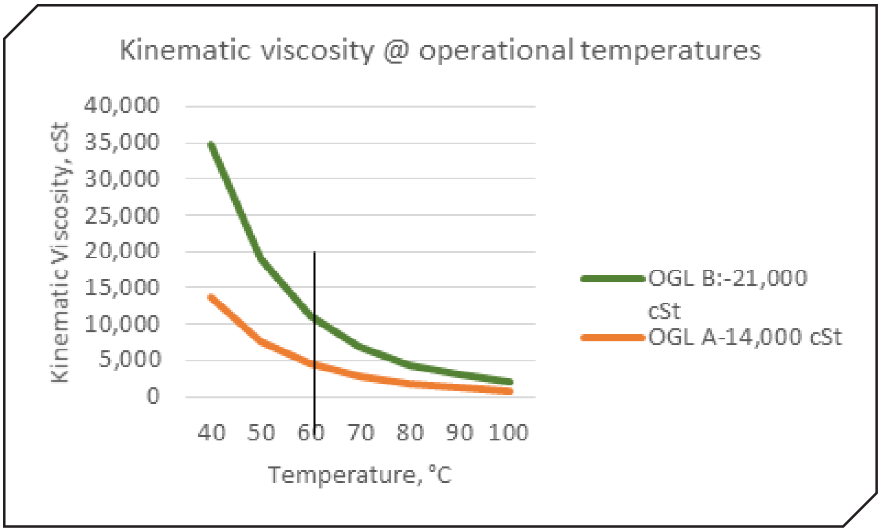


Figure 5 Viscosity of Lubrizol's OGLs with PP technology at different temperatures.

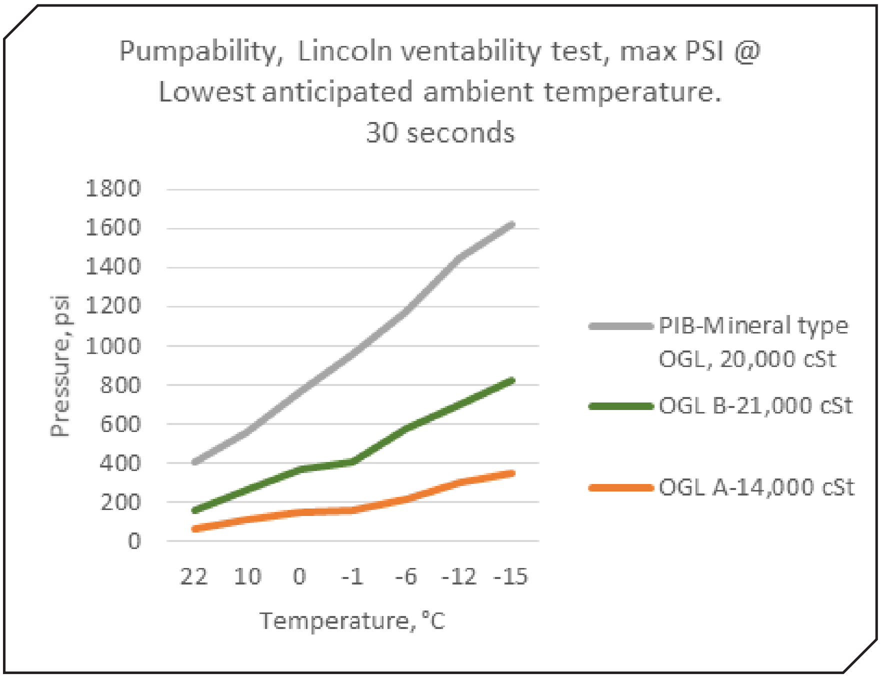


Figure 6 Residual pressure at lowest testing temperature.

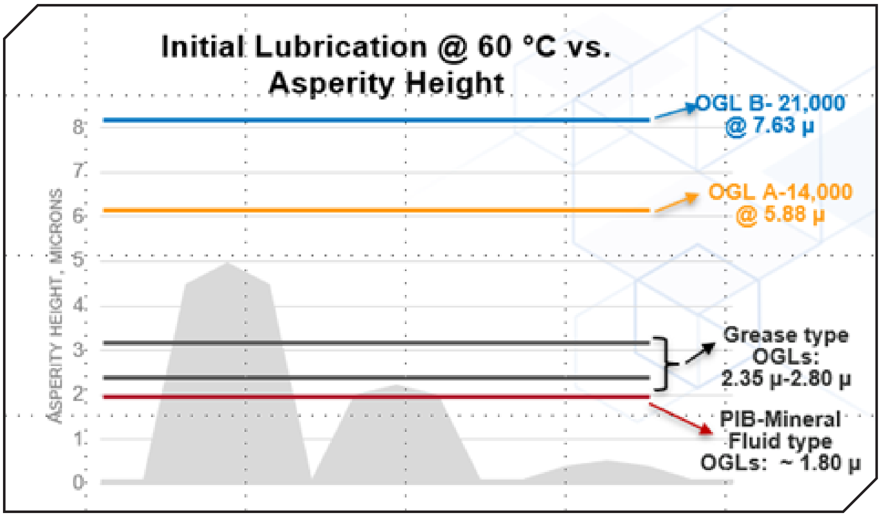


Figure 7 Comparing different OGL tiers film thickness at typical operational temperature.

formulated with PPs can demonstrate lower traction coefficient compared to even standard PAO-based synthetic IGO, which can reduce the gearbox operating temperature significantly. Temperature reduction by the FZG rig shows that IGO formulated with PP runs 17 C cooler compared to conventional mineral oil-based formula.

PPs can be used with Group III base oil to generate performance similar to or slightly better than conventional PAO-based synthetic IGO, and this offers a more cost-effective way of formulating synthetic IGOs.

The results of those tests (seen in the illustrations below) reveal that PPs perform equally well in the less expensive oil as a base. This means that IGOs with PPs can offer the same protection as the more expensive PAO-based synthetics and can provide a cost-effective alternative.

Experimental Design to Test PP in OGL Formulations

Open gears can range in size and be up to 90 feet in diameter. They take 12 months to manufacture and cost nearly $1 million, so keeping them in appropriate working order is paramount. OGLs must be designed for boundary and mixed lubrication as well as high viscosity for full-film lubrication.

To see how PPs perform in OGLs in the real world, three different fluids were tested:

- Grease-type OGLs.
- HV PIB-mineral type OGL.
- Fluids formulated with PPs.

A basic performance test was performed on the fluids to determine the kinematic viscosity at different temperatures, low temperature fluidity or pumpability, theorical film thickness in typical gear sets at operational temperatures, temperature reduction and energy efficiency.

The results (seen in the illustrations above) reveal that OGLs with PPs provide superior lubricant film thickness at initial and operational temperatures that are lower than their more traditional counterparts. These factors improve the overall performance of the OGL and provide more protection for the systems in which they are used.

Our View

Synthetic IGOs formulated with PP as the viscosity modifier can offer reduced operating temperature, higher energy efficiency and low traction coefficient while reducing the total formulation cost by 20%-40% compared to a conventional synthetic formula. This newer formulation approach can extend oil drain interval and offer a more sustainable solution to IGO development.

In OGL, the performance polymer provides versatility as a base fluid. It also provides improved performance characteristics to OGL used in the mining, cement and sugar cane industries. Finally, it provides product sustainability, as well as reduces lubricant consumption and energy usage.

For more information on industrial gear oils, open gear lubricants and performance polymer technology, please contact your Lubrizol representative.

Dr. Shubhamita Basu is the North America Product Manager for Industrial Oils at Lubrizol, where she manages the hydraulic fluid, industrial gear oil and turbine oil portfolio. Dr. Basu has worked extensively in developing new molecules, engine oils and limited slip-gear oil applications, as well as formulating hydraulic fluid and industrial gear oils. She has also led an energy efficiency initiative and spearheaded environmentally acceptable lubricant development.

Carlos Nazario is the North America product manager of Grease Additives for Lubrizol. He has worked extensively in developing and applying new lubricants for heavy-duty equipment and has formulated specialized extreme-pressure greases and gear oils, open-gear lubricants and energy-efficient and environmentally acceptable lubricants for heavy-duty equipment.

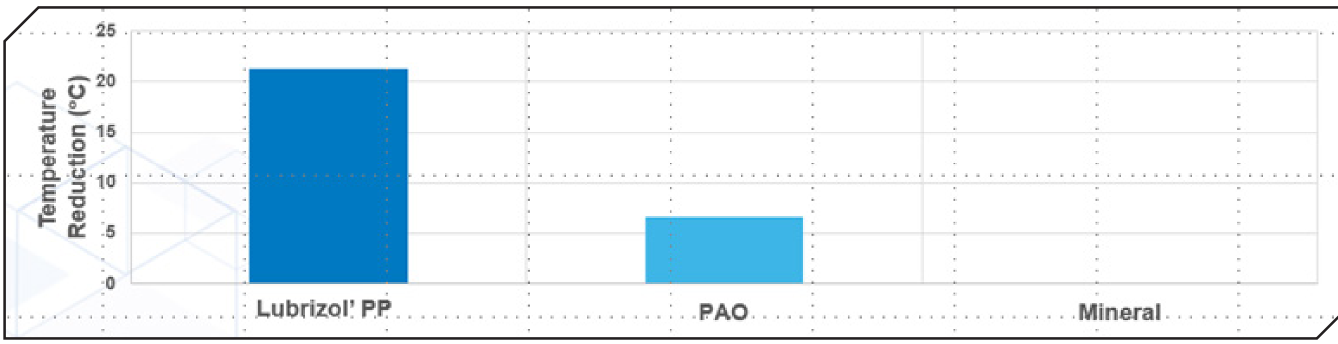


Figure 8 Lubrizol OGLs with PP technology shows better performance in temperature reduction in FZG rig.

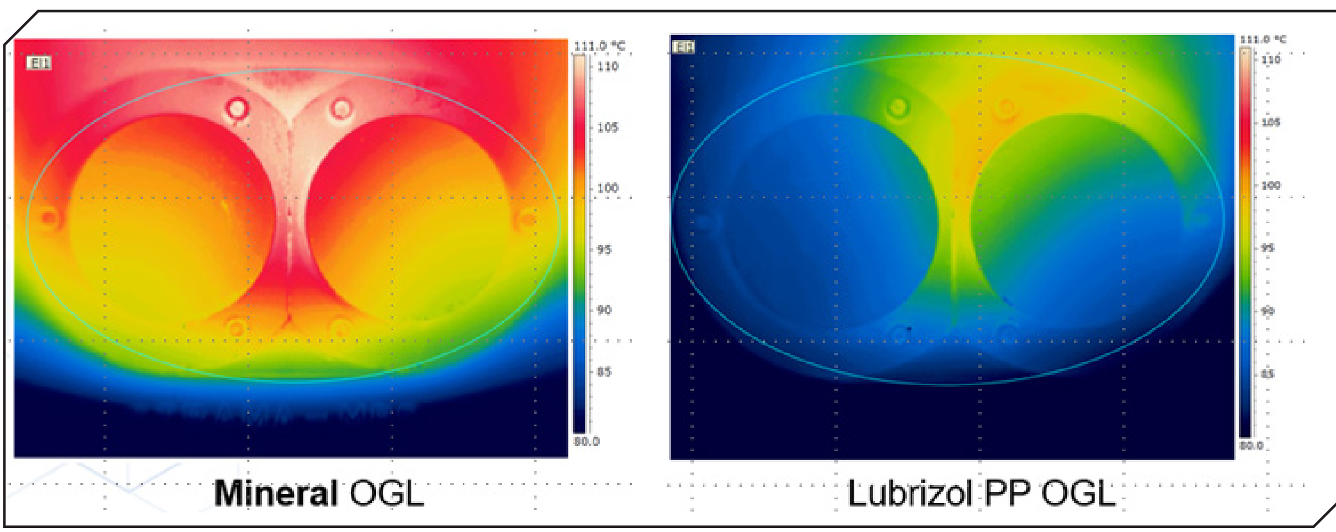


Figure 9 Significant temperature reduction between general market mineral OGL and Lubrizol OGL with PP technology.

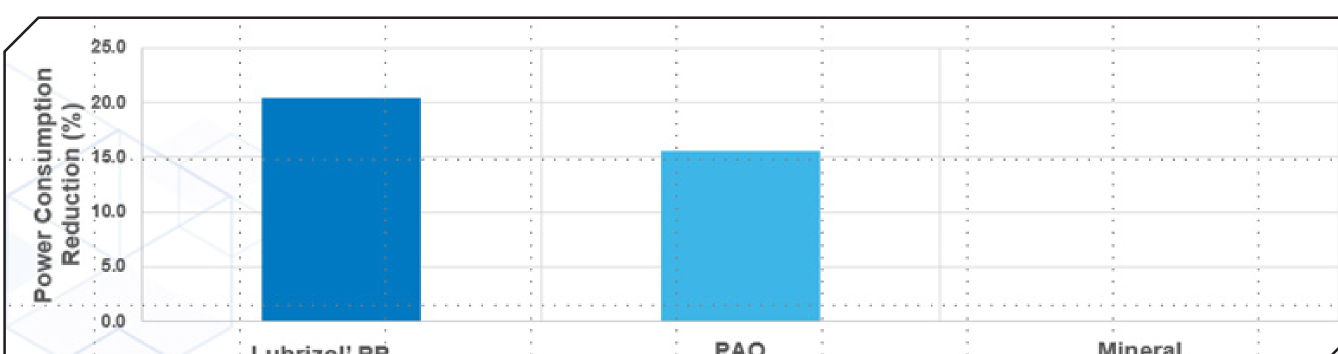


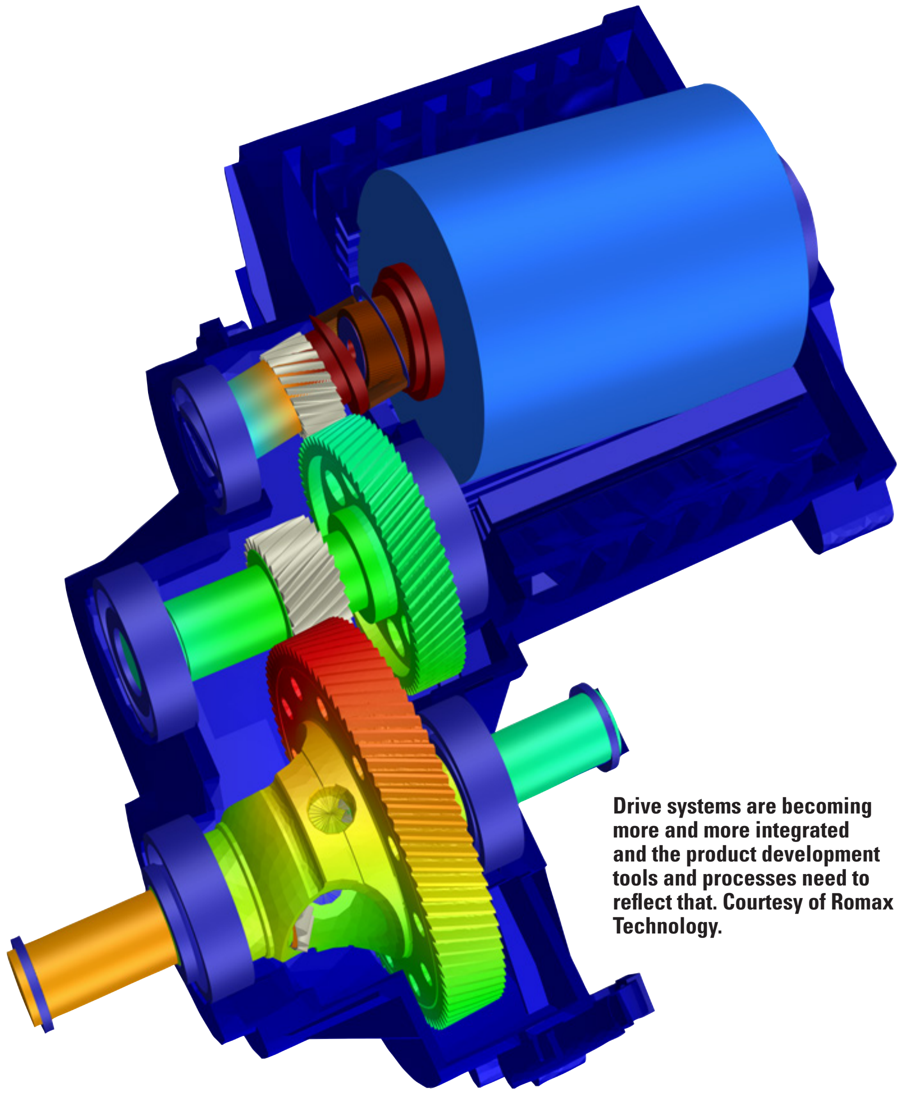
Figure 10 Lubrizol OGL with PP technology shows better performance in energy consumption in FZG rig.

The Move Toward Systematic Design

E-Mobility is changing the gear market at an incredibly rapid pace, and the software is adapting to meet these new challenges

Matthew Jaster, Senior Editor

Electrification is everywhere—from the cutting tools to the machine tools as well as the gear noise analysis and the new transmission technologies—we're living in a world of E-mobility. The software is no exception. Many of the gear design software suites available from the likes of GWJ Technology, Dontyne, KISSsoft, Romax Technology and SMT have been carefully prepping for the electrification trend as well as the slow and steady move toward systematic design in gear manufacturing.



Drive systems are becoming more and more integrated and the product development tools and processes need to reflect that. Courtesy of Romax Technology.

The Electrification Movement

In general, electrification has changed how vehicle engineers think about noise, according to Paul Langlois, software engineering director at SMT. "With IC engines, the combustion noise masked gear noise to some extent. In electric vehicles this is no longer the case. This has played into a strength of the MASTA software which already had exceptional accuracy in the analysis and prediction of NVH issues. What we have added is the ability to look at the full powertrain system and understand excitation from the gear and the electric motor and the response of the system model. The focus on noise means that the majority of EV transmission gears are finish ground rather than shaved or honed. Using a generating grind system (worm grinding) can introduce other complications such as adverse bias or profile hollows if the gear design and the manufacturing process are not aligned properly. The manufacturing modules in the MASTA software, which SMT have been refining for nearly 20 years, can help designers get to the right solution faster," Langlois said.

Along with the electrification of cars comes the demand for low noise gearboxes, since the missing motor sound of a combustion engine plus much higher input speeds of an electric motor make the remaining gears much more sensitive concerning noise emissions. The buzzword—as mentioned—is "NVH."

"We offer advanced tools for noise sensitivity analysis, so that very early in the design state the engineer can already check for critical speeds, resonance frequencies and the system response on excitations from the gear meshing of the motor. For ongoing calculations in this context, we work with a partner in the field of vibration analysis software, accepting that we cannot be the best in class everywhere. So, we offer a third-party product for multi body dynamics in a package with KISSsoft," said Dr. Stefan Beermann, CEO, KISSsoft AG.

For the manufacturing topic, Beermann handed the analysis over to his esteemed colleague Dr. Antoine Türich at Gleason:

"E-Mobility is changing the gear manufacturing twofold: Less gears but with much higher quality requirements. This results in much tighter tolerance requirements, which are harder to achieve and to control. Hence, hard finishing such as grinding, honing or hard power skiving is more or less mandatory for all e-drive gears. But even with these hard finishing processes, it is not easy to achieve and hold these tight tolerance requirements under production conditions. The traditional sampling measurement including statistical control will step by step be replaced by up to 100% inline inspection concepts," Türich said.

At Romax Technology, the push towards electrification is in the company's DNA.

"Drive systems, and especially electrified ones, are becoming more and more integrated and the product development tools and processes need to reflect that, which is why Romax tools consider the electric machine together with the drivetrain components in one system that is always analyzed in a coupled way. For example, our customer Valeo was recently awarded an Automotive News PACE award for its innovative 48V eAccess powertrain solution for small urban vehicles," said Travis Histed, business development manager, Americas – System Dynamics, Romax Technology.

These new architectures need to be considered from a system-level perspective in order to properly optimize the components individually; they all must come together to form a complete system that delivers on durability, efficiency, noise, and cost, Histed added. "Romax tools can integrate the electric machine into the mechanical system so that these interactions can be understood and tuned."

Mike Fish, director at Dontyne Systems, said that there's a determined—and quite correct—push towards closer integration between design software with production equipment that falls under the 'Industry 4.0' umbrella. "This has been our intention since the company's formation in 2006 with the creation of the Gear Production Suite. "The fast and efficient flow of design data around a plant is essential and expensive when not controlled accurately. Our software provides that platform," Fish said.

The move toward electrification has been very beneficial for Dontyne as it has increased the requirement. "Flexibility and ease of use has helped companies produce designs quickly," Fish added. "Manufacturing simulations have allowed companies to check correct production before cutting metal."

Trends & Topics in Gear Manufacturing

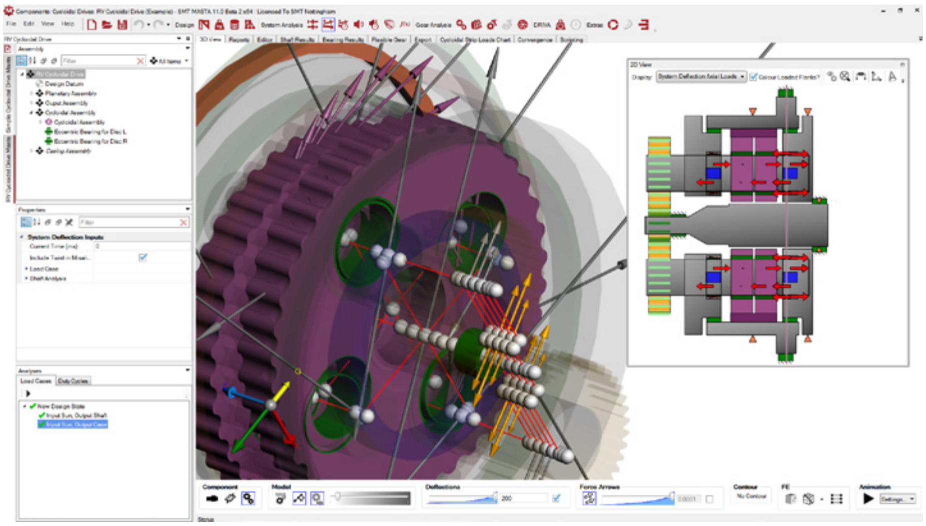
We asked our software experts to describe the trends and relevant topics currently taking place in the gear and gear drive markets.

NVH is one if not the key driver in e-mobility and requires all aspects to be considered, from the correct gear design to the appropriate manufacturing and finally the gear inspection to make sure that the produced gear will not make any

noise problems, said Beermann.

"Increasing noise requirements together with higher power density make tolerances tighter than ever. An interesting aspect in the future will be to analyze during the design process whether the desired modifications and tolerances will be possible to be manufactured with certain hard finishing processes. Therefore, manufacturing simulation within the design process will certainly gain higher importance," Beermann said. "Currently, a lot of new players are entering the EV-market who have limited experience with gear design and manufacturing. Putting more "intelligence" and know-how into the design and simulation process will help those new players to become successful."

Romax is closing the loop between software and hardware. "With our joint offering with Dontyne, it is now possible to simulate the gear manufacturing process in Romax and incorporate those simulated gears back into your Romax system model. Now that we are a part of Hexagon's Manufacturing Intelligence division, I expect to see this loop fully close and CAE to play a much bigger role in the production and quality control parts of the process in the future, among other things, as part of the digitization megatrend," Histed said.

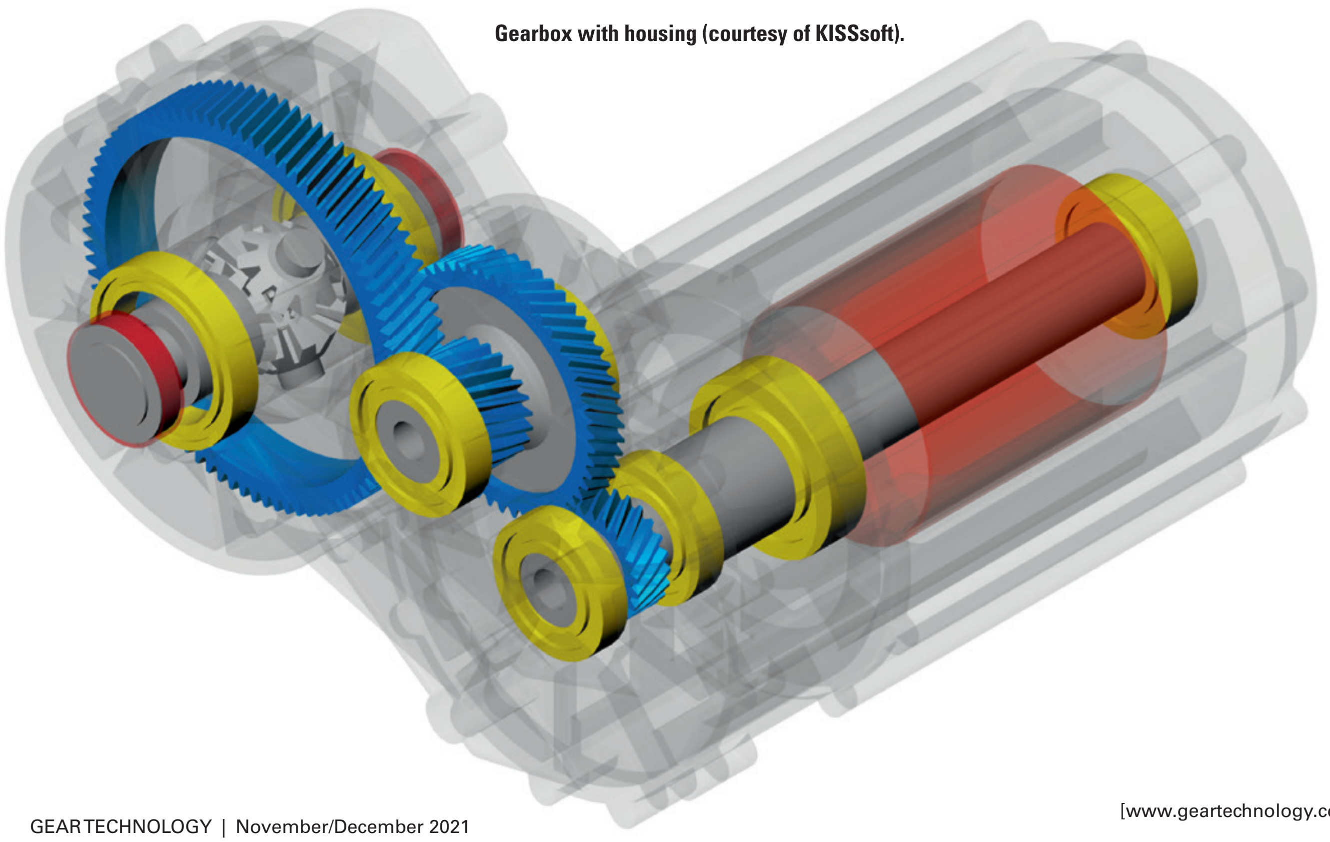


Examining cycloidal drives with SMT.

Additionally, Histed believes democratization is a major trend in engineering software. "We are continually looking for ways to make our products more intelligent, easy to use, and flexible to fit into the constantly evolving industry processes. This enables best practices and intellectual property to be embedded into robust systems, helps empower engineers who are new to their field and frees up scarce domain experts to continue innovating," he said.

At SMT, the first trend is that tolerances are getting tighter. For automotive gears the allowable tolerance on micro-geometry can be in the order of +/-2 microns. This is driven heavily by the NVH requirements for electric vehicles. Before this time general tolerances on micro-geometry were in the order of +/-10 microns. Having a better understanding of NVH and how to design the gears for a system using software like MASTA can mean these tight requirements can be relaxed. Robustness studies can be easily performed to understand the performance with a full tolerance band. This can only happen if the gear designers and manufacturing teams work more closely together.

Gearbox with housing (courtesy of KISSsoft).



Better use of materials is another trend. "SMT has previously completed research work on plastic gears, and these will start to see more common use in precision applications including robotics, which is likely to surge as a marketplace in the next decade or so. Also, for steel gears the understanding of material limits will improve to allow for a better selection of appropriate gear steel for an application. Many organizations still use generic material properties to cover many different types of materials. This can lead to oversized designs as extra safety factors are built in," Langlois said.

The final, and inevitable trend is 3D printing (or additive manufacturing). The manufacturing methods are improving, and gears manufactured by this method could provide some geometric advantages and opportunities to lightweight. This will initially be dependent on application, but in the long-term 3D printing may become and major manufacturing method for all gear types, Langlois said.

Custom Adaptability

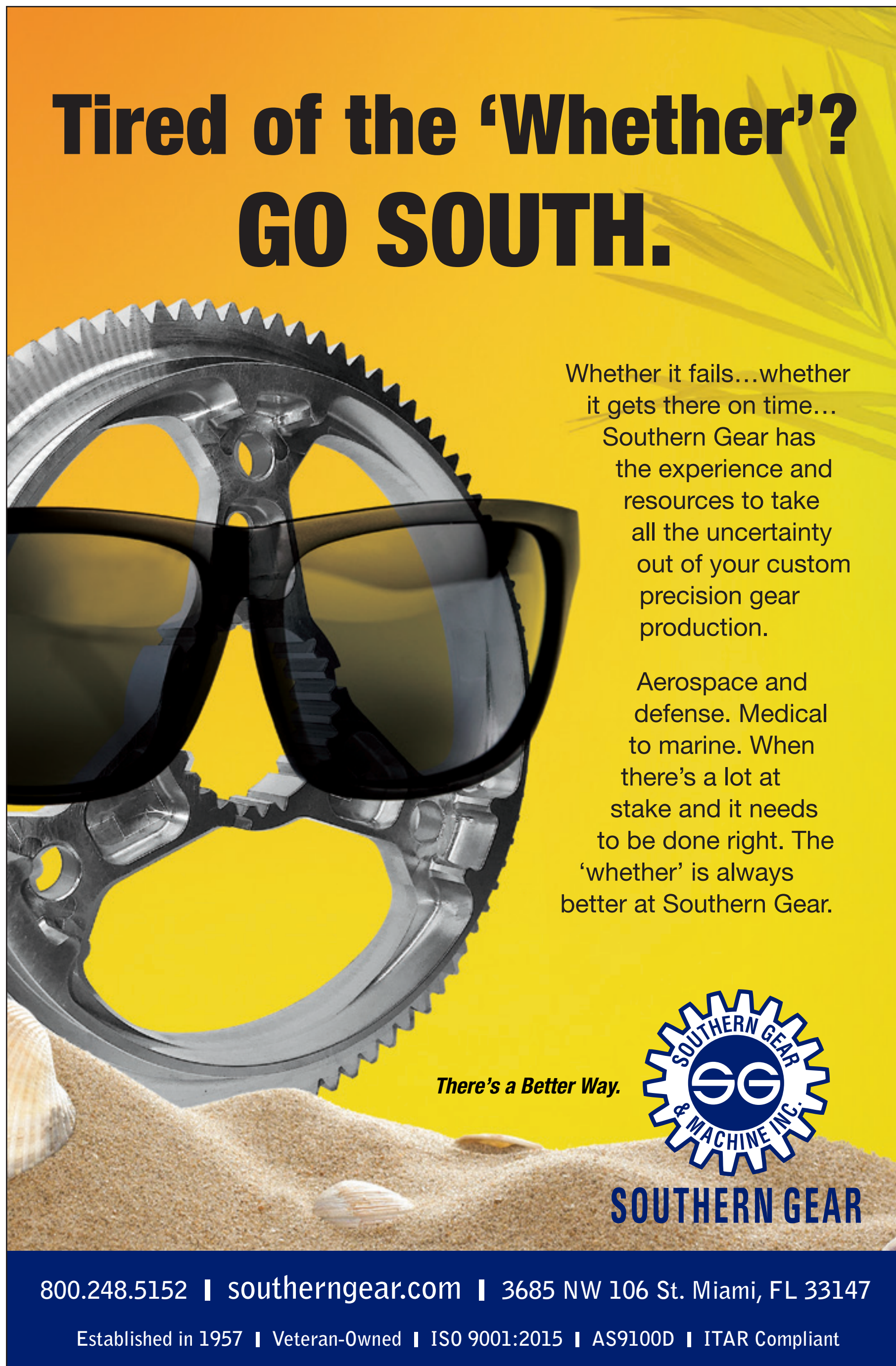
Dontyne has added programmers in the last two years to expand the company's ability to flex to client's specific requirements. Customization—as it turns out—is another trend that is changing the software game, according to our experts.

"From the beginning, KISSsoft was highly adaptable to the user's needs. You can change the default values in the dialogs, the data in the database (material, tolerances, ….), the contents and appearance of the reports, and the directories used on the hard drive. In addition, you can define design rules that are checked with each calculation and if this is not enough, we added a script language named "SKRIPT" in the software to do additional calculations, provide custom interfaces or automate processes," Beermann said. "Some of our customers are using KISSsoft only in the background of their own software via the COM interface. So, our problem is usually not how the user can adapt something to his needs, but which is the best way of many to do that."

At SMT, customization of the product to specific customer needs has always been a driving focus. "We have had two complimentary approaches to this. On the one hand we have very close working relationships with our customers. We encourage continual feedback on our products and the development of MASTA is driven by our customer's needs. On the other hand, we have developed advanced scripting functionality. "

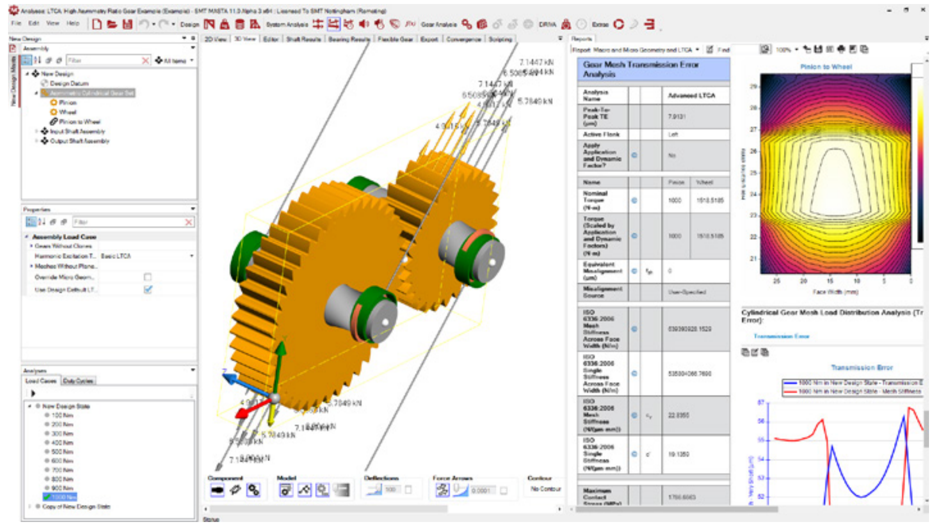
MASTA scripting capabilities allows any customer to write custom scripts to input data, output data, run analysis or create automations. This means that the customer can integrate the software with existing tools and communicate with MASTA via an extensive API. The MASTA API exposes nearly all of the underlying parameters, calculations and outputs to the user.

"SMT have generated a number of example scripts including model import and export via the REXS data format. Scripting could also be used for any custom data format. As MASTA's scripting functionality is accessible via common software languages which are already familiar to engineers, such as Python, C# and Matlab, the engineer can



start writing scripts without any need for learning a new scripting language," Langlois said.

Histed added that companies are rapidly evolving to deliver robust gearboxes for new architectures as fast as possible. To do this they need more collaborative tools that allow gear, bearing, structures, and motor designers to work together and reduce reliance on redundant tools and repetitive model building. "Romax tools are focused to give each discipline the capability it needs to optimize the gear or bearing or housing design, while having a common modelling platform that allows them to collaborate and communicate in a much more effective way.," Histed added.



Examining asymmetric gears with SMT.

New Look, New Functionality

Romax's partnership with Hexagon Manufacturing Intelligence includes state of the art manufacturing and measurement technologies. "There is a very clear path of tools in our portfolio to go from "as designed, as manufactured, as assembled, as used" and feed data back at each stage to the design step. We are in a great position to leverage our existing technology and augment it developing practical applications of Industry 4.0 ideas," Histed said.

With KISSsys, Beermann said the company has offered system software since 2000. "It does its job, however, the user interface is not the most modern one anymore. We are currently working on a new user interface that will be highly intuitive and gives the user more guidance. The general data structure also got a major update, accounting for the experiences we collected during the last 20+ years," Beermann said.

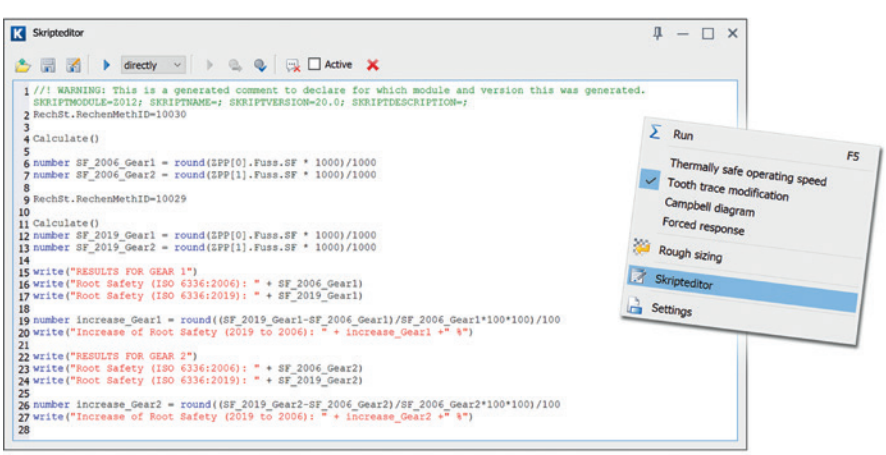
SMT have always provided a full system modelling solution with the MASTA software. SMT has believed since its beginning that system level analysis of gear drive systems is essential for accurate results and insights. "The MASTA software is built to be intuitive to use and we have refined the speed of the modelling functions to give maximum benefit to our users. Most recently this has included 3D CAD integration that allows users to model directly from 3D CAD. Users can also import housing and structural CAD model and convert them easily into FEA models. The user interface and fast modelling capability means that the software can be used for initial concept layout without the need for additional concepting modules. The software also includes bearing model catalogs from all the major bearings suppliers," Langlois said.

Building an Intelligent Shop Floor

With a continued push to solving the skilled worker shortage in areas like gear manufacturing, these software organizations continually examine how their software suites can assist on the shop floor.

Software such as MASTA can improve the efficiency of the design and development process for a geared drive or transmission. The manufacturing modules can be used to simulate the cutting process before cutting metal which can reduce the amount of rework. "MASTA's high accuracy means that typical development issues can be found earlier in the design cycle. This reduces the burden of development testing. An example is contact pattern development. Traditionally the refinement of contact patterns was an iterative method using testing. Because of the accuracy of MASTA this is now performed virtually by many of our customers," Langlois said. "MASTA software also has the capability to be automated using the unique scripting function. The use of this in the design, development and manufacturing can remove the need for manual repetitive analysis tasks, such as copying data from one system to another without errors."

Being able to simulate manufacturing errors and assess them very quickly using Romax tools allows the designer to identify system sensitivities and design



KISSsoft added a script language named "SKRIPT" in the software to do additional calculations, provide custom interfaces or automate processes.

around them in the first place.

"Error-proofing the process by directly producing gear manufacturing files from the design software (including simulated manufacturing deviations) ensures that the manufactured part is much closer to the designer's intent. As mentioned previously, a key to tackling this issue is democratization, and embedding of knowledge and best practices in software workflows. For example, our joint development with Dontyne of cylindrical gear manufacturing simulation embedded in Romax can be fully automated, enabling design space exploration and manufacturing variability studies. It is also able to take common design parameters as inputs and automatically estimate the tooling parameters so that the user does not have to have a deep understanding of gear manufacturing. Considering the particular skills and needs of the person who is going to use a given feature is integral to our product development process" Histed said.

Beermann added that software might cover up some shortcomings of skilled personnel on the shop floor, but it will never be able to really replace it.

"In the end, software can increase the efficiency and maybe help with some expert knowledge crystallized in code. Still, if the personnel are not sufficiently skilled or simply not there, the second part of the equation is missing. Automation will be more important in this regard if you find the even more skilled personnel necessary to set up the automation."

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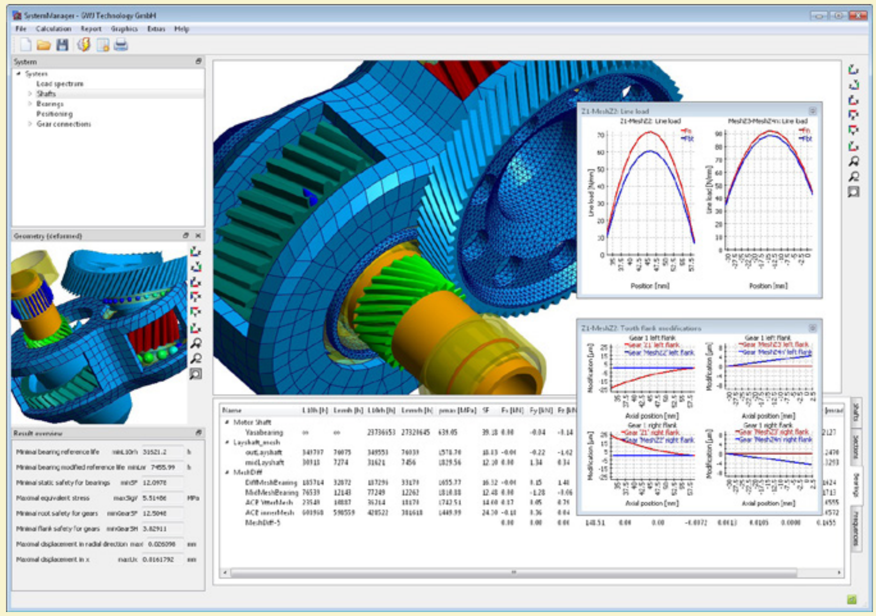

GWJ Provides Online Gearbox Workshop for Formula Student Teams

Following the success of last year's workshop, GWJ Technology, organized once again the three-day online workshop "Gear Calculation, Design and Optimization - System Calculation" for Formula Student teams. The virtual workshop brought together about 60 participants from over 30 different racing teams. The program was very diverse.

In the first part of the workshop, the focus was on the introduction to gear calculation and the calculation software eAssistant. Especially the basics for calculation and dimensioning of the geometry and the load capacity of cylindrical gears and planetary geartrains were covered on the first workshop day. Terms and principles were discussed that are essential for the calculation of gears. With the web-based calculation software eAssistant, the attendees got an ideal tool for the following days.

In addition, a lot of tips and hints as well as optimization strategies were shared. The participants were also given some insights into the eAssistant 3D CAD plugins to easily generate 3D models with just a few clicks. The focus turned to the eAssistant SystemManager on the second day. SystemManager is a software extention for the configuration and calculation of entire systems of machine elements, e.g. multi-stage gearboxes, shift gear transmissions or different types of planetary geartrains. After introduction to the SystemManager basics functions and an in-depth look, the attendees got the idea of what they could do with the software. SystemManager software offers many possibilities — from the fast and easy design and calculation of complete systems to the automatic meshing of housings and planet carriers.

So, the Formula Student teams get the chance to efficiently integrate the eAssistant SystemManager into their projects and to use the potential of the software in the long term. The third day provided practical examples and this session evoked many questions and comments from the participants which in turn generated a lot of valuable discussion that resulted in newly gained insights for the students. The final day ended with tons of new ideas and fresh input and most of all inspiration and drive for future projects.

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Optimizing the Digital Shop Floor

Federal Gear Enables IIoT Platform with MachineMetrics

Matthew Jaster, Senior Editor

Digital manufacturing is not just a 'Matrix-like' sequence of computer codes and programming magic. The gear industry cannot snap its collective finger and become a frontrunner on IIoT solutions overnight. There is a very extensive 'to-do' list in order to bring all your mechanical, electrical, and smart interfaces into a single, cohesive package.

There is a machining component to the digital factory, for example, and you will find MachineMetrics —located in Northhampton, MA—at the center. The company created an industrial IoT platform designed for discrete manufacturing that connects and captures data from any machine regardless of the age or the name on the machine tool.

This technology allows manufacturers to measure, analyze, and optimize the performance of every machine on the shop floor, providing real-time data that the manufacturer can utilize to increase productivity, ramp up capacity and become more competitive. Who would not want an edge—or at the very least a head start—in the race to digital manufacturing?

The Flexibility Factor

Federal Gear & Machine—Eastlake, OH—has been an official member of the AGMA since 1927. They occupy a 22,000 square foot facility in the eastern suburbs of Cleveland, Ohio and offer both gearing and machining solutions. The company continues to focus on providing exceptional value to its customers by providing unique products and services tailored to customers' individual needs, a philosophy that has remained consistent since the company was founded in 1914.

With an emphasis on quality and flexibility, Federal Gear & Machine regularly examines its production schedule to see where the company can make improvements.

"We had a specific need to get more accurate information off the shop floor," said David Hegenbarth, president, Federal Gear & Machine. "When I asked operators what the cycle time was for a specific job their answers would not jive with their actual production. We were losing production time but could not identify why. We needed to better utilize our capacity and minimize downtime."

Federal Gear investigated several different machine monitoring solutions from simple ones that only monitored if the machine was running or not, to complex systems that required significant hardware and software implementation.

"MachineMetrics offered a simple implementation with significant data gathering capabilities. It may be overkill for what we need now, but as we grow, we will utilize increasingly what MachineMetrics has to offer. This—combined with fact that they could interface with different ERP and accounting packages—made it the most powerful and flexible solution we reviewed," Hegenbarth said.

An Uptick in Performance & Productivity

Federal Gear ended up selecting Machine Metric's Machine Data Platform to use out of the box applications and workflows to automate processes to examine bottlenecks and production challenges.

"They started their analytics journey at the very beginning," said Graham Immerman, vice president of marketing at MachineMetrics. "We call this

Measuring and quantifying machine data is essential to remain competitive in manufacturing today. Photos courtesy of MachineMetrics.

'descriptive analytics' where we focus on what is really happening in the factory. Real-time visibility like this creates instant performance improvements."

Additionally, Federal Gear wanted their machine operators to become more involved in the continuous improvement process. "Our interfaces allowed everyone to participate in the data analytics to understand what was happening on the shop floor and how could it be improved," Immerman added.

Results came quickly and were extremely satisfying, according to Hegenbarth. Once Federal Gear installed the system and set up the individual monitoring requirements, the machines began collecting data immediately.

"We are now able to monitor and quantify our machine performance. We can highlight the cause of downtime, address these issues, and minimize them. This allows us to recover capacity and be more productive. Our operators can see where they are losing time and make adjustments on their own to improve their production rates," Hegenbarth said.

By highlighting downtime and capturing quality issues with data companies, Federal Gear can utilize real data to monitor and improve all operations. "We are no longer relying on gut feelings and operators' memories. We have all the data at our disposal," Hegenbarth said.

With the successful implementation of MachineMetrics platform, Hegenbarth will continue to evaluate Federal Gear's operations and install MM solutions on new machines where they believe data collection will allow the organization to improve throughput.

The IIoT Journey

The move to a collected and seamless digital factory floor is happening across the globe, but there are many factors that will determine how these solutions will thrive in an area like gear manufacturing. Perception being one of the greatest challenges.

"Convincing operators this is not a punitive or big brother type system, for example," said Hegenbarth. "Operators must feel that this is a tool to assist them do better, and if they do better the company does better."

Immerman believes 'people' are the greatest challenge to digital transformation. "Companies lack the skilled labor necessary to do the jobs that are needed. They also don't have any mechanisms in place to capture the experience and knowledge lost from workers that retire. These factors tend to create inefficiencies on the shop floor.

These can effect every component of the company from pricing to production to delivering goods."

The goal then is to remove the burden of non-essential manual tasks and decision-making for manufacturers. This is essentially what MachineMetrics offers its customers.

"We're not just throwing things on dashboards or reports," Immerman said. "Manufacturers need tasks to be automated so they can focus on what they do best which is innovating product to process, plain and simple."

This process starts with the machine assets as well as the personnel.

"Despite all the buzzwords you hear from marketing personnel on IIoT solutions, the truth is many organizations are not using the data they already have — from their machines or the operators running them — to unlock value quicker and create immediate productivity gains," Immerman added.

MachineMetrics Utilization Reporting.

So why in 2021 is an area like machine utilization so low in manufacturing?

"First, they're not using analytics or data to drive decisions. Second, manual data entry can create all sorts of misunderstandings to what is *actually* taking place during production. And the worst culprit might be that many organizations are simply living in a state of reactivity."

Immerman suggests that when all these manufacturing systems can't connect, you *literally* cannot connect the dots. Manufacturers still use calendars to maintain their machines. They can't identify process inefficiencies of setups or changeovers. They have machines on their shop floors that run out of material and sit idle for hours on end.

"Our job is to create solutions to these challenges that are user-friendly and will let the personnel on the shop floor focus on much more important tasks and priorities," Immerman said.

A Solid Case for Analytics

Since implementation, Hegenbarth has watched his personnel become more involved in every aspect of the shop floor.

"I have had operators show me data where they have downtime to justify a new tool or fixture so they can improve their production," he said. "Proper incentive systems for individuals and departments need to be established to improve machine utilization."

Federal Gear currently has a mix of dedicated manual and CNC machines. In the future, the manual machines will fade away and be replaced with new flexible CNC machines with automation and robotics.

"The key will be the ability to be flexible and adapt to ever changing needs and markets. If your machines are capable of manufacturing gears and aerospace parts, you are able to pivot your business to new opportunities utilizing the assets you already have," Hegenbarth said.

All this information and knowledge is right there on the shop floor for the taking if the company has the wherewithal to acquire it.

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"They started their analytics journey at the very beginning," said Graham Immerman, vice president of marketing at MachineMetrics. "We call this 'descriptive analytics' where we focus on what is really happening in the factory. Real-time visibility like this creates instant performance improvements."

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BOLD LISTINGS throughout the Buyers Guide indicate that a company has an advertisement in this issue of ***Gear Technology***.

But Wait! Where are the Gear Manufacturers Listed?

If you are looking for suppliers of gears, splines, sprockets, gear drives or other power transmission components, see our listing of this issue's power transmission component advertisers on page 54. In addition, you will find our comprehensive directory in the December 2021 issue of ***Power Transmission Engineering*** as well as in our online directory at *www.powertransmission.com*.

Handy Online Resources

The Gear Industry Buyers Guide — The listings printed here are just the basics. For a more comprehensive directory of products and services, please visit our website, where you'll find each of the categories here broken down into subcategories: *www.geartechnology.com/dir/*.

The Power Transmission Engineering Buyers Guide — The most comprehensive online directory of suppliers of gears, bearings, motors, clutches, couplings, gear drives and other mechanical power transmission components, broken down into sub-category by type of product manufactured: *www.powertransmission.com/directory/*.

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Although every effort has been made to ensure that this Buyers Guide is as comprehensive, complete and accurate as possible, some companies may have been inadvertently omitted. If you'd like to add your company to the directory, we welcome you. Please visit *www.geartechnology.com/getlisted.php* to fill out a short form with your company information and Buyers Guide categories. These listings will appear online at *www.geartechnology.com*, and those listed online will automatically appear in next year's printed Buyers Guide.

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Boltex Manufacturing
www.boltex.com

Buehler - An ITW Company
www.buehler.com

CFS Machinery Co. Ltd.
www.dropforging.net

Canton Drop Forge
www.cantondropforge.com

Castalloy
www.castalloycorp.com

Celanese
www.celanese.com

Compressed Gas Technologies Inc.
www.nitrogen-generators.com

Concast Metal Products
www.concast.com

Cornell Forge
www.cornellforge.com

Cramlington Precision Forge Limited
UNIT 8 ATLEY WAY
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CRAMLINGTON NORTHUMBERLAND NE23 1WA
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Phone: 0044(0)1670716811
enquiries@cpfl-tvs.co.uk
www.cpfl-tvs.com
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Creative Hi-Tech Ltd.
www.creativehitech.com

Crucible Industries LLC
www.crucible.com

DSM Engineering Plastics
www.dsm.com

Dayton Forging and Heat Treating
www.daytonforging.com

Deco Products Company
www.decoprod.com

DuPont
plastics.dupont.com

Dura-Bar
www.dura-bar.com

Earle M. Jorgensen Co.
www.emjmetals.com

ElectroHeat Induction
www.electroheatinduction.com

Ellwood City Forge Group
www.ellwoodcityforge.com

Erasteel Inc.
www.erasteel.com

Eutectix, LLC
eutectix.com

Excel Gear
www.excelgear.com

Finkl Steel
www.finkl.com

Fomas USA
www.fomasgroup.com

Forging Solutions LLC
www.forging-solutions.com

Fox Valley Forge
www.foxvalleyforge.com

Fuji Machine America Corp.
www.fujimachine.com

Galaxy Sourcing Inc.
www.galaxysourcing.com

Gemec Co., Ltd.
www.gemec.com.cn

Gibbs Gears Precision Engineers
www.gibbsgears.com

Guven Bronz Metal
www.guvendokum.com

Hunter Chemical LLC
www.hunterchem.com

IMT Forge Group including Clifford-Jacobs Forge
www.imtforgegroup.com

Intech Corporation
www.intechpower.com

Interstate Tool Corp.
itctoolcorp.com

Jones Metal Products Company
www.jmpforming.com

Kuraray America, Inc.
www.kuraray.com

Lalson Tools Corporation
www.lalsoncuttingtools.com

Larson Forgings
www.larsonforgings.com

Mackeil Ispat & Forging Ltd.
mackeilforgings.com

Maguire Technologies
www.maguiretech.com

Martin Tool & Forge
www.martinsprocket.com

Masternet Ltd.
www.masternetltd.com

McInnes Rolled Rings
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Phone: (800) 569-1420 or (814) 459-4495
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sales@mcrings.com
mcinnesrolledrings.com
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McKees Rocks Forgings
www.mckeesrocksforgings.com

Midwest Themal-Vac Inc.
www.mtvac.com

Moore-Addison Precision Plastic Blanking
www.mooreaddison.com

Mosey Manufacturing Co. Inc.
www.moseymfg.com

National Bronze Mfg. Co.
www.nationalbronze.com

Nichiei Company, Ltd.
www.nichiei-ind.com

Ovako AB
www.ovako.com

PCK Buderus India
pck-buderus.com

Parag Casting Co.
www.paragcasting.com

Patriot Forge
www.patriotforge.com

Penticton Foundry Ltd.
www.pentictonfoundry.com

Perry Technology Corporation
www.perrygear.com

Presrite Corporation
www.presrite.com

QMS Inc
qms-ky.com

QSC Forge & Flange
www.qscforge.com

QuesTek Innovations LLC
www.questek.com

Reade Advanced Materials
www.reade.com

Renishaw Inc.
www.renishaw.com

Rewitec GmbH
www.rewitec.com

Schmiedewerke Groeditz GmbH
www.stahl-groeditz.de

Scot Forge
www.scotforge.com

Sedlock Companies
www.sedlockcompanies.com

Sensor Products Inc.
www.sensorprod.com

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www.somersforge.com

Southwest Metal Products Ltd.
www.southwestmetal.com

Spectrum Machine Inc.
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Steuby Manufacturing Company, Inc.
www.steubymfg.com

Sullivan Steel
sullivansteelservice.com

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www.sunbeltturretsteel.com

Thyssenkrupp rothe erde USA
www.ringsandbearings.com

TimkenSteel Corporation
www.timkensteel.com

UMC - United Metals Co.
www.umcmetals.com

United Cast Bar, Inc.
www.unitedcastbar.com

Viking Forge
www.viking-forge.com

Voestalpine High Performance Metals
www.voestalpine.com

Walker Forge
www.walkerforge.com

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www.saw-lutions.com

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www.willmanind.com

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www.yarde.com

Yash International
www.yashtools.com

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www.anca.com

Abtex Corp.
www.abtex.com

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www.accucutdiamond.com

AccuBrass
accubrass.com

Acme Manufacturing Co.
www.acmemfg.com

Affolter
www.rotectools.com

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www.alliancebroach.com

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www.americanbroach.com

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www.andersoncook.com

Apex Broaching Systems
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www.buderus-schleiftechnik.de

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www.banyangt.com

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Fax: (815) 965-0019
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www.cnccenter.com

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www.capital-tool.com

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www.chamfermatic.com

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www.clemcoindustries.com

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cdmcmachine.com

Colonial Tool Group
www.colonialtool.com

Comco Inc.
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Compressed Gas Technologies Inc.
www.nitrogen-generators.com

D.C. Morrison Company
www.dcmorrison.com

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www.drakemfg.com

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www.bourn-koch.com

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Fuji Machine America Corp.
www.fujimachine.com

GMTA German Machine Tools of America
www.gmtamerica.com

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www.novagrinders.com

Meister Abrasives USA
www.meister-abrasives.com/USA

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Mutschler Edge Technologies
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Nachi America Inc.
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Nagel Precision
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Nidec Machine Tool America
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Ohio Broach & Machine Co.
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Okuma America Corporation
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PITTLER T&S GmbH
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PRAEWEMA Antriebstechnik GmbH
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Parker Industries Inc.
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www.precisionfinishinginc.com

Precision Surfacing Solutions
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Prime Technologies
www.gear-testers.com

QC American
www.qcamerican.com

Röders GmbH
www.roeders.de

Ravjeet Engineering Specialty Ltd.
www.ravjeet.com

Redin Production Machine
www.redinmachine.com

Reishauer AG
www.reishauer.com

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www.reishauer.com

Rotec Tools Ltd.
www.rotectools.com

Russell Holbrook & Henderson
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www.serwema.de

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www.steelmans.com

Sunnen Products Company
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Surface Finishing Equipment Co.
www.sfecindia.net

Surplex GmbH
www.surplex.com

Thyssenkrupp rothe erde USA
www.ringsandbearings.com

Toolink Engineering
www.toolink-eng.com

Ty Miles, Inc.
www.tymiles.com

U.S. Equipment
www.usequipment.com

Ultramatic Equipment Co.
ultramatic-equipment.com

WFL Millturn Technologies, Inc
www.wfl-usa.com

WMZ - Werkzeugmaschinenbau Ziegenhain GmbH
www.dvs-technology.com/wmz

WardJet
www.wardjet.com

West Michigan Spline, Inc.
www.westmichiganspline.com

Wheelabrator
www.wheelabratorgroup.com

Willrich Precision Instrument Company
willrich.com

Wolverine Broach Co., Inc.
www.wolverinebroach.com

Yieh Chen Machinery
www.yiehchen.com

GRINDING WHEELS & ABRASIVE TOOLS

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www.2Linc.com

3M Abrasives
www.3m.com/Abrasives

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www.abtex.com

Accu-Cut Diamond Tool Co.
www.accucutdiamond.com

AccuBrass
accubrass.com

Ajax Tool Supply
www.ajaxtoolsupply.com

Alliance Broach & Tool
www.alliancebroach.com

Banyan Global Technologies LLC
www.banyangt.com

Brighton Laboratories
www.brightonlabs.com

CGW - Camel Grinding Wheels
www.cgwcamel.com

Carborundum Universal Ltd.
www.cumiabrasives.com

Cleveland Deburring Machine Co.
cdmcmachine.com

Comco Inc.
www.comcoinc.com

Continental Diamond Tool Corporation
www.cdtusa.net

DTR Corp. (formerly Dragon Precision Tools)
1261 WILEY ROAD, UNIT K
SCHAUMBURG IL 60173
Phone: (847) 375-8892
Fax: (224) 220-1311
alex@dragon.co.kr
www.dragon.co.kr
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ralf-georg.eitel@dvs-technology.com
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DVS Tooling GmbH
www.dvs-tooling.de

Diametal AG
www.diametal.ch

Diamond Abrasive Products
www.diamondabrasiveproducts.com

Dianamic Abrasive Products Inc.
www.dianamic.com

Dr. Kaiser Diamantwerkzeuge
www.drkaiser.de

ESGI Tools Pvt. Ltd.
esgitools.com

FFG - Modul
www.star-su.com

Gear Resource Technologies Inc.
www.gear-resource.com

Gehring L.P.
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Greg Allen Company
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itctoolcorp.com

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Mutschler Edge Technologies
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NAXOS-DISKUS Schleifmittelwerke GmbH
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Nagel Precision
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Precision Surfacing Solutions
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Radiac Abrasives
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www.hangsterfers.com

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Houghton International
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www.hydrotexlube.com

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Klüber Lubrication North America L.P.
www.klueber.com

Lubegard / International Lubricants Inc.
www.lubegard.com

Lubrication Engineers
www.lelubricants.com

Lubriplate Lubricants Co.
www.lubriplate.com

ML Lubrication Inc.
www.ml-lubrication.com

MMT Productivity
www.mmtproductivity.com

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www.ws2coating.com

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www.motul.com

Nye Lubricants
www.nyelubricants.com

Particular Technology, Inc.
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RedLine Tools
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Tecsia Lubricants USA
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TheLubricantStore.com
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www.acieta.com/robotics-products/gripper-systems

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www.wfl-usa.com

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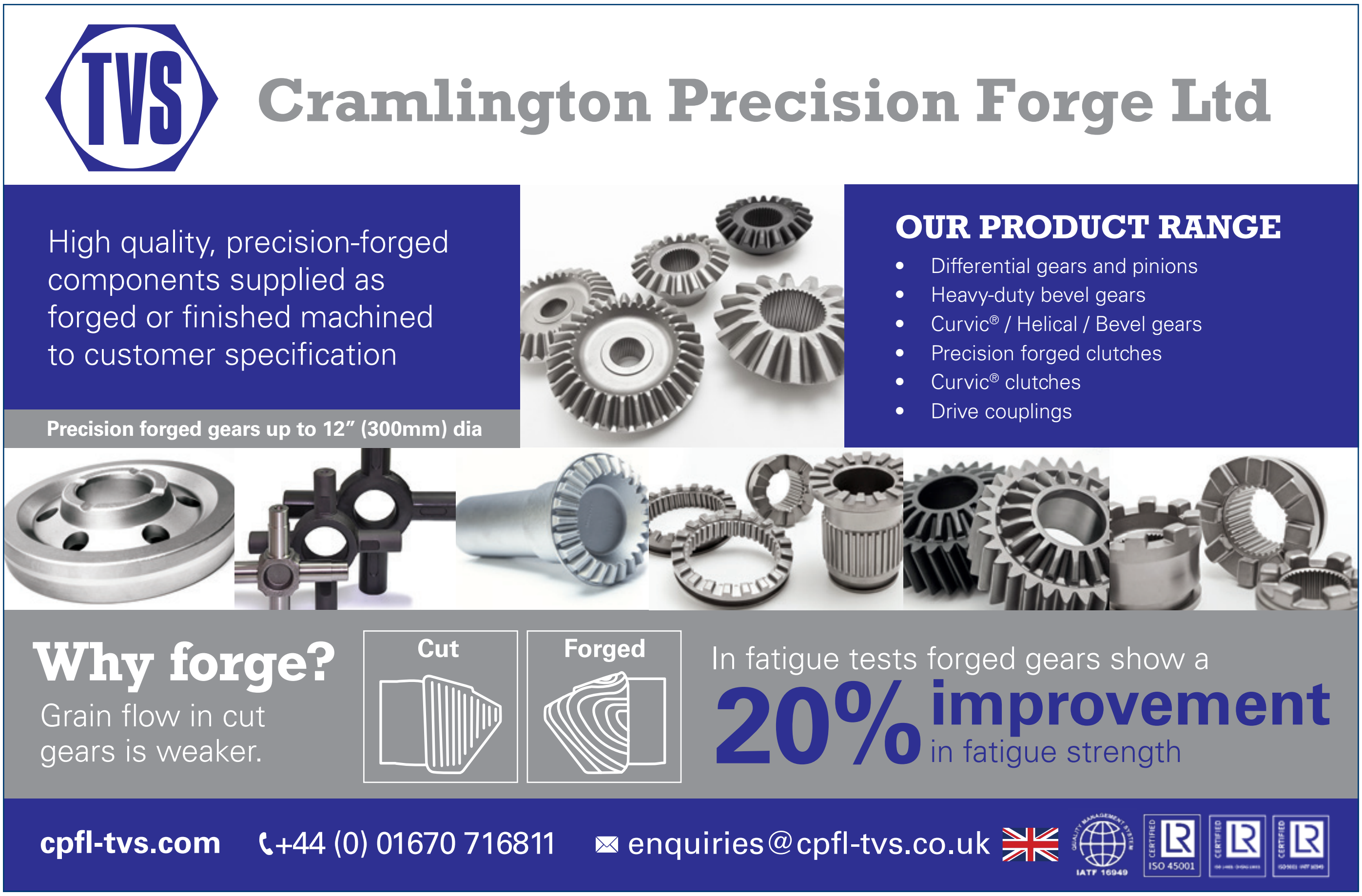
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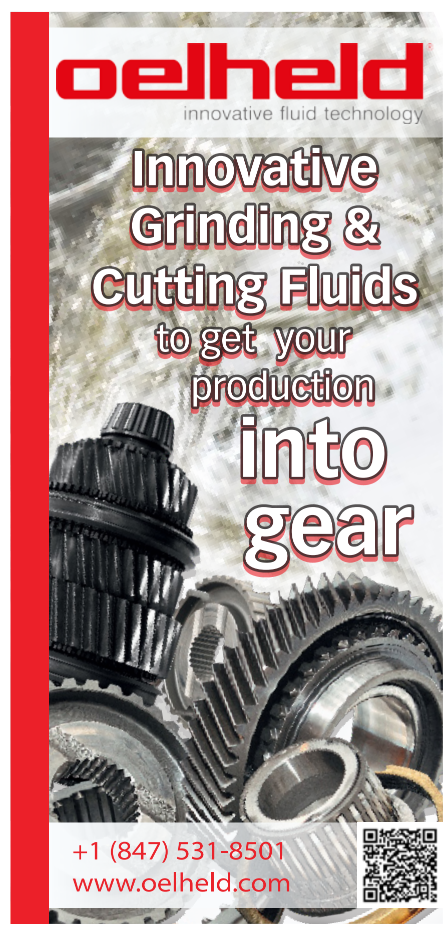
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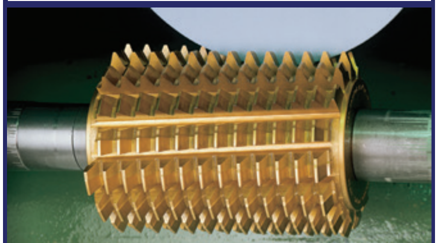

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Dry Lubricated Rolling-Sliding Contact – Operation Behavior and Calculation of Local Frictional Energy

Sebastian Sklenak, Jens Brimmers and Christian Brecher

Initiation and Motivation

For numerous reasons, the tooth contact in a power-transmitting gearbox, which is subjected to high mechanical loads, is usually designed as an oil-lubricated contact (Fig. 1). In this case, the oil film on the contact surfaces is intended to create a separation between the base and counter body [Ref. 1]. The separation of the contact surfaces results from the elastohydrodynamic lubricating film buildup, which is created by the tangential velocity between the two tooth flanks. The lubricating film reduces the stress in the contact zone and is thus intended to prevent tooth flank damage, such as micropitting, pitting and scuffing [Refs. 2–3]. In addition to reducing friction, one of the lubricant's main tasks is to dissipate the frictional heat generated in tooth contact. Other advantages of liquid lubricants are the removal of wear particles generated by abrasive wear in the tooth contact and the corrosion protection of the gear surfaces.

However, for certain operating conditions and environments, liquid lubrication of gear drives is not possible or can only be implemented with great restrictions or at high cost (Fig. 1). In the food industry, guidelines specify the handling of hazardous operating materials, such as lubricants, in machines [Ref. 4]. Accordingly, the use of liquid lubricants requires the design of complex sealing systems and continuous checks of the lubricated assemblies, so that fluid-free rolling-sliding contact can be an alternative solution for this application. In the aerospace industry, the use of lubricating oils and greases is limited due to the extreme operating conditions. These include in particular the large temperature and pressure range to which the lubricant is exposed during its service life. These extreme operating conditions lead to outgassing in many greases and oils, which in turn leads to changes in the operating properties of the lubricant. Due to the high system reliability required in the aerospace industry, the use of lubricating oils and greases is often excluded [Ref. 5]. Furthermore, from an economic point of view, the type of lubrication plays a role in the design of a gearbox. Considerable costs are incurred for the design and maintenance of the lubrication system as well as for the purchase and disposal of the lubricant (Fig. 1).

Due to an interruption in the lubricant supply, the gearing in Figure 1 exhibits severe deformation of the teeth of both gears. The discoloration on the face of the gearing indicates overheating of the material, so that the resulting reduction in strength leads to failure of the gearing. Investigations into the interruption of the lubricant supply show that conventional gears do not achieve running times close to those of conventional applications when subjected to high mechanical loads [Ref. 6]. For applications where lubrication with oil or grease cannot be guaranteed or is not feasible, solid lubricant systems offer an alternative for reducing power loss. However, the structure of the dry tribological system differs from that of conventional lubrication systems, so that, for example, there is no lubricant circuit for dissipating the power loss. This means that precise knowledge of the tribological mechanisms is required, especially for the optimization of dry rolling-sliding contacts with high mechanical

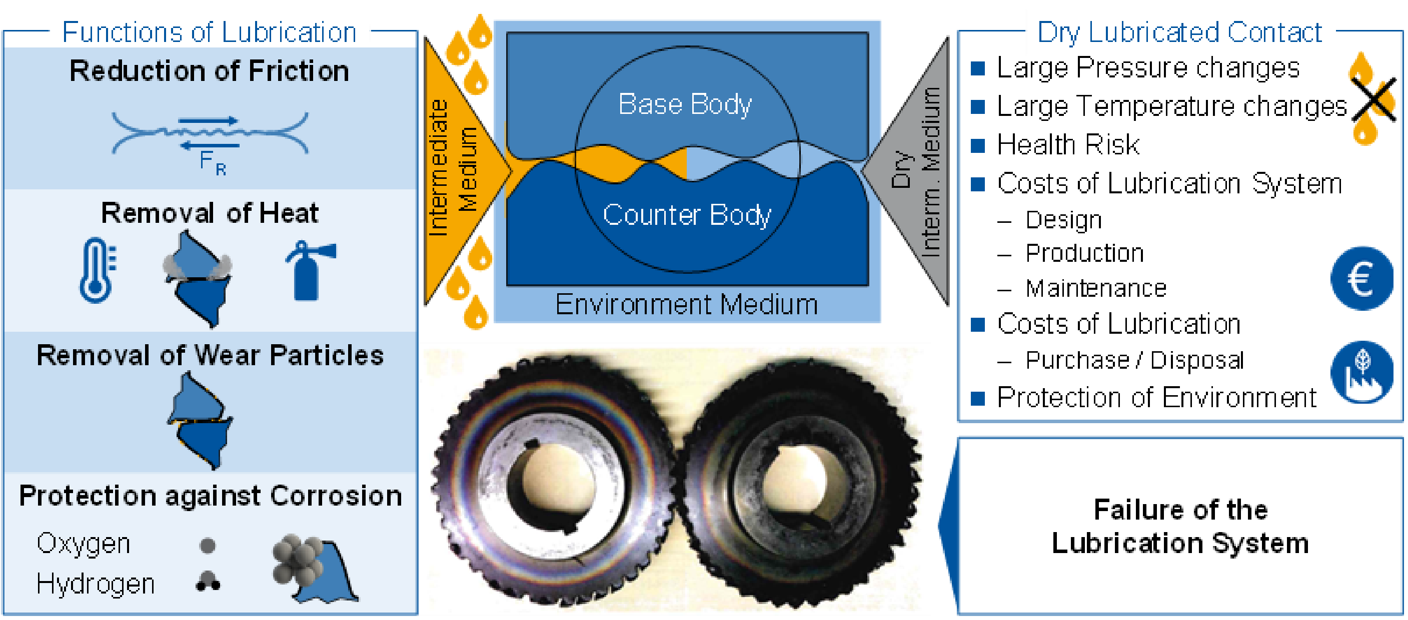

Figure 1 **Functions of lubricant in a rolling contact and applications for dry lubrication [Ref 6].**

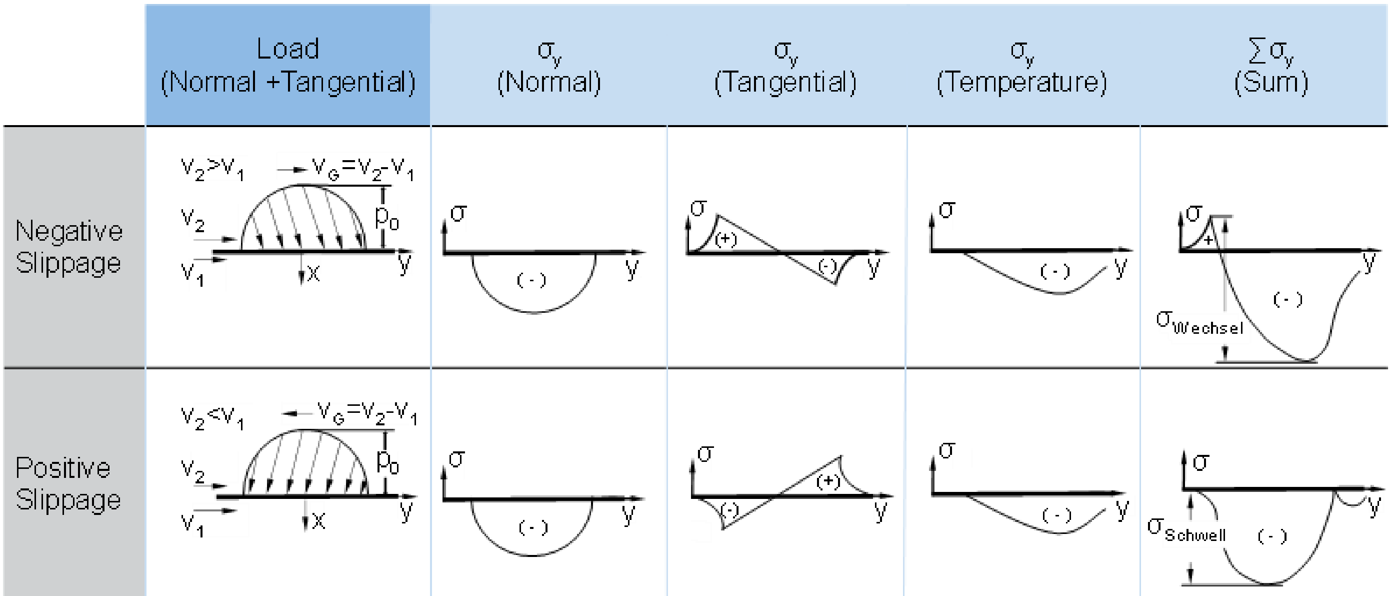

Figure 2 Stresses due to dry lubricated rolling contact [Ref. 1].

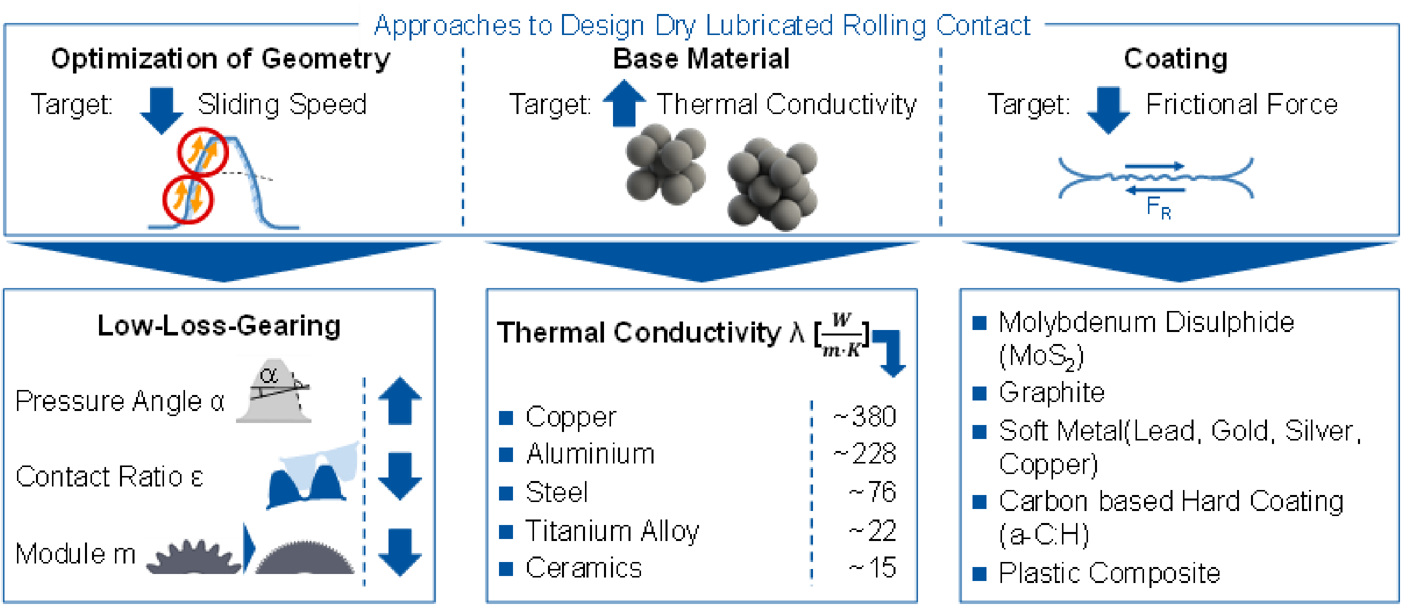

Figure 3 Approaches for dry lubricated rolling-sliding contacts [Refs. 10–11].

loads. The transfer and action mechanisms in dry rolling-sliding contacts are the subject of current research in the priority program DFG SPP 2074 of the German Research Foundation DFG.

State of the Art

In dry rolling-sliding contact, the stress on the macroscopic contact surface is composed of the three local components of normal force (pressure distribution), tangential force (friction force distribution) and temperature (thermal expansion). In the sum of the three components, the stress component parallel to the direction of sliding accounts for the largest proportion of the total stress state [Ref. 1]. Figure 2 compares the individual distributions of the three components for the equivalent stress σ_y for negative and positive slip, respectively. It is clear that the maximum stress amount of the individual components does not differ between negative and positive slip. However, the sum of stresses for negative slip compared to positive slip shows a larger and changing stress, so that the contact area has an increased risk of failure due to the more critical stress.

For a design of the gears in dry and mechanically highly loaded rolling-sliding contact with a long service life, three different approaches are pursued separately and in combination with each other (Fig. 3). With the aid of a loss-optimized gear geometry, the sliding velocities of the tooth flanks can be reduced, so that the thermal stress is reduced and the wear behavior is improved [Refs. 7–8]. Loss-optimized gears (so-called low-loss gears) are characterized by a large pressure angle, a small profile overlap and the smallest possible module (low tooth height) [Ref. 8]. Changing the base material for gears influences the dry running properties. In addition to high-alloy steels [Ref. 5] and aluminum and titanium alloys [Ref. 9], plastics [Ref. 3] are also used for dry gear stages. Ceramic materials are already used for dry rolling-sliding bearings in high-temperature applications. However, ceramics are unsuitable as a base material for gear applications due to the high tensile strength required and especially due to the shock-like stress peaks in tooth meshing [Ref. 3].

As a third starting point for an optimized design of dry rolling-sliding contacts, solid lubricants are used in the form of a coating (Fig. 3). The use of solid lubricants can lead to a reduction in stress due to a reduced frictional force and lower thermal expansion. Among solid lubricants, PTFE has one of the lowest coefficients of friction for both static and sliding friction. However, PTFE has a relatively low thermal operating range compared to other solid lubricants, such as soft metals [Ref. 11]. Soft metals, such as lead, gold, silver, and copper, are used for rolling contacts in rolling bearings due to their low coefficient of friction and good thermal resistance [Ref. 11].

In the field of investigation, the use of single and multi-layer carbon-based coating systems for lubricated tooth contact to reduce stress and wear has already been analyzed in detail [Refs. 12–13]. The work of Brecher shows that PVD coatings have a significant effect on the frictional behavior and load carrying capacity of gears and rolling-sliding contacts [Refs. 12–13]. Investigations on dry ball-on-disk contact with diamond-like carbon coatings show a strong dependence of the displacement and friction coefficients on humidity. In experimental investigations of the mass temperature and coefficient of friction in dry rolling-sliding contact, the influence of slip was considered for a carbon-based hard coating and a molybdenum disulfide coating [Ref. 14]. The slip was increased in stages in analogy to the test procedure for the scuffing load capacity DIN ISO 14635 [Ref. 15]. In deviation from DIN ISO 14635, the load changes for each stage are non-uniform and dependent on the change in mass temperature. Analysis of the tests showed that the frictional properties improve compared with the uncoated and unlubricated rolling-sliding contact, but do not reach the magnitude of an oil-lubricated rolling contact.

Kropp investigates dry tooth contact for various combinations of material and coating [Ref. 16]. The number of load- cycles-per-load level deviates from the standardized test procedure for scuffing. Analysis of the test results shows that the base material of the test specimens has an influence on the service life of the coating [Ref. 16]. However, no clearly better combination of coating system and base material could be observed here compared to the usual gear steel 16MnCr5. The results show that further investigations of other combinations of coating and substrate material are necessary to achieve a significant improvement compared to the usual gear steel.

Increased coating thickness and reduced roughness can increase the service life of carbon coated tooth flanks [Ref. 7]. Studies on the service life of coated gear flanks show no increased service life for variants that were smoothed with a running-in process before applying the coating [Ref. 3]. In addition to the coatings, the condition after production and the residual cooling lubricant from production can also influence the frictional behavior and load capacity of oil-lubricated gears [Ref. 17]. It is questionable how the influences of manufacturing, such as different surface structures and residual cooling lubricant, affect dry rolling-sliding contact.

In summary, it can be seen for the tooth contact that the stress in the dry rolling-sliding contact differs significantly from the stress in the oil-lubricated rolling-sliding contact. There are approaches to implementing and investigating dry gear applications, but the mechanisms of action have not yet been researched to the same extent as is the case with oil-lubricated gear applications.

Objective and Approach

The state of the art shows that dry operation with conventional gears is not feasible for many applications. The reduction in service life is related to the increased power loss, so that the question arises as to how the frictional force behaves in dry rolling-sliding contact and how the surface structure affects the distribution of the local frictional energy. The aim of this report is to gain knowledge of the frictional force behavior in dry rolling-sliding contact and to calculate the time-variable pressure distribution and local frictional energy for different orientations of the surface structure (Fig. 4).

Extending the scope of existing standards usually requires extensive experimental investigation of the areas of the standards to be extended (Fig. 4). The experimental investigation requires a uniform test concept and a defined damage criterion. Initial preliminary tests will be used to investigate the influences

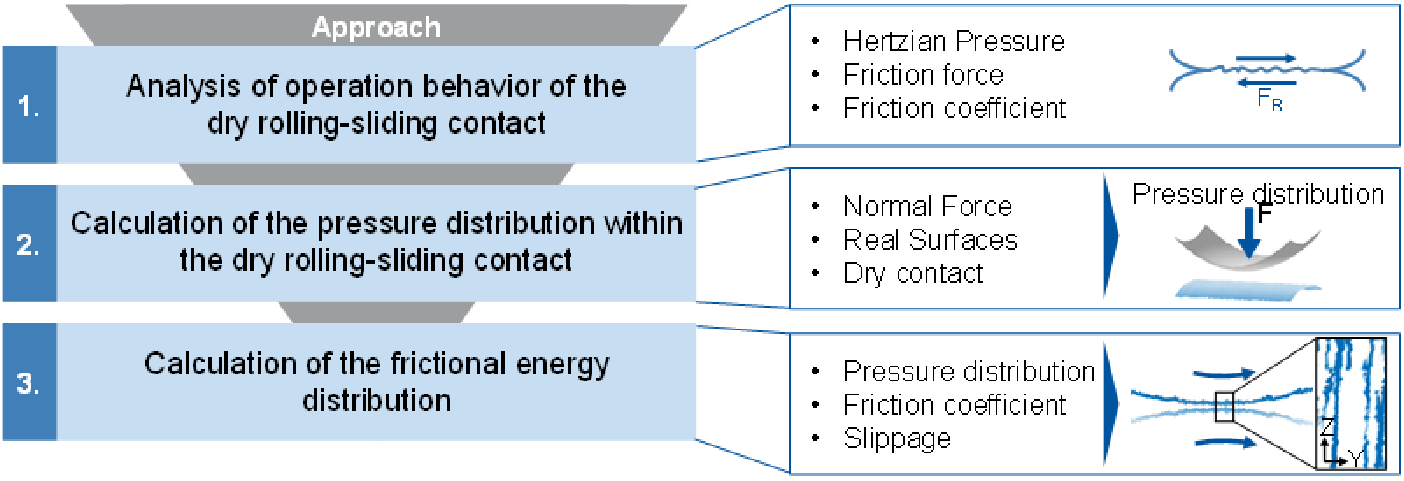

Figure 4 **Objective and approach.**

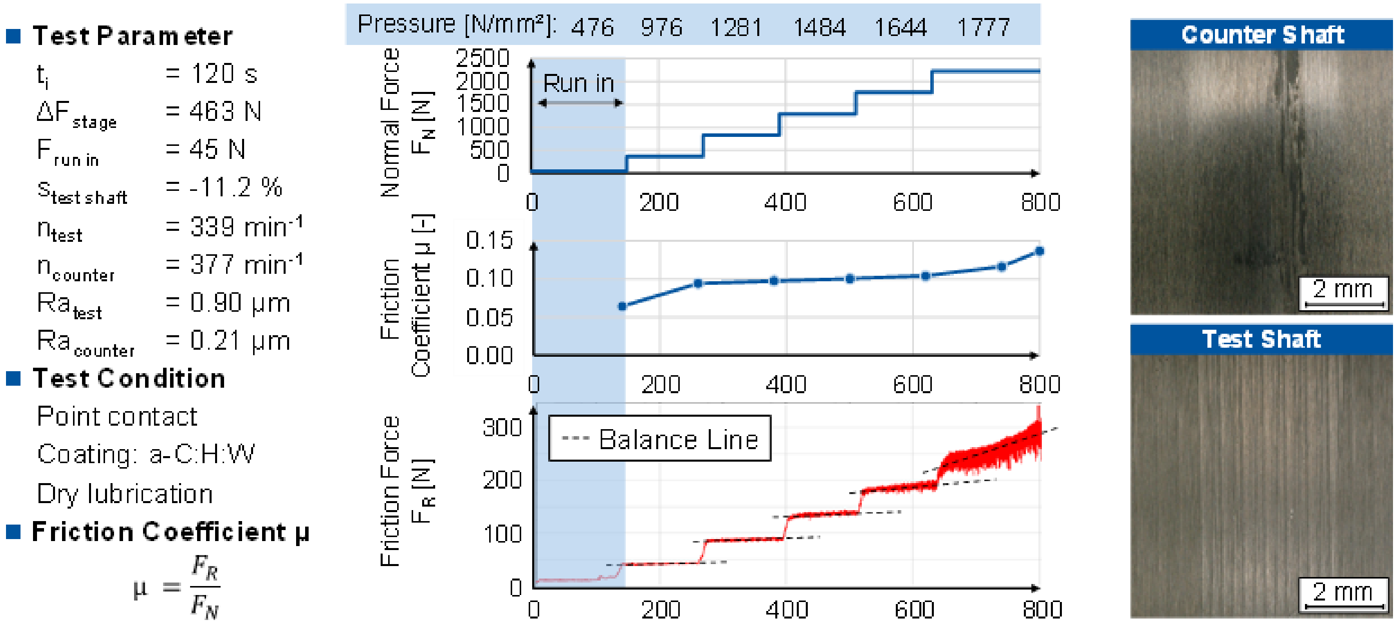

Figure 5 **Pre-test pressure ramp-up with dry lubricated rolling-sliding contact.**

on the service life and the operational behavior regarding friction force of the dry rolling-sliding contact.

In the dry contact of rough surfaces, a large number of microcontacts are created, so that the apparent macroscopic contact area is limited to a smaller real area [Refs. 18–19]. Thus, a calculation method for the temporal, high-resolution and large-area pressure distribution within a load cycle is required for the investigation of the effective mechanisms in the dry contact (Fig. 4). For the theoretical investigation of the influence of different orientations of the surface structure on the time-varying pressure distribution, the rolling-sliding contact between rough surfaces with a micro structure either transversely and/or longitudinally to the sliding direction is calculated and analyzed. Based on a variable pressure distribution, the local frictional energy will be calculated and analyzed for 3 different variants.

Experimental Investigation of Dry Lubricated Rolling-Sliding Contact

The first preliminary tests on dry rolling-sliding contact at the WZL friction force tribometer were used to investigate whether the existing test concepts and test parameters for investigating oil-lubricated contacts can be transferred to dry contact. The test procedure used is a staged pressure run-up analogous to the test procedure for scuffing damage. If the damage criterion is not met, the pressure is increased by one stage for a constant motor speed after an interval t_i. The damage criterion is defined as a sudden increase in the frictional force or the maximum frictional force or a strong subjective noise increase. Figure 5, for example, shows the friction force curve of a test between two a-C:H:

W-coated surfaces. The test was interrupted after the fifth load level due to a strong increase in the frictional force. The frictional force curve shows a constant average frictional force with little scatter at the first levels. As the load level increases, the balancing grades in the friction force diagram show that the friction force increases despite the constant normal force. The reason for the increase in the coefficient of friction is assumed to be a relationship between the increasing test specimen temperature and the continuous coating wear during the test run. A subsequent analysis of the running surfaces of the test and counter shafts revealed a coating failure (Fig. 5).

Furthermore, the preliminary tests show that the friction force tribometer is suitable for investigating the dry rolling-sliding contact. This is shown, among other things, by the necessary load range of the normal force, which is smaller for dry tests than for oil-lubricated tests, but is covered by the load range that can be mapped in the test rig. In the macroscopic form of the pressure distribution, a distinction can be made between a point contact and a line contact. For the dry contact, the preliminary tests indicate better repeatability for the line contact. When varying the interval duration, it can be seen that tests with a short interval duration of $t_i = 120$ s tend to achieve a higher pressing level compared to those with a long interval duration of $t_i = 1200$ s. For the influence of the interval duration, it is suspected that the lower number of load cycles lead to less wear in the contact area and that a short interval duration results in a lower mass temperature compared to a long interval duration. When using the test procedure for the oil-lubricated rolling-sliding contact, it is particularly important to maintain a constant interval duration because of the influence on the pressure level that can be achieved. In addition, the scatter of test results is higher than for oil-lubricated rolling-sliding contact. Repeat tests are therefore necessary for a systematic investigation of the dry rolling-sliding contact.

In summary, it can be stated that a maximum temperature, or a temperature change, or a maximum frictional force can be defined as a damage criterion and thus as an abortion criterion for the experimental test on dry rolling contact. Due to the influence of temperature, comparability between tests with different speeds of the test shaft is not possible. The analogous test procedure for the frictional load capacity is a suitable test concept for the experimental investigation of the dry rolling-sliding contact.

Contact Calculation within the Disk-on-Disk-Contact

Depending on the manufacturing process used, different surface structures arise on the contact surface which deviate from an ideally smooth surface, so that the real microscopic contact surface is composed of the contact of many individual roughness peaks [Refs.18–19]. The combination of individual microcontact points and a relative speed of the two contacting surfaces results in a varying local pressure within a load change [Ref. 20]. Due to the influence of thermal effects on the wear behavior in the dry rollingsliding contact, the local pressing process is crucial for a wear or service life prediction. For a better understanding of the tribological mechanisms in dry rollingsliding contact, the influence of different orientation of the surface structure on the temporal change of the pressure distribution is investigated with the aid of a calculation model (Fig. 6).

Calculation Method

For the high-resolution and large-scale calculation of the pressure distribution, a contact model based on the half-space is used in combination with an optimized meshing strategy (method of combined solutions) [Ref. 20]. The advantage of an analytical half-space model over a finite element analysis is the greatly reduced computational cost. Thus, the high-resolution pressure distribution in contact of real surface topographies as a result of a normal force can be calculated and analyzed for different rolling positions.

For the calculation of the variable pressure distribution, the rotation of the topography data is necessary after each pressure calculation of a rollingsliding position. Using different angles of rotation between the test and counter disk, a slip between the two contact surfaces can be mapped so that the angle of rotation of the counter disk $\Delta\alpha_{GS}$ is greater than the angle of rotation of the test disk $\Delta\alpha_{PS}$ in the case of negative slip from the point of view of the test disk. Figure 6 schematically shows the method for calculating the change in the pressure distribution. The line contact between two cylindrical disks is analyzed. The area of interest is meshed with a fine mesh of rectangular elements. The remaining area of the macroscopic contact region is meshed with a coarser resolution to account for the interactions and to reduce the computational effort. For the pressure calculation, the stationary pressure distribution on the test disk is considered. To observe the change in the pressure distribution, the finely meshed area is shifted in the Y-direction in conjunction with the topography of the test disk (Fig. 6).

Changing Pressure Distribution

Figure 7 shows the discretized pressure curves for a partial range of the load change on the test topography. For the contact calculation, a purely elastic material behavior is assumed, so that high pressures occur relative to an elastic-plastic material behavior for the investigation of the pressure distribution. The force equilibrium of the elastic contact calculation is calculated for the examination of the pressure distribution on the present cutout with an area of 500 µm * 50 µm. Thus, the cutout transmits the same normal force for all three variants.

The pressure distribution of a section of the macroscopic line pressure distribution for five rollingsliding positions (WS) is shown. Between the two topographies, the slip s_{test} = -100 % in relation to the test surface, so that a rotation angle per rollingsliding position of $\Delta\alpha_{WS,test} = 0.0135°$ results in a sliding distance of $\Delta s_{slip,counter} = 5$ µm. To investigate the influence of different surface structures, three variants are compared with each other. The three variants result from different combinations of the orientation of the grinding grooves. In the case of the surface with transverse grinding, the grinding grooves run in the direction of the axis of rotation (axial), and in the case of the surface with circumference grinding, the grinding grooves run in the circumferential direction and thus in the direction of the frictional force.

A comparison of the pressure distribution curves between the

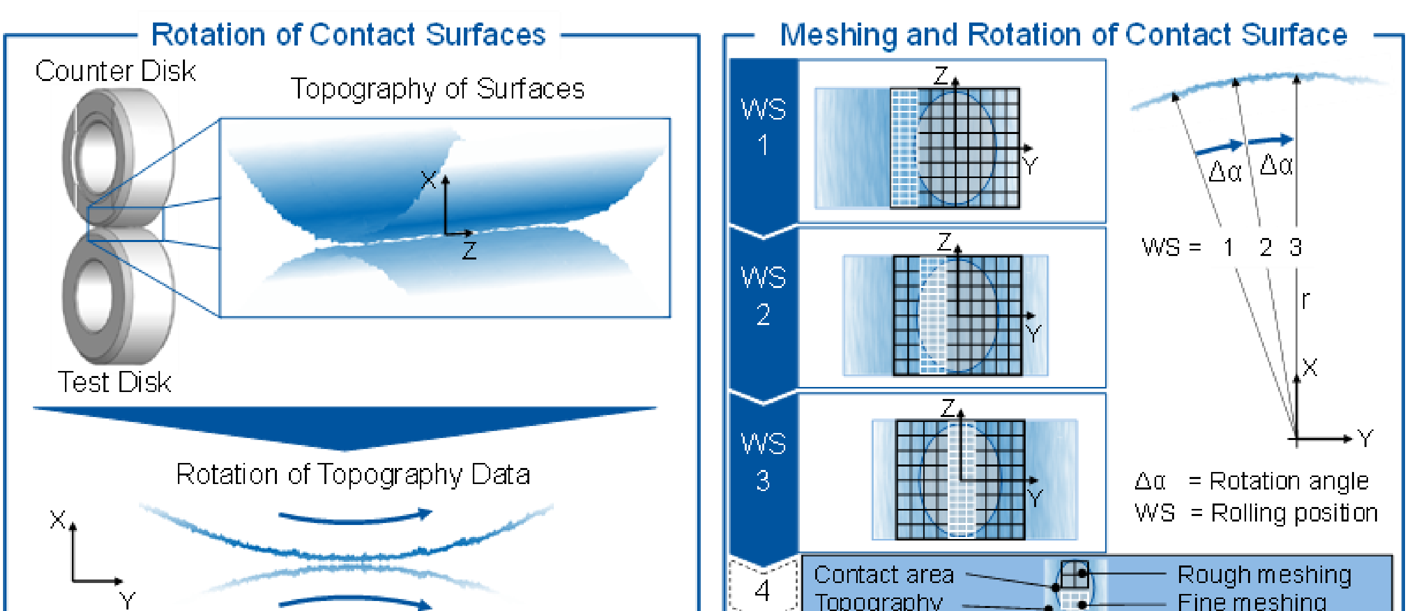

Figure 6 Calculation method of changing pressure distribution within dry rolling contacts.

variants with different grinding groove orientations (see Fig. 7) reveals significant differences. Variant 1 shows a section of the pressure distribution from the contact of transversely ground surfaces. The bending contact line that can be seen in rolling positions WS1 to WS3 results from the stochastic distribution of the roughness peaks and the topographic measurement of the surface. The characteristic picture of the pressure distributions of variant 1 changes with each rolling-sliding position. Here it can be seen that for individual micro contacts there are several contact changes within the macroscopic contact area. In contrast, the pressure distribution of variant 2 exhibits an approximately constant contact pattern for all rolling-sliding positions. Variant 3 shows the contact pattern from the contact between a transversely ground and a circumference ground surface. Here, on the one hand, areas can be seen which have contact with the opposite topography over all rolling-sliding positions. On the other hand, moving areas can be seen across the rolling-sliding positions, which can be traced back to the transversely ground surface structure of the counter disk. A contact change within the macroscopic load change interrupts the friction-induced energy supply, so that the local heat input is reduced. Thus, the contact changes simultaneously have a positive effect on the local temperature gradients and the service life of the contact.

Local Frictional Energy

The advantage of a uniform distribution of the microscopic contact areas over all rollingsliding positions can be illustrated with the local friction-related energy conversion. If the entire contact is considered macroscopically, the friction-related average energy conversion can be calculated according to Equation 1 [Ref. 19]. For the calculation of the microscopic distribution of the friction energy, the normal force F_N can be calculated from a sum of the pressures and the edge lengths dz and dy of all elements according to Equation 2.

Figure 8 shows the summed frictional energy over all 5 rollingsliding positions of the 3 variants for a section of the macroscopic contact area. Analogous to the pressure distribution, the distribution of the friction-related energy conversion also shows a more uniform distribution for variants 1 and 3. However, variant 2 exhibits higher local friction energies due to

$$E_R = \mu \cdot F_N \cdot s_{slip} \qquad (1)$$

E_R	[Nm]	Frictional Energy
F_N	[N]	Normal Force
μ	[-]	Friction Coefficient
S_{slip}	[m]	Slide Path

$$F_N = \sum_{i=1}^{n} p_i \cdot dy \cdot dz \qquad (2)$$

F_N	[N]	Normal Force
dy	[mm]	Edge Length of Element in y
n	[-]	Number of Elements
p_i	[N/mm²]	Pressure of Element i
dz	[mm]	Edge Length of Element in z

the approximately constant contact pattern over all rollingsliding positions, although the local pressures of variants 1 and 3 are greater.

In addition to the summed friction energy, Figure 8 shows the friction energy of a characteristic element with edge length dy = 1 µm and dz = 5 µm over the contact distance for the contact between two transversely ground surface structures. The two diagrams show the frictional energy conversion of a single element over the entire macroscopic contact distance of $l_{contact}$ = 0.4 mm. The frictional energy is shown with a resolution of 80 rolling-sliding positions over the entire contact distance. For the calculation of the friction energy curves, the pressure is considered constant over the increment of the sliding distance Δs_{slip}. The upper diagram shows the frictional energy curve for a slip of s_{test} = -10 % and a resulting slip path of Δs_{slip} = 0.5 µm per

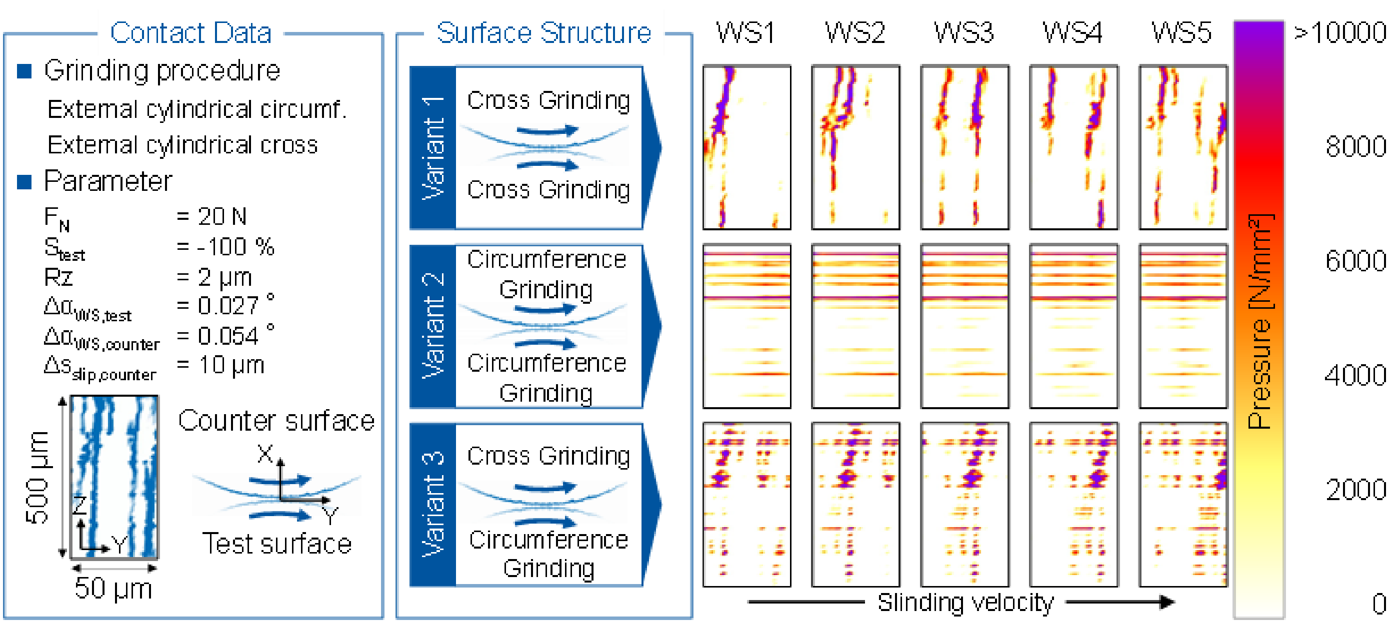

Figure 7 Pressure distribution depending on the contact position and surface structure.

rollingsliding position. The frictional energy curve shows that the microscopic element under consideration is in contact with the opposing topography three times over the contact distance. For a slip of s_{test} = -28 %, this results in a higher number of contact changes. The three contact phases from the upper diagram are therefore also the first three contact phases in the lower diagram. A comparison of the first contact phase in each case shows that a higher amount of frictional energy is mapped due to the greater sliding distance Δs_{slip}. In addition, further contact phases are added within the contact distance at higher slip.

Overall, a contact model exists which is suitable as a basis for a prediction model for the prediction of the coating wear and the service life taking into account thermal effects depending on the number of load cycles for the fluid-free contact of coated surfaces. With the assumption that the total frictional energy in the dry rollingsliding contact is converted into heat [Ref. 19], the method for calculating the local frictional energy provides a basis for considering thermal effects in the contact model. Furthermore, using the spatial and temporal distribution of the frictional energy, a method for calculating the layer wear can be implemented and developed for application to the dry contact.

Summary and Outlook

The reduction of the friction coefficient and wear in most rolling contacts like the tooth contact in a gear box is achieved by the usage of a fluid lubrication system with oil or grease. The production and maintenance of these systems produce high costs. Furthermore, specific circumstances like vacuum or a high pressure range lead to instability of the properties of fluid lubricants. From this perspective a dry lubrication is necessary for many applications because a fluid lubrication system is not feasible. The conventional lubrication system has two primary functions. First, the reduction of the friction coefficient by separating the rolling surfaces, and second, the removal of the heat from the contact zone and the system. Secondary functions are the removal of particles from the contact zone and the protection of the surfaces against corrosion. To optimize the dry lubricated rolling contact, three different approaches can be used: the gearing geometry, the core material of the gears, and the coating of the contacting surfaces. The objective of this report is the knowledge regarding the deficits of the dimensioning and the analysis of the dry lubricated rolling contact. Furthermore, the changing pressure distribution within a rolling contact of rough surfaces is analyzed.

The state of the art of dimensioning the gearing for dry lubricated rolling-sliding contact shows that current methods within the standardized guidelines for the calculation of the load capacity are not valid for dry lubrication with high mechanical load. The characteristics of the damage pattern from dry lubricated contact are similar to the characteristics of a scuffing damage. But for experimental analysis no uniform testing method is available. Pre-tests on the WZL disk-on-disk friction test rig show that the test rig and the testing procedure for scuffing are suitable for experimental investigations on the dry lubricated rolling contact. To reduce the costs of testing specimens and test rig capacity, prediction models are used to forecast the wear behavior and load capacity of gears and machining tools. There is a prediction model to forecast the wear of coated tooth flanks in fluid lubricated contact. The application of this prediction model on the dry lubricated rolling contact requires high resolution in order to take the whole contact area into account to consider thermal effects.

In order to forecast the wear behavior in a dry lubricated rolling contact, a method for the calculation of the changing pressure distribution is presented. The contact patterns of the three variants with different surface structure show that the combination of the two surface structures affect the changing behavior of the pressure distribution. The distributions of the frictional energy show the influence on the thermal effects within the contact area. To forecast the wear behavior considering thermal effects, experimental data from investigations on the test rig are required in the future.

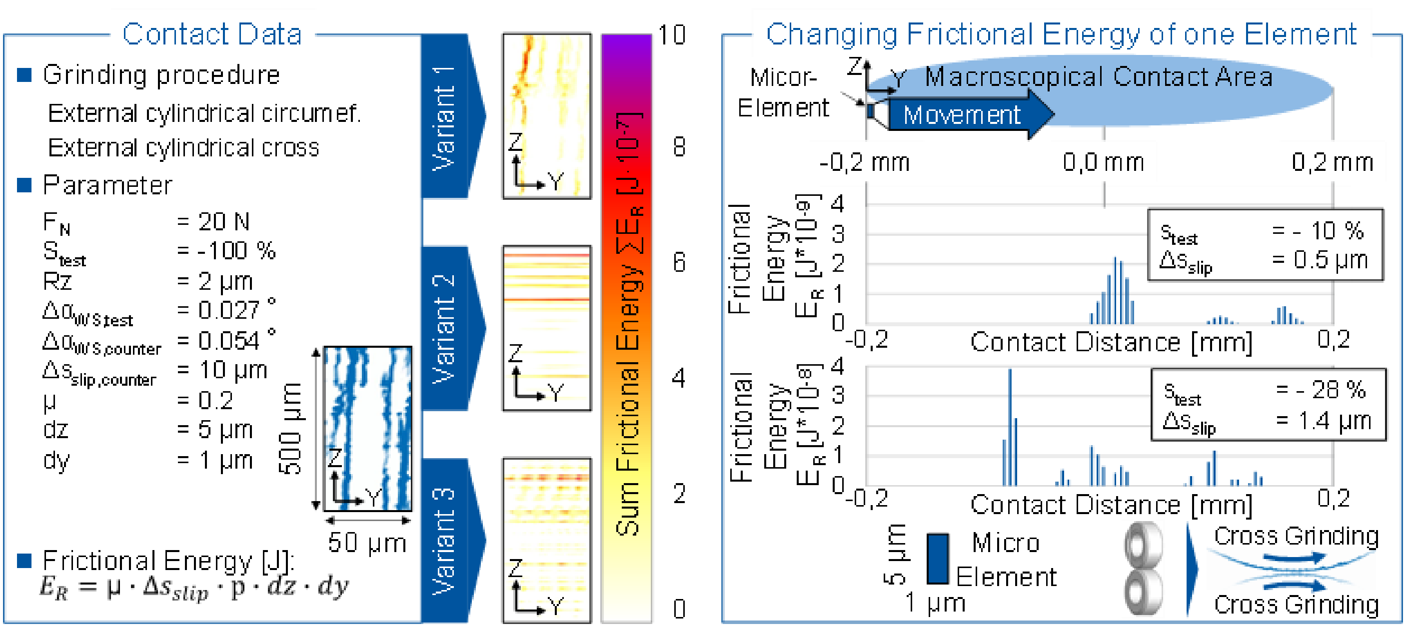

Figure 8 **Distribution and history of the local frictional energy.**

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Investigation of the Potential of Using Surrogate Models in the Gear Design Process

Jens Brimmers, Marius Willecke, Christoph Löpenhaus and Christian Brecher

This paper was first presented at the International VDI Conference on Gears 2019, 3rd International Conference on High-Performance Plastic Gears 2019, 3rd International Conference on Gear Production 2019, Garching/Munich (VDI-Berichte 2355, 2019, VDI Verlag GmbH, Page 727–740).

State of the Art

Surrogate models, also known as response surface models or metamodels, are approximation models, which are based on mathematical functions (Ref.1). In engineering, surrogate models are used to correlate the input and output variables of experiments and simulations (Refs. 2–10). This is especially true for very time-consuming, costly or high number of experiments/simulations. In this case, the surrogate model can be evaluated much faster in comparison to the experiment or complex simulation. This is most important for design space exploration or optimization where a high number of experiments of simulations is necessary (Ref. 5). In order to reduce the time effort, the extensive simulation is only performed for a reduced number of parameter sets. These initial parameter sets are defined by means of methods of design of experiment (DOE), e.g., full-factorial sampling or latin hypercube sampling (Ref. 11). For computational problems a latin hypercube sampling or the Monte-Carlo approach (random sampling) is often used to identify the initial parameter sets. Once the initial parameter sets are identified, the simulation is performed at these given points. The results of the simulation are used to fit a surrogate model to the given input variables in order to approximate the system behavior of the engineering system. Possible approximation types for surrogate models are shown in Figure 1. The most common modeling types are models based on radial basis functions (RBF), kriging models, also known as Gaussian process models, and models based on multivariate adaptive regression splines (MARS).

RBFs are functions whose value only depends on the Euclidian distance from the origin (Ref. 12). An approximation model consists of a number of different radial basis functions, which are weighted accordingly. The weights of each basis functions are tuned in order to improve the quality of the approximation for the given number of data points. In the example in Figure 1 the function $f(x) = 1 + \sin(x^2)$ was evaluated at six test data points and approximated by the usage of an RBF surrogate model consisting of Gaussian basis functions, as a type of RBF. The approximation follows the trend of the sine function but is not able to predict any of the test data points in high accordance.

Kriging or Gaussian process models originate from geosciences and are usually used to predict the location of certain commodities like oil or gold for which only a finite number of boreholes exists (Ref. 13). The Gaussian process consists of two parts, one global and one local part. The global part can be

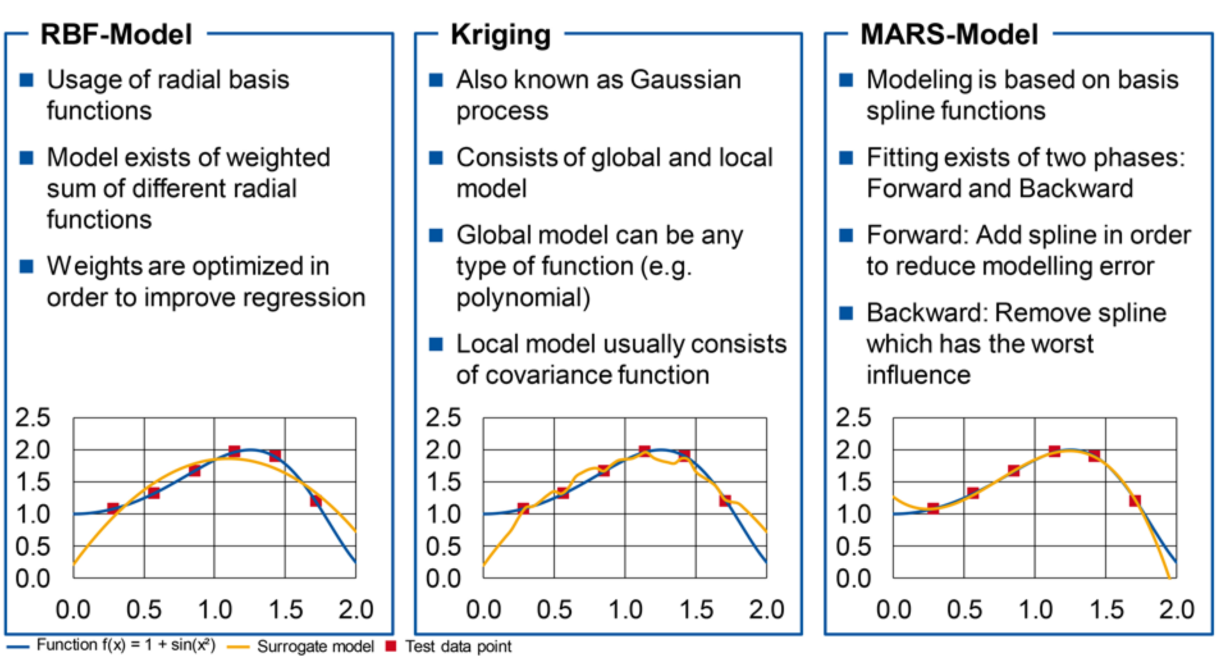

Figure 1 Overview of different surrogate modeling types.

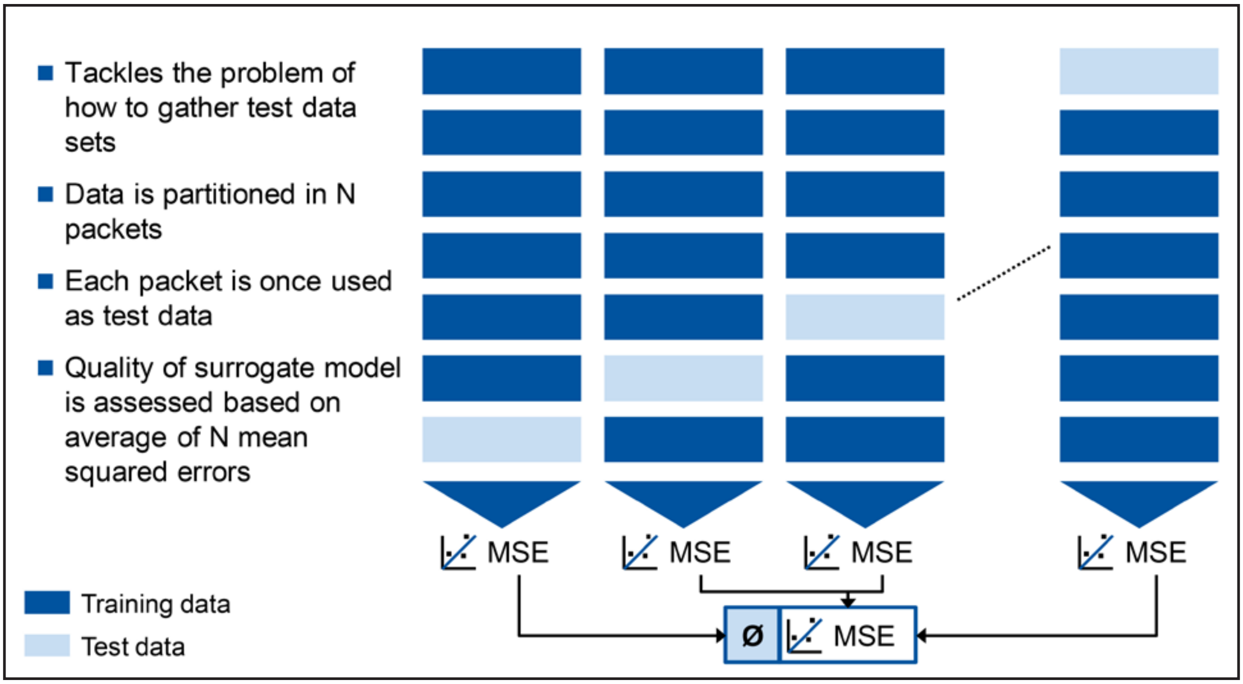

Figure 2 **Cross-validation as a method to assess the quality of the surrogate model.**

any type of function (e.g., exponential or polynomial), whereas the local part consists of a stochastical process, usually a co-variance function. For the example of the sine function (Fig. 1), the Gaussian process model (quadratic global model) follows the trend of the sine function and matches each given test data point (Refs. 14–15).

The third type are multivariate adaptive regression splines (MARS) (Ref. 16). A MARS model consists of different basis splines, e.g., linear function, etc. The fitting process consists of two parts, the first part being the forward-phase, where new basis splines are added in order to improve the quality of the approximation and therefore reduce the residuum; the second phase is the backward-phase, where the number of basis splines is tried to be reduced. The basis spline with the worst influence on the approximation is thus removed. For the example of the sine function (Fig. 1), the MARS model (up to degree of 3) is able to approximate each given test data point and the trend within the boundaries of the test data points with high accordance. Only for the area of extrapolation, higher residuum can be seen.

In order to evaluate the quality of a surrogate model, the error between prediction and given data point (residuum) is calculated. The mean squared error (MSE) is a possible method to calculate the residuum and is widely used in literature for regression problems (Ref. 5). For regression problems, it is necessary to have separate training and test data points in order to evaluate the quality of the prediction for points not being part of the training data. The surrogate model is trained on the training data set and evaluated at the test data points. The mean squared error as a measure of quality of the prediction and the test data is calculated. The lower the error, the better the model is. For engineering problems, where the usage of surrogate models is interesting, it is very hard to come by test data sets, as it takes additional time and money to generate these data points. In order to still be able to differentiate between training and test data sets, the cross-validation method is used (Fig. 2, (Ref. 5).

The given data is partitioned in N small data packets. Each packet is used as test data set once whereas the remaining data sets are used to train the model. Thus, the surrogate model setup is conducted N times. The quality of the surrogate model is the average mean squared error of each test data set.

Objective and Approach

The state of the art shows that surrogate models offer a great potential in reducing the necessary number of long experiments/simulations and have been applied to various fields of engineering problems, most notably to geoscience problems. Until now, there has been no application/comparative study of different surrogate modeling techniques within the field of gear design. Especially for the micro geometry design of gears, a high number of parameter sets have to be investigated. This leads to a great number of variants, which need to be simulated.

The aim of the report is to investigate the potential of using surrogate models within the gear design process. The report focuses on the comparison of different surrogate modeling techniques/types and their suitability for the gear design process. In addition, the surrogate models are used to optimize the micro geometry in respect to the defined design objective.

The approach for using surrogate models within the gear design process is shown (Fig. 3.).

The process is demonstrated based on a flow chart and starts with the definition of the design objective.

There are several gear design objectives (durability, efficiency, NVH, weight, cost), which usually are in conflict with each other (Ref. 17). Thus, a weighted objective function is used to describe the design objective, which considers different objectives. Next, the parameter space is defined. For each micro geometry parameter, lower and upper boundaries are set. Following, DOE methods (e.g., latin hypercube, random sampling) are used to do a design space exploration for a defined number of sets and get initial data points with which to train the surrogate model. These data points are then simulated with the help of the FE-based tooth contact analysis ZAKO3D (TCA) in order to characterize the operational behavior of the gears (Ref. 18). Based on the results, the surrogate model is trained and tested based on the method of cross-validation. If the cross-validation error is low enough, the process is proceeded; otherwise, the hyperparameter (parameter for the model generation) of the surrogate model is tuned in order to reduce the cross-validation error further. Next, the decision whether to use the surrogate model as a regression formula or for an optimization of the objective function is to be taken. If the model should be used as a regression formula, the process is at its end and the surrogate model gives a good approximation formula which can

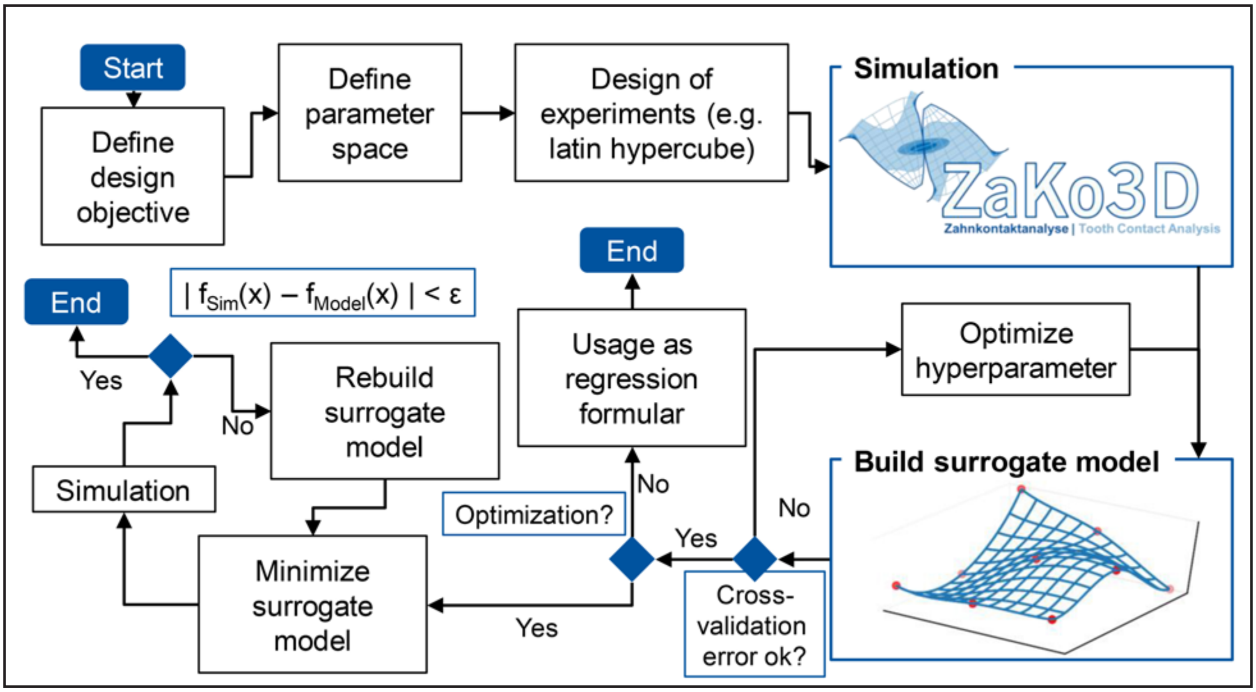

Figure 3 Overview on how surrogate models can be used for the gear design process.

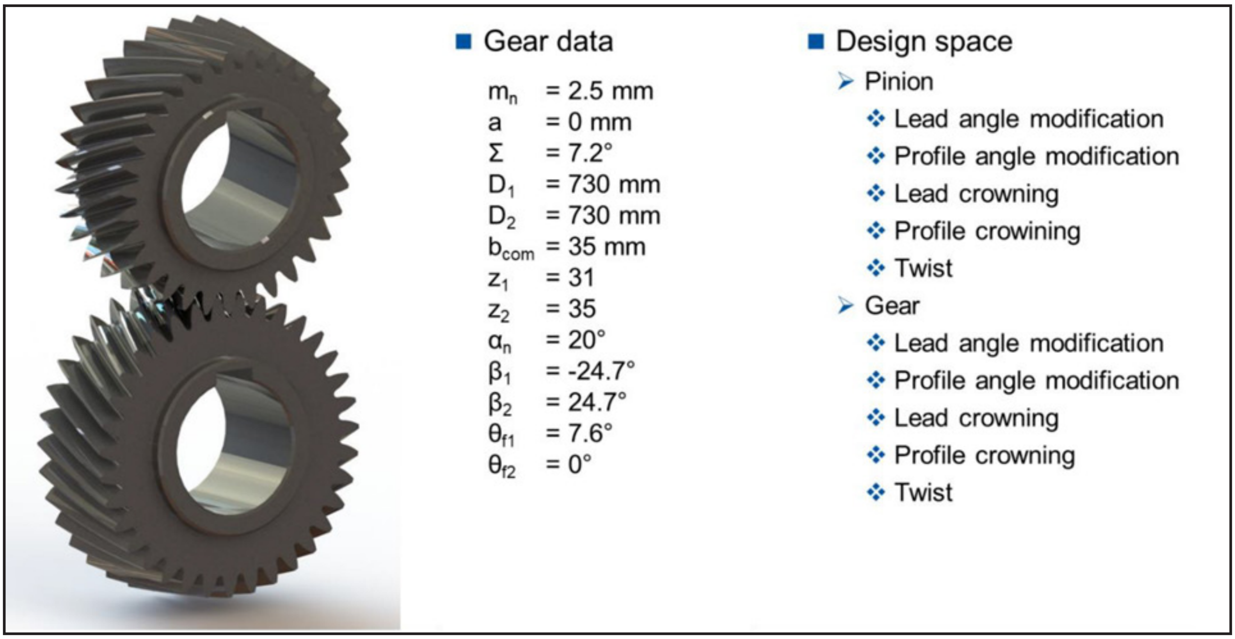

Figure 4 Gear data of test gear set and design space.

be easily evaluated in contrast to the simulation method. If the surrogate model should be used for an optimization, it is then used to minimize the approximated objective value with optimization techniques (e.g., gradient-based optimization). The optimal parameter set is recalculated in the simulation (here TCA). Next, the error between the surrogate model and the simulation is checked for the optimal parameter set. If the error is below a certain threshold, the optimization is ended. Otherwise, the surrogate model is retrained adding the optimal parameter set and the iterative process starts again.

Definition of Test Gear Set and Design Space

The test gear set which is used for this report is depicted in Figure 4. In order to investigate the potential of surrogate models, a beveloid gear set from an automobile application is chosen. The beveloid gear set has a normal module of $m_n = 2.5$ mm, number of teeth of $z_1/z_2 = 31/35$, a normal pressure angle of $\alpha_n = 20°$ and a crossing angle of $\Sigma = 7.2°$. The pinion is a beveloid gear with a root cone angle of $\theta_{f1} = 7.6°$, while the gear is a helical gear.

The design space for the investigation consists of ten different micro geometry parameters. For each, pinion and gear, the lead and profile angle modification, the lead and profile crowning as well as the twist are modified. The chosen upper and lower boundary for each parameter can be seen in Table 1.

The design objective for this report is the tooth root stress σ_{F2} acc. to van Mises at the gear for a torque of $T_2 = 100$ Nm. The occurring tooth root stresses are normalized to a scale of [0,1] in order to reduce the effect of the magnitude.

Comparison of Surrogate Modeling Techniques

Surrogate modeling techniques offer a great potential in approximation of complex simulations models. In order to set up a surrogate model, a defined initial set of points for the chosen design space has to be calculated. Design of experiment methods help in order to sample the points and have an even spread in the design space. Thus, the potential of surrogate models in the gear design process is also influenced by the DOE methods chosen to define the initial set of points. In order to investigate the influence of DOE methods, four different DOE methods were chosen. Out of the four methods, three methods are based on a latin hypercube while the last method is a random sampling within the boundaries of the design space (Refs. 11, 19). The sampling was done using the *Python* library *PYDOE2* (Ref. 20). Each of the three latin hypercube methods uses a different criterion for sampling the points. The criterion "center" centers the points within the sampling interval. The criterion "correlation" minimizes the correlation between each of the sampling points. The criterion "maximin" maximizes the minimum distance between each of the sampling points. The four methods were used to define samples for N = 300, 600 and 900 sample points within the abovementioned design space.

The comparison of the four DOE methods was done using a kriging model with a constant global polynomial (Fig. 5). The methods were compared on the value of the root mean squared

Table 1 Boundaries for the design space

Parameter	Lower boundary / µm	Upper Boundary / µm
Lead angle modification Pinion	-60	80
Profile angle modification Pinion	-42.5	0
Lead crowning Pinion	-50	0
Profile crowning Pinion	0	20
Twist Pinion	-30	30
Lead angle modification Gear	-80	80
Profile angle modification Gear	-20	20
Lead crowning Gear	-50	50
Profile crowning Gear	0	20
Twist Gear	-30	30

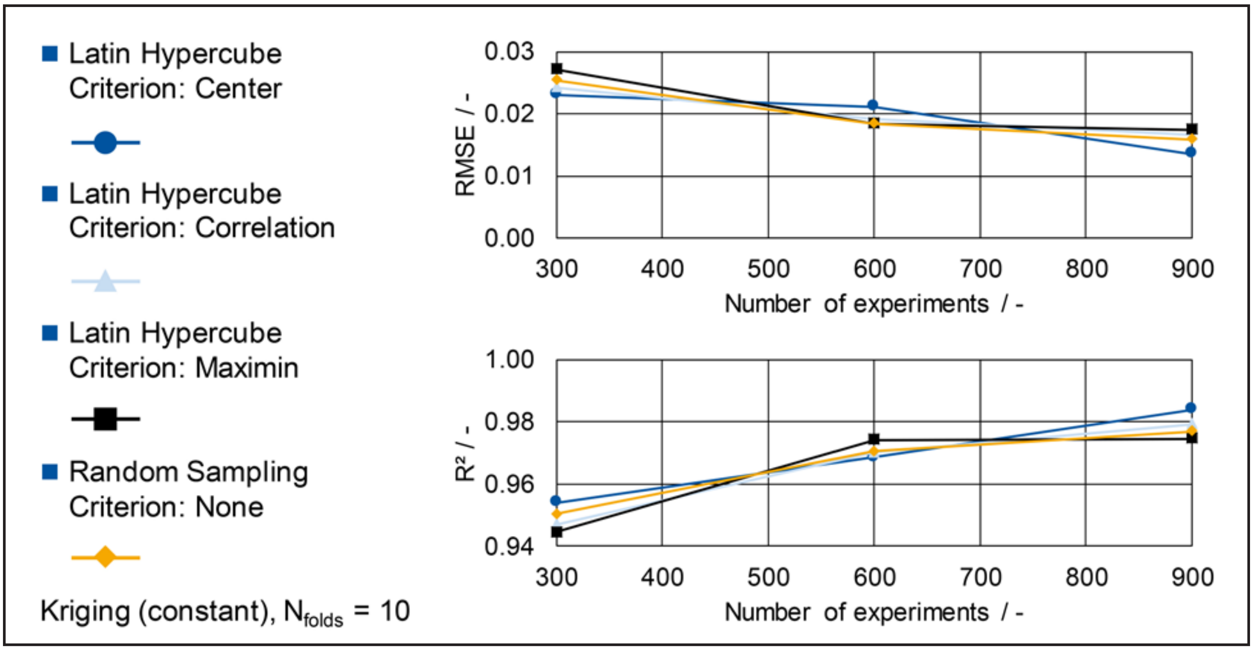

Figure 5 Comparison of DOE sampling methods.

error (RMSE) and the coefficient of determination R^2. Each of the two values is the mean of a cross-validation using $N_{folds} = 10$.

The comparison of the four DOE methods shows no defined influence of the sampling method on the quality of the approximation using the kriging model. For each of the methods a coefficient of determination $R^2 > 0.94$ can be achieved. Thus, a sampling using a latin hypercube with the center criterion is used onwards because of the highest mean coefficient of determination.

The figure also shows the influence of the number of experiments (sampling points). With rising numbers of experiments the quality of the approximation is increasing, which is to be expected. In order to investigate whether the coefficient of determination converges to a certain value with increasing number of experiments, a higher number of experiments is added.

The surrogate modeling techniques mentioned in the state of the art are compared to each other in terms of approximation quality (Fig. 6). The RMSE and R^2 are used as quality criterion for the comparison and are the mean values of a cross-validation using $N_{folds} = 10$. The kriging model uses a linear polynomial as a global function and uses a Gaussian correlation as a local function. The model is set up using the *SMT Toolbox* written in *Python* ((Ref. 1). The RBF model uses no global polynomial and is set up using the *SMT Toolbox*. The MARS model uses basic splines up to the degree of three and a maximum number

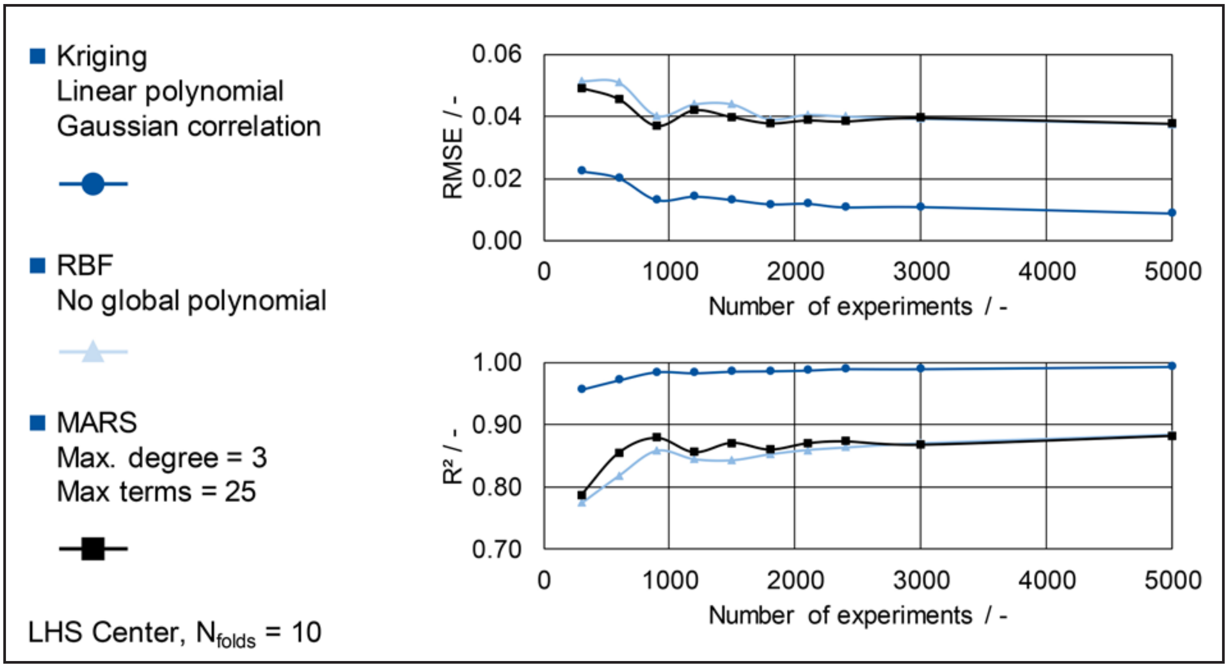

Figure 6 **Comparison of different surrogate modeling techniques.**

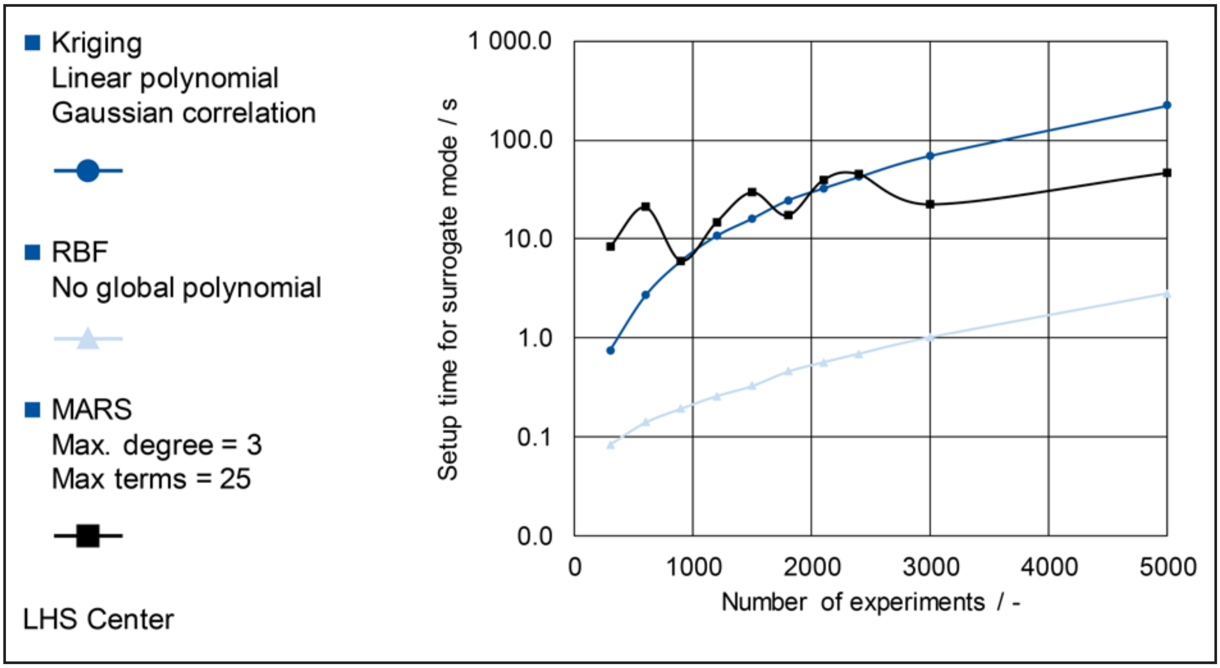

Figure 7 **Comparison of setup time for the different surrogate modeling techniques**

of terms of 25. The model is set up using the *Python* library *PY-EARTH* (Ref. 21).

For each of the three modeling techniques we can see an increase in quality with an increasing number of experiments. Comparing the three techniques, the kriging model has the best overall performance in terms of approximation quality. The RMSE is below 0.023 for each of the selected number of experiments and is steadily decreasing to a RMSE = 0.0093 at N = 5,000 experiments. The RBF and MARS model in contrast show a magnitude which is more than double in comparison to the kriging model. The difference between the RBF and the MARS model is minor, while the MARS model shows a slightly better approximation.

The same observation can be made for the coefficient of determination. The kriging model shows the best approximation with $R^2 > 0.95$ for each of the samples — even at a low number of N = 300 experiments. For N = 5,000 experiments $R^2 = 0.993$ can be achieved. The coefficient of determination for the RBF and the MARS model stays below a $R^2 < 0.9$ for each sample.

The results of the kriging model show that the marginal approximation quality (increase in quality with increase in number of experiments) is almost constant after N = 1,500 experiments. For the given example gear set, a number of N = 1,500 experiments should be enough to build a very good surrogate model.

Based on the results shown, we can conclude that the kriging method is the most suitable surrogate modeling technique for the gear design process of the three chosen techniques. Even for a low number of experiments, the coefficient of determination already shows very good results.

Although the approximation quality is the most important factor when it comes to surrogate modeling, the duration for setting up the model also plays a role in the design process. Therefore, Figure 7 shows the comparison of the setup time for the three used models in a logarithmic scale.

The lowest setup time is achieved by the RBF model, which is faster by a magnitude of 10 in comparison to the kriging and MARS model. For a low number of experiments the kriging model is faster than the MARS model. For a high number of experiments N > 2,500, the setup time for the kriging model is greater than the setup time for the MARS model. The setup time for the MARS model is not heavily influenced by the sample of experiments in comparison to the other two models.

Although the kriging model shows the highest setup time (especially for high number of experiments), the magnitude of the time to setup the surrogate model is still below or in the range of the simulation time for one sample point. Thus, we can conclude that the kriging model offers the highest potential for the usage in the gear design process.

Summary and Outlook

The gear design process is relying heavily on the use of simulation methods for predicting the operational behavior of gears. The cross influences of different geometry parameters (being macro or micro geometry) and positional parameters are oftentimes non-linear. In addition, there usually is a wide design space, which needs to be tested/explored to find the most suitable parameter setting. Thus, a great number of variants needs to be simulated in a tooth contact analysis. The high number of variants causes a high effort in calculation time and resources. In order to reduce the necessary number of experiments and therefore reduce the design time for gears, this paper focusses on the potential of using surrogate modeling techniques in the gear design process.

The investigation is conducted for a beveloid sample gear set with a design space consisting of ten different micro geometry parameters. The design space is explored using four different sampling techniques from the design of experiment (DOE). The results show that the chosen sampling techniques only have a very minor effect on the quality of the approximation. Because of the highest mean coefficient of determination, a centered latin hypercube was chosen for the further investigation. The comparison of the surrogate modeling techniques shows that a kriging model offers the highest approximation quality; this is even true for a low number of experiments. It can also be observed (which was to be expected), that an increasing number of experiments leads to an increase in the approximation quality. For the particular test gear set, a number of N = 1,500 experiments already offers offer a very good approximation.

Future research should focus on the application of the surrogate models in the optimization process. In addition, other modeling techniques, like convolutional neural networks or K-nearest neighbor approaches, should be investigated.

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The "Metallurgical Notch" in Type B Induction Hardened Gears

Robert Errichello, Andrew Milburn and Rainer Eckert

Introduction

Induction hardening is often used for large gears that are too large for existing carburizing furnaces. Large gears are usually heat treated by the tooth-to-tooth scanning induction hardening process, and that is the subject of this report. A major advantage of induction hardening is that the distortion and growth is much less than that associated with carburizing because only the case is heated while the core remains below the transformation temperature. However, induction-hardened gears have lower surface hardness and less load capacity than carburized gears, and this limitation must be recognized in any comparison of carburized and induction-hardened gears.

Advantages of Induction Hardening Over Carburizing

Induction hardening offers many advantages (Ref. 1):

- Capable of heat treating large gears
- Less distortion and shape change than carburizing
- Short process time maximizes productivity
- Repeatable quality with proper quality control
- Efficient process saves energy costs
- Environmentally friendly
- Any smoke or fumes are easily removed
- Significant reduction of heat exposure
- Significant reduction of scaling and decarburization
- Far less startup and shutdown time lowers labor cost
- Reduced maintenance costs
- Less floor space required

Disadvantages of Induction Hardening

Induction hardening has several possible pitfalls (Refs. 2–3).

- Less load capacity than carburized gears
- Back tempering
- Root and flank cracking
- Melting and overheating
- Unhardened areas
- Uneven hardening patterns
- Distortion and growth
- Heat treat parameters are difficult to control and heat treating defects are difficult to detect

Manufacturing considerations and pitfalls for induction hardening. Quoting from Ingham and Parrish (Ref. 2), "Induction hardening has problems. In the wrong heat treater's hands, the results can be disastrous." Quoting from Midea and Lynch (Ref. 3), "Any number of relatively minor variations can force the hardening process out of specification. Proper operator training, adequate maintenance and a fundamental understanding of the hardening process are all part of the equation. For induction hardening of gears, the devil is in the details."

Figure 1 shows a tooth from an induction-hardened gear that failed by bending fatigue because the hardened pattern did not include the full contour of the root fillet. There were 89 teeth on the gear and all teeth failed in an identical manner.

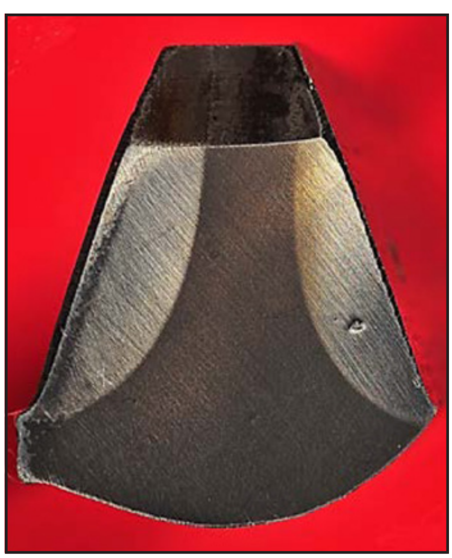

Figure 1 Bending fatigue failure of induction-hardened gear.

A classic bending fatigue crack started in the right root fillet at the point where the induction- hardened pattern emerged at the surface of the root fillet. AGMA 2101 (Ref. 4) classifies this as type B flank hardening and allows only σ_{FP} = 150 N/mm^2 bending stress instead of the usual 380 N/mm^2 for type A hardening pattern where the entire root fillet is hardened. Therefore, type B flank hardening has only 39% of the bending strength of a type A hardening pattern. Furthermore, AGMA 2101 (Ref. 4) allows σ_{FP} = 485 N/mm^2 for a carburized gear. Therefore, an induction hardened gear with a type B hardening pattern has only 31% of the bending strength of a carburized gear. Therefore, to have any chance of competing with a carburized gear, an induction-hardened gear must have a full contour (type A) hardening pattern, which would allow 78% of the bending strength of a carburized gear.

Figure 2 (taken from Fig. 8 of (Ref. 2)) shows a typical residual stress profile at the root of an induction-hardened gear. It shows that there are high compressive residual stresses at the surface and through the case hardened zone, which are beneficial because compressive residual stresses increase both macropitting resistance and bending fatigue resistance. However, there are detrimental tensile residual stresses that exist below the case/core boundary that peak at a depth of about twice the effective case depth. This is a critical area that can initiate subcase fatigue cracks, especially if nonmetallic inclusions are in the area of tensile residual stresses. Therefore, material cleanliness must be carefully controlled to avoid subcase fatigue or subsurface initiated bending fatigue. See ANSI/AGMA 1010-F14 (Ref. 5) for more information on these failure modes.

With type B hardening pattern the residual tensile stresses occur at the surface of the root fillet where they dramatically increase the risk of bending fatigue. Hence, metallurgists call the run-out of the hardened layer a "metallurgical notch." Figure 3 (taken from Fig. 19, (Ref 2)) shows the mechanism of a "metallurgical notch."

Uneven hardening pattern. Ideally,

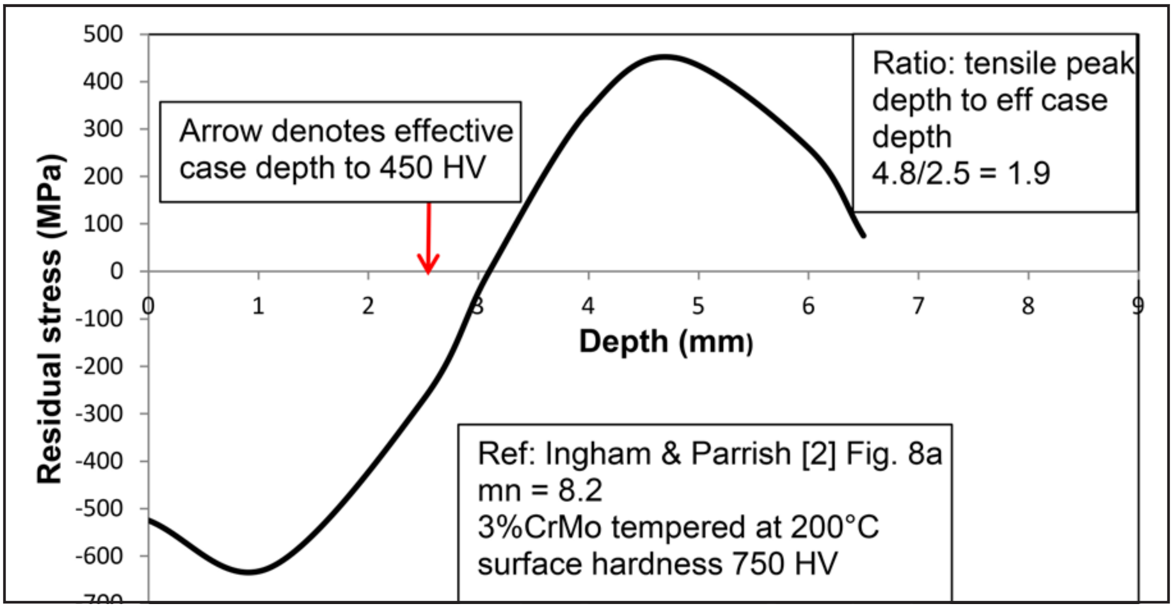

Figure 2 Induction-hardened residual stress profile (Ref. 2).

the inductor should be positioned symmetrically between the flanks of two adjacent teeth and at the correct depth. Asymmetrical inductor alignment, incorrect depth within the tooth space, or inadequate inductor rigidity, can result in uneven hardening patterns with excessive case depth on one flank and inadequate case depth on the adjacent flank. Figure 1 shows that the failed gear had a deeper case depth on the left flank than on the right flank.

Back tempering. As a tooth space is heated to temperatures above 720°C, some heat conducts through the teeth where it results in back tempering of previously hardened teeth. Therefore, a certain amount of softening by back tempering is inevitable, which can cause a loss of hardness that can range from a few points HRC to over 10 HRC (Ref. 3). Therefore, back tempering must be controlled by an adequate flow of quenchant to avoid excessive softening. The tooth tip and topland are critical areas for back tempering because there is a relatively small mass of metal at the tooth tip and there is a short distance for heat to travel from the heated flank to the previously hardened flank. To avoid back tempering,

This paper was originally prepared for the AGMA Metallurgy Committee. It was submitted with the recommendation to include the following definition to the next edition of AGMA 923: Metallurgical notch: If an induction hardened gear with type B flank hardening has a pattern that terminates (runs out) at the surface of the root fillet it is accompanied by tensile residual stress that adds to the bending stress, which greatly reduces the bending fatigue resistance. This is known as a "metallurgical notch."

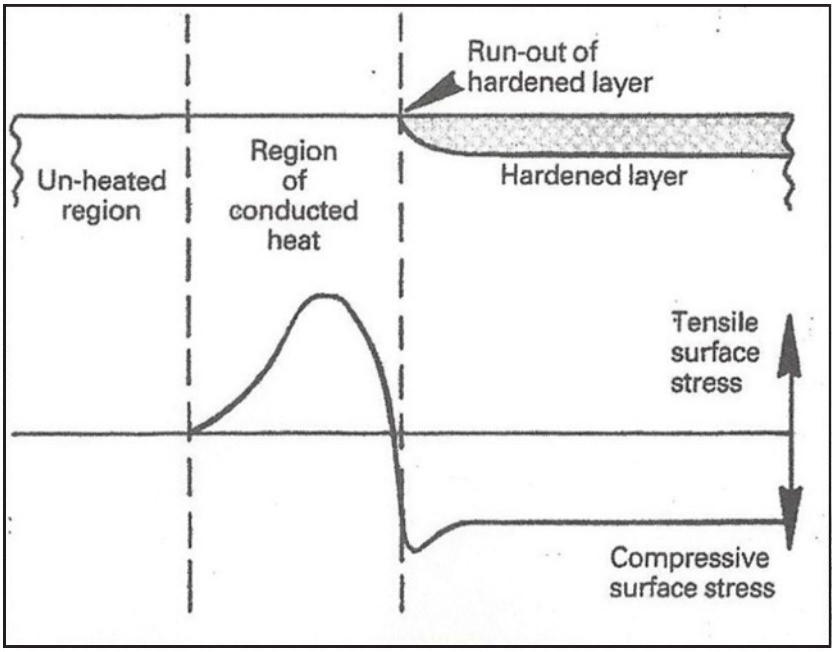

Figure 3 Residual stresses at end of hardened layer (Ref. 2).

additional cooling can be used on the previously hardened flank. Figures 4a and 4b (taken from Figs. 3a and 3b of reference (R3)) demonstrate how cooling jets can help prevent back temper. See reference 3 for guidelines to minimize back tempering.

Unhardened areas. Electromagnetic edge effects where the inductor enters or leaves the tooth space can result in areas that are left unhardened. Therefore, parameters such as how far the inductor is introduced into the tooth space before energizing, how long it dwells there in the energized state before starting its heating traverse, and how long it dwells at the end of the traverse must be closely controlled to avoid unhardened areas. Furthermore, the power density and traverse rate versus inductor position must be closely controlled. Within hardened areas the residual stresses are compressive, but in unhardened areas there are tensile residual stresses. Consequently, unhardened areas are defects that have very low bending fatigue resistance. Figure 5 is an example that shows unhardened areas near the end of the teeth (Fig. 18, Ref. 2).

Generally, induction-hardened gears are not as reliable as carburized gears because there are many more heat treating parameters that are difficult to control, and the manufacturing defects are difficult to detect. The most frequent root cause of failure of induction-hardened gears is inadequate case depth in the root fillet (for example, see Figs. 1 and 5). When the hardness pattern terminates (runs out) at the surface of the root fillet it is accompanied by tensile residual stresses (see Fig. 3), which often culminate in a bending fatigue failure. It is imperative to recognize that if a gear design requires a type A pattern, and a type B is manufactured, the gear will fail in service.

Definition for "metallurgical notch." Metallurgical notch: If an induction hardened gear with type B flank hardening has a pattern that terminates (runs out) at the surface of the root fillet it is accompanied by tensile residual stress that adds to the bending stress, which greatly reduces the bending fatigue resistance. This is known as a "metallurgical notch."

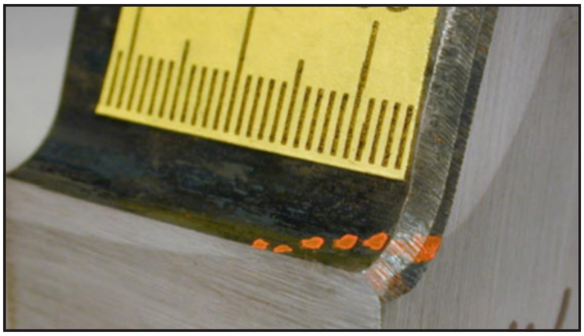

Figure 5 Unhardened area at end of tooth.

Figure 4a Induction hardening with cooling jets turned off (Ref. 3).

Figure 4b Induction hardening with cooling jets turned on (Ref. 3).

Conclusions

1. Induction hardening offers significant advantages over carburizing such as less distortion, higher productivity, environmental friendliness, and lower costs.
2. Induction-hardened gears have less load capacity than carburized gears. This limitation must be recognized in any comparison of carburized and induction- hardened gears.
3. Induction hardening has several possible manufacturing pitfalls including back tempering, root and flank cracking, melting and overheating, unhardened areas, uneven hardening patterns, and distortion and growth.
4. Induction-hardened gears are not as reliable as carburized gears because there are many more heat treating parameters that are difficult to control, and heat treating defects are difficult to detect.
5. If a gear design requires a type A flank hardening pattern, and a type B is manufactured, the gear will fail in service.
6. Type B flank hardening pattern is an example of a "metallurgical notch."
7. Type B flank hardening has only 39% of the bending strength of a type A hardening pattern.
8. Type B hardening pattern has only 31% of the bending strength of a carburized gear.

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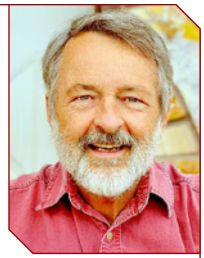

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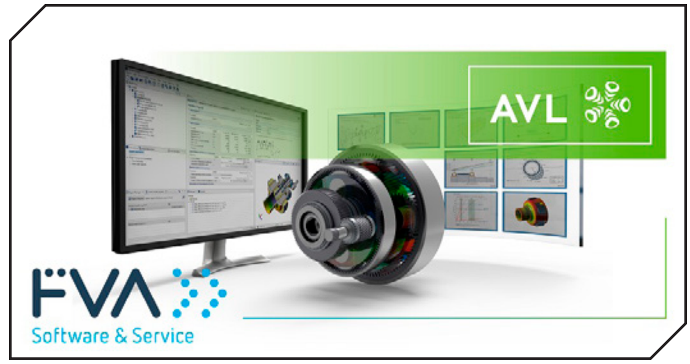

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- EXCITE: Durability and NVH analysis based on fully flexible structural dynamics simulation
- PreonLab: Highly efficient lubrication analysis with particle based CFD
- FIRE M: Optimization of Performance, Efficiency and Thermal aspects of propulsion systems, based on multi-physics CFD
- CRUISE M: Virtual System Integration, Function Development and Calibration

New developments in these areas will be available as further technical details come into play.

www.fva-service.de/de/software/

Solar Atmospheres

RECEIVES NADCAP 24-MONTH MERIT STATUS

Solar Atmospheres announces that its Greenville, SC facility has been awarded Nadcap 24-month merit status for heat treating, brazing and carburizing. The organization is extremely pleased PRI has recognized Solar's adherence to strict specification

requirements, flawless process execution, and a daily commitment to quality processing which is evident among all employees at Solar Atmospheres.

All Solar Atmospheres facilities, Souderton, PA; Hermitage, PA; Fontana, CA and Greenville, SC have now earned Nadcap 24-month merit status demonstrating Solar's corporate commitment to quality.

"This is the goal that all Nadcap suppliers strive for, and it's not an easy task," states Steve Prout, president of the Solar Atmospheres Greenville, SC facility. "It truly is a team effort from the employees handling our customers' products while conducting the thermal processes and testing, to the post process compliance and review. Everything must be in order and completed without issue. Our team in Greenville, as well as all our other locations, are committed to top-tier heat treating services. This 24-month Nadcap accreditation award is evidence of our unwavering commitment."

www.solaratm.com

Felsomat USA

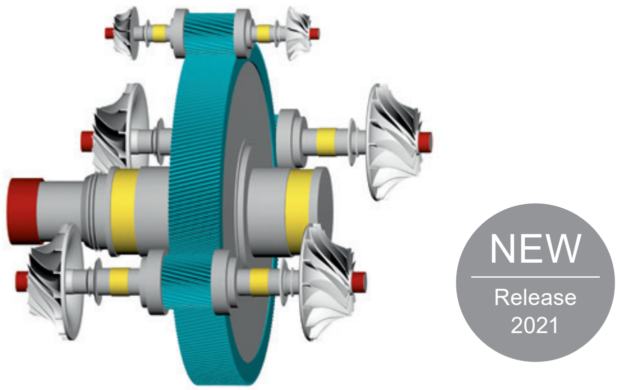
HOSTS OKTOBERFEST IN SCHAUMBURG, ILLINOIS

On Thursday, October 28, Felsomat offered delicious German beers, traditional tasty treats, and the opportunity to explore their innovative technologies in person.

Felsomat prepared a schedule full of live machining demonstrations, exciting technology presentations, and networking opportunities. Two highlights of the open house included the FHC 180 Gear Hobbing machine and the Crankshaft Deburr System

FHC 180 Gear Hobbing Machine

This complete system consists of a gear hobbing machine that includes gear chamfering and a load + unload automation system. The machine will load and unload parts automatically, and then when the hobbing is complete will automatically chamfer the gear and load the part onto alloys for heat treatment. Not only will this improve your processing times, but it will also improve part quality and minimizing clamping errors.



KISSsoft Features

- Bearing calculation with inner geometry in the „SKF Cloud“
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- Import possibility of cylindrical gear flank measurement grid
- System reliability at a glance with AGMA 6006-B20
- Compare variants of gear modifications

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KISSsoft AG/Gleason Sales
Brian P. Stringer
Phone (585) 494-2470
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Drivetrain Design Solutions **KISSsoft**

Crankshaft Deburr System

Deburring can be complicated, and precision during the process is essential. Ensure perfection with the innovative crankshaft deburr system from Felsomat. With this complete system, you'll be able to deburr all oil holes and cross holes in the crank with one system. This complete system will also allow you to chamfer the holes, includes robotic loading and unloading with precision location at the deburr station, allows for the attachment of a gear on the end of the crankshaft using heat stake operation, and the loading/unloading from dunnage while preventing damage to the crank.

www.felsomat.com

Klingelnberg

RELEASES LATEST ISSUE OF GEARS

In the eighth issue of its GEARS inline customer magazine, Klingelnberg presents the projects and developments it has advanced in recent months, with a special focus on trends and developments in renewable energy, particularly wind energy. An exclusive interview on this topic with Gary Gu, executive director the Asian gearbox manufacturer NGC Transmission Equipment, reveals some fascinating responses.

In addition to a range of solutions for wind energy, the current issue also includes customer reports. Mexican automobile manufacturer Transmisiones y Equipos Mecánicos S.A. de C.V. (TREMEC) reports on its experience with the Höfler Cylindrical Gear Generating Grinding Machine Speed Viper. The customer received an entire production system consisting of design software, new operating software and an innovative machine. TANDLER GmbH & Co. KG, which specializes in gears and transmissions, demonstrates the advantages of retrofitting and explains when it's worth it to overhaul a machine. Klingelnberg also introduces its latest machine development: With the Höfler Cylindrical Gear Roll Testing Machine R 300, Klingelnberg is introducing onto the market a machine that is designed for a compact, flexible, high-precision testing technology for 100-percent quality control of cylindrical gears.

Additional articles include: Gary Gu, executive director of the gearbox manufacturer NGC, and Prasad Kizhakel, chief sales officer of the Klingelnberg Group, discuss opportunities, trends, and technologies in wind. Dr. Hartmuth Müller, head

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of technology and innovation, explains the history of wind turbine generators and highlights a range of concepts. Product showcases on the Precision Measuring Center P 152, Höfler Cylindrical Gear Roll Testing Machine R 300 and Speed Viper. Jan Greune, head of operations at Tandler, and Loïc de Vathaire, service manager, bevel gear technology at Klingelnberg, discuss the advantages of a machine retrofit.

To order the magazine, call +49 2192 81-0 or send an email to *marketing@klingelnberg.com* with "GEARS inline" in the subject line.

www.klingelnberg.com

STLE

CONTINUES TRIBOLOGY AND LUBRICATION PODCAST SERIES

The Society of Tribologists and Lubrication Engineers (STLE) — the technical society for individuals in the field of tribology and lubrication engineering — is pleased to announce the immediate availability of a new, free podcast titled "Potential Benefits of Tribochemistry."

The podcast features interviews with STLE board members, Kuldeep Mistry, Ph.D. (The Timken Company) and Nicolas Argibay, Ph.D. (Sandia National Laboratories), on how tribochemistry can help perfect motion through the reduction of friction and wear. Tribochemistry enables researchers to design machinery systems that leverage the interaction of specific lubricants with select metal surfaces under standard operating conditions, allowing manufacturers to maximize machine efficiencies and productivity.

The new episode is second in STLE's podcast series, "Perfecting Motion: Tribology and the Quest for Sustainability." The program is hosted by Neil Canter, Ph.D., STLE advisor, technical programs and services and Tribology and Lubrication Technology (TLT) writer, and covers several tribology and lubrication topics — including additive manufacturing, lubricant additives, nano-lubricants, nano-additives, lubricant testing, graphene and more.

"The benefits of tribology and lubrication in manufacturing are numerous," says Canter. "Not only can tribology enable advancements to extend component life in equipment, but it can also enable manufacturers to improve the quality and quantity of outputs and operate their equipment more safely."

STLE offers tribology and lubrication content in a variety of different formats — print, digital, video and now audio. To listen to STLE's new podcast or to access archived episodes, visit www.stle.org/podcast or follow "Perfecting Motion: Tribology and the Quest for Sustainability" on Spotify, Apple Podcasts and Google Podcasts and others to be notified when new episodes are released.

http://www.stle.org/podcast

United Grinding

PARTNERS WITH TITANS OF CNC FOR GRINDING EDUCATION

United Grinding has partnered with Titans of CNC, the well-known global manufacturing education provider, to support specialized education for precision grinding in the manufacturing industry.

The partnership includes the development of a grinding academy, designed to teach individuals new to the industry the basics of grinding in an easily digestible, digital format. United Grinding will launch a new website to support this partnership - titansofgrinding.com - and it will house a variety of information about the partnership. The site will also include a list of machines that Titans of CNC has utilized for training and production and serve as a source for all of the video content Titans of CNC has produced involving United Grinding machine technology.

According to Titan Gilroy, CEO and founder of Titans of CNC, his focus is on the development and delivery of high-level manufacturing education through the Titans of CNC Academy. With its free, online, video-based, step-by-step training system, Titans of CNC continues to provide answers to real manufacturing problems.

"My team and I are excited to officially partner with United Grinding to bring awareness and advanced grinding education to a worldwide audience," said Gilroy. "United Grinding has a great reputation in the industry due to the quality, performance, and versatility of their entire machine line-up. This is why we have chosen to develop the most advanced grinding curriculum in the world on the platform that is United Grinding."

Gilroy started Titans of CNC as a machine shop in Northern California that produced some of the most challenging components for the aerospace industry. From there, the shop progressed to a reality TV series recognized as a leading CNC educational platform among a global network of engineers, machinists, hobbyists, students and educators.

"Our motivation is the success of our customers. Our ambition is, therefore, to accompany our customers along their way and to provide our expertise as a strong and reliable partner to make them even better," stated Stephan Nell, CEO of the United

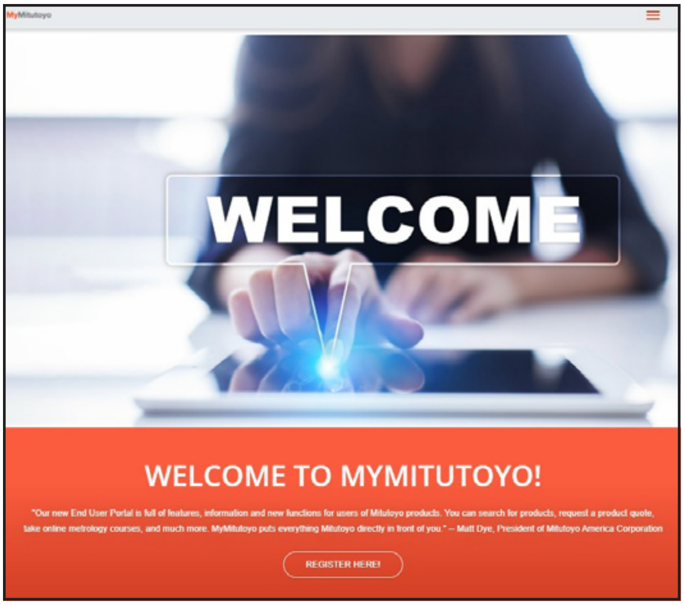
Grinding Group. "The need for trained machinists is greater now than ever, and in our new partnership with Titans of CNC, we are proud to recommit our efforts to building the next generation of young machinists."

Grinding.com

Mitutoyo America

LAUNCHES NEW WEBSITE/ DISTRIBUTOR PORTAL

Mitutoyo America Corporation has announced the launch of the new Mitutoyo website as well as MyMitutoyo, the new end user portal.



Mitutoyo.com has a brand new, updated look with better functionality and an improved user experience, making access to Mitutoyo products, services, and information faster and easier. Mitutoyo products on the new website are better connected to more robust technical specifications and product information for more useful, accurate product searches. This allows visitors to research and qualify Mitutoyo products and solutions for their needs more effectively.

The new Mitutoyo.com also better highlights the company's metrology services and solutions including calibrations, installation, and repairs, as well as enhanced and easier-to-navigate resource and education pages. Mitutoyo.com is also integrated with the new end user portal, MyMitutoyo, giving users the option to request a price quote, find a distributor or request more product information with a click of a button.

The Mitutoyo End User Portal, branded as MyMitutoyo, provides many new features and benefits for Mitutoyo customers, including the ability for customers to search for Mitutoyo products they want, put them in a cart and then generate a quote online to send to a distributor using the new Distributor Locator feature.

The Distributor Locator lists Mitutoyo distributors or Mitutoyo M³ Solutions Centers nearest the zip code a customer enters in their profile during free registration. The Distributor Locator also can filter distributors for specific product groups, choose a preferred distributor, and send quotes to several different distributors if a customer chooses.

Mitutoyo customers can also register their Mitutoyo products to receive product-specific manuals, technical specifications, product use and maintenance videos, discounts, helpful hints and more.

Additionally, the End User Portal features a list of online metrology courses that offers registered users on-demand, self-paced education, and training just like being in the classroom, but with more flexibility.

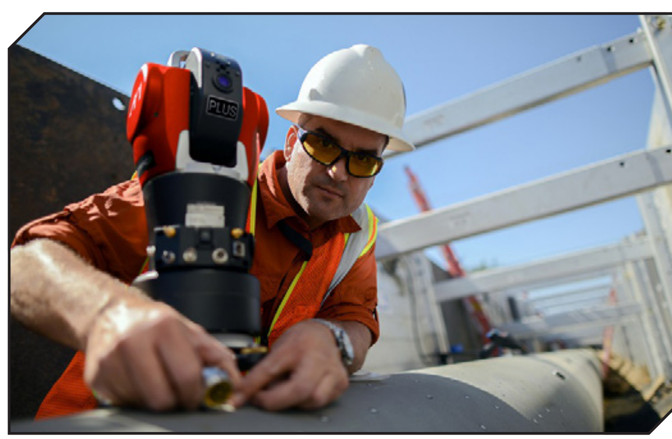
www.mitutoyo.com

API and Prosper Machine Tool

ANNOUNCE RESELLER, SUPPORT AGREEMENT

API has announced their partnership with Prosper Machine Tool, a family-owned machine tool distributor, to provide premium metrology services in Texas.

While some of the most essential work in Aerospace, Defense, and Oil & Gas manufacturing continues to expand throughout Texas, supply of critical dimensional metrology equipment and services often lags behind demand. To bring hands-on customer service to these underserved industries, API and Prosper Machine Tool are bringing together their application expertise, customer service, and world-class equipment.



API Metrology and Prosper offer a combined ten decades of dedicated experience in portable Laser Tracker metrology. This partnership unites API Metrology's state-of-the-art dimensional Metrology equipment, including Radian Laser Tracker Series and XD Laser Interferometer, and Prosper's history of solution-based metrology services. Prosper also offers a full parts and service department that handles installations, parts and any needed repairs.

www.apimetrology.com

January 3–7—SciTech 2022

San Diego, CA. From its creation in 1963, the American Institute of Aeronautics and Astronautics (AIAA) has organized conferences to serve the aerospace profession as part of its core mission. Spanning over 70 technical discipline areas, AIAA's conferences provide scientists, engineers, and technologists the opportunity to present and disseminate their work in structured technical paper and poster sessions, learn about new technologies and advances from other presenters, further their professional development, and expand their professional networks. The AIAA Science and Technology Forum and Exposition (AIAA SciTech) has continued to grow in each succeeding year, drawing participants from around the globe. SciTech participants tackle the most pressing issues impacting the future of aerospace, while the technical program presents innovative research and technologies that offer solutions. The newly developed hybrid format allows attendees to attend, present and interact virtually or in-person.

www.aiaa.org

January 18–20—World of Concrete 2022

Las Vegas, NV. World of Concrete has been serving the global concrete & masonry construction industries for 46 years. The goal is to provide this important community with the connections, intelligence, and opportunities that help customers grow, do business, and make better informed business decisions. The show attracts original equipment manufacturers from around the world and exclusive U.S. distributors of equipment, tools, products and services for the commercial construction, concrete and masonry industries. Education topics include materials, safety, business management, quality control, new technologies and more.

www.worldofconcrete.com.

January 20–26—IMTEX 2022

Bangalore International Exhibition Center, Bangalore, India. IMTEX 2022 provides a range of metal-cutting machine tool technologies, products and solutions to meet the demands of the manufacturing industry. The event attracts visitors from a wide spectrum of manufacturing and ancillary industries starting with key decision and policy makers sourcing the latest technologies and manufacturing solutions for their production lines. Products include milling, turning, gear manufacturing, grinding, honing machines, flexible manufacturing systems, machining centers, and more. Co-located with IMTEX is ToolTech 2022, an International Exhibition of Cutting Tools, Tooling Systems, Machine Tool Accessories, Metrology and CAD/CAM and IMTEX Forming 2022.

www.imtex.in.

January 25–27—AGMA Fundamentals of Gear Design and Analysis

Clearwater Beach, FL. Offered by AGMA, attendees will gain a solid and fundamental understanding of gear geometry, types and arrangements, and design principles. Starting with the basic definitions of gears, conjugate motion, and the Laws of Gearing, learn the tools needed to understand the inter-relation and coordinated motion operating within gear pairs and multi-gear trains. Basic gear system design process and gear measurement and inspection techniques will also be explained. In addition, the fundamentals of understanding the step-wise process of working through the iterative design process required to generate a gear pair will be reviewed.

www.agma.org/education/advanced-courses/2022-fundamentals-of-gear-design-and-analysis/.

January 25–27—IPPE 2022

Atlanta, Georgia. The International Production & Processing Expo is the world's largest annual poultry, meat and feed industry event of its kind. A wide range of international decision-makers attend this annual event to network and become informed on the latest technological developments and issues facing the industry. The 2022 IPPE will provide a full week of education programs, in addition to new technology, events on the show floor and networking opportunities with key leaders from the animal food, meat and poultry industries. The vast trade show floor will showcase the most current innovations, equipment and services used in the production and processing of animal food, meat and poultry products. Combining the expertise from the American Feed Industry Association, North American Meat Institute and U.S. Poultry & Egg Association, IPPE will also feature countless hours of dynamic education sessions focused on the latest industry issues.

ippexpo.org.

January 26–27—Grinding Conference

Stuttgart-Fellbach, Germany. This event from WZL of RWTH Aachen University is a grinding conference that provides the interface between science and industry. Under the title "Cylindrical/uncircular grinding - efficient and sustainable," the contribution of grinding technology to resource conservation and climate neutrality will be discussed. To this end, current findings from research and development will be made comprehensible and usable for users. The joint evening event offers the opportunity to exchange ideas with speakers and participants in a familiar atmosphere. The Machine Tool Laboratory WZL of RWTH Aachen University as well as the established advisory board are looking forward to your participation and welcome all exhibitors.

www.wzl.rwth-aachen.de/go/id/pziph?lidx=1#aaaaaaaaaapzjrt.

February 21–23—MIM2022

West Palm Beach, Florida. MIM2022: International Conference on Injection Molding of Metals, Ceramics and Carbides is a global conference and tabletop exhibition highlighting advances in the metal injection molding (MIM) industry, with two days of technical sessions focusing on the latest innovations in metal injection molding. Innovation is responsible for the rapid growth of the powder injection molding industry (metal injection molding, ceramic injection molding, and cemented carbide injection molding), an over $2 billion advanced manufacturing industry. This conference will provide a venue for the latest technology transfer. Conference highlights include a Powder Injection Molding Tutorial, two days of technical sessions, and a tabletop exhibition and networking reception.

MIM2022.org

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Gleason Model 13 Universal Tester, 13" Gear Diameter, #39 & #14 Tapers, Gearhead ID = 0.0001" (0.0025 mm). Face = 0.0000" (0.0000 mm); Pinion ID = 0.0001" (0.0025 mm). Face = 0.0001" (0.0025 mm)

Gleason Model 17A Hypoid Tester, 20" Gear Diameter, #39 & #14 Tapers, Hydraulic Clamping, Gearhead ID = 0.0008" (0.02 mm). Face = 0.0002" (0.0050 mm); Pinion ID = 0.0003" (0.0075 mm). Face = 0.0001" (0.0025 mm)

Gleason Model 519 Universal Tester, 36" Gear Diameter, 12" Pinion, #60 & #39 Tapers, ID Both Spindles = 0.00005" (0.00127 mm). Speeds 200 to 2000 rpm, 1967

From an aircraft gear shop—they make no commercial gears:

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Gleason Model 463 Spiral Bevel Gear Grinder, Optional No 60 workhead taper, up to 22" wheel, coolant, filter, 1984

Gleason Model 463 Spiral Bevel Gear Grinder, No 39 workhead taper, 10" wheel, High Speed spindle arrangement to 3,600 rpm, coolant, filter, 1983

Klingelnberg Model AH1200 (48") Bevel Gear Quenching Press including Manipulator, Furnace & Dies Seen Minimum Usage Built 2008

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☐ I am a SUPPLIER to the GEAR INDUSTRY (24)
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A Gearhead's Guide to the Holiday Season

Matthew Jaster, Senior Editor

What holiday offering do you give the engineer or manufacturer in your life? Why should you come to the holiday party empty-handed this year? There are so many gizmos, gadgets and whatchamacallits to consider this season the only question will be if Amazon, UPS or the Postal Service can send them before March 2022! Here's some of our holiday favorites this season:

For the Aerospace Engineer

Autopilot, gyro stabilizer, up to ten minutes of flight time! The POWER UP Smartphone Controlled Paper Airplane let's you fly great distances via your phone for only $79.99. Apparently even the strongest of winds can't keep this aircraft from logging serious miles. Buy it for the "kids" and watch mom or dad take full control of the airplane's unique capabilities.

www.poweruptoys.com

For the Mechanical Engineer

Nikola Tesla Wall Prints in frames would look nice in any office. These blueprints show off some of Tesla's most popular mechanical patents.

For the Human Resources Manager

Tired of looking like you just woke-up for the Zoom meeting even if you just woke up for the Zoom meeting? Apparently, celebrities even use the OlumiRing to magically enhance the lighting around their laptops. Sit in style during budget meetings for only $24.00 plus shipping and handling. Are you ready for your close-up?

oluminate.com

For the Mad Scientist

Imagine walking into a room and having the ability to flip a large electric paddle to turn on your lights just like Dr. Frankenstein? Amazing, right? Gone are the days of flipping a tiny, insignificant light switch now that the Frankenstein Switch Plate Cover ($14.99) is available on Amazon. It will not work, however, if you don't shout, "IT'S ALIVE!" at the top of your lungs every time you enter the room. Think of how much fun this would be for your office buddy next door!

For the Robotics Enthusiast

Blast off into STEM with this robot assembly kit. Build. Code. Create. Make and program three fearless robots — AstroBot, Rover, or Astron — or create and control one of your own ($199.99) These bots will be set (using Blocky code) to navigate obstacles, pick-up objects, control light and sound effects, plus show emotion. Explore new custom action with PRP (Pose, Record, Play) functions.

giftshop.thehenryford.org/jimu-astrobots-kit-stem.html

For Your Supervisor

Your supervisor has survived most of the pandemic and has sat through enough video conference calls to get a job at your local television news outlet. They don't want engineering or manufacturing gifts because they eat, live and breathe engineering and manufacturing. They need a break. May we suggest a West Coast-Style IPA Beer Brewing Kit ($45.00)?

Show your love for the legendary, seafaring ale of the British Empire with this IPA brewing kit containing everything you'll need to turn your kitchen into a craft brewery: 100% malt extract, specialty grains, high quality yeast, and, of course, aromatic Summit and Cascade hops sourced from Washington state's Yakima Valley. And if they don't like beer simply buy them a nice bottle of scotch or bourbon and be on your way.

www.uncommongoods.com/product/west-coast-style-ipa-beer-brewing-kit

Happy Holidays! Cheers to Gears and a prosperous 2022!

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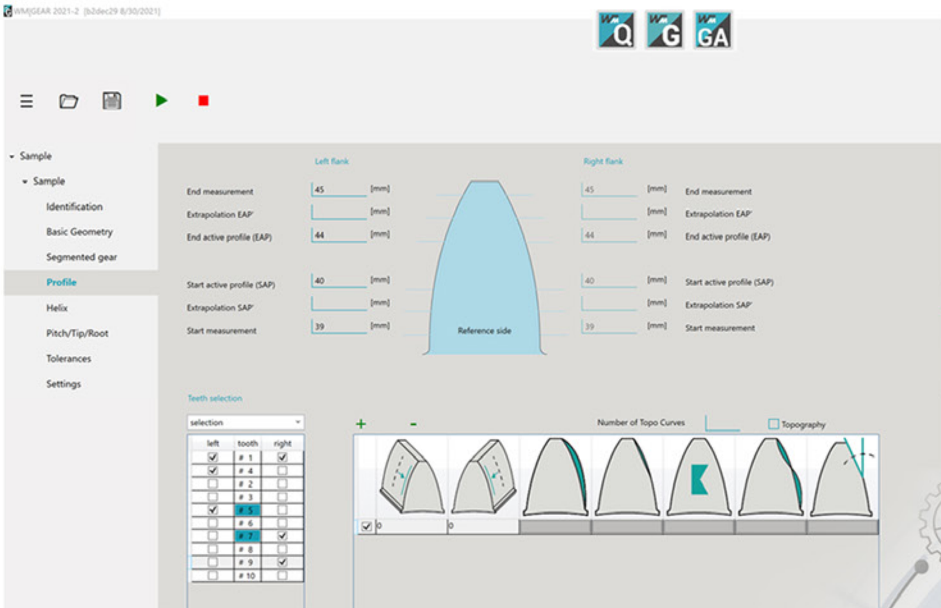
The all-new GT series have been designed to meet the high accuracy requirements in gear measuring technology with effortless precision. It is the most modern software out there with the bonus that you do not need to buy separate software modules.



WM | Gear®

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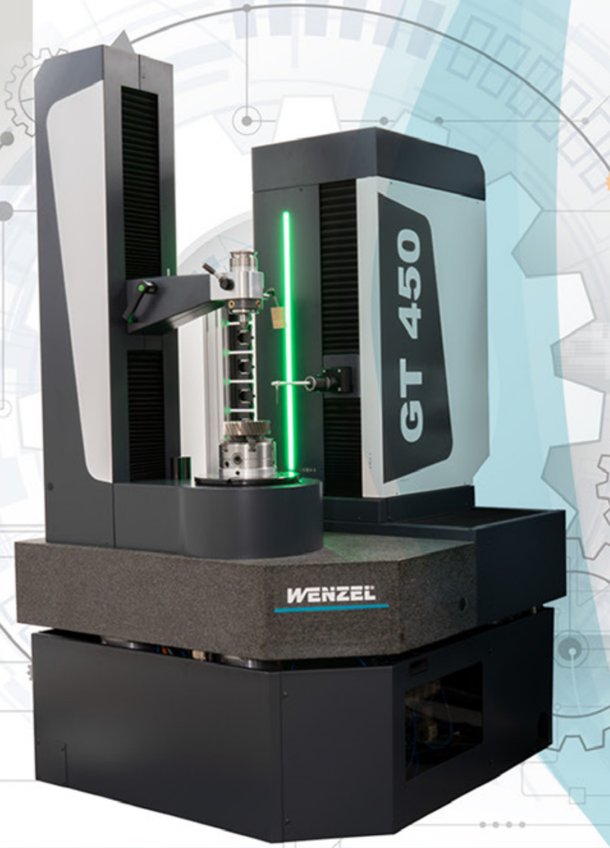

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DIMECON – DIGITAL MEASURING CONFERENCE

KLINGELNBERG

Subject to changes

DIMECON – an acronym made from the first two letters of the words Digital Measuring, plus CON from Conference. Starting in November 2021, Klingelnberg will be hosting a series of talks on relevant issues in quality assurance and measuring technology. The main theme of the inaugural DIMECON series will be root cause analysis of unpleasant gear noise and a presentation of specific solutions for quiet-running, quality transmissions. The company will focus on production equipment and test instruments for drive components in electromobility.

Registration and dates at: https://dimecon.klingelnberg.com/en/
It's quick and easy! There will be four event dates in total. Participation is free of charge, of course.

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WWW.KLINGELNBERG.COM