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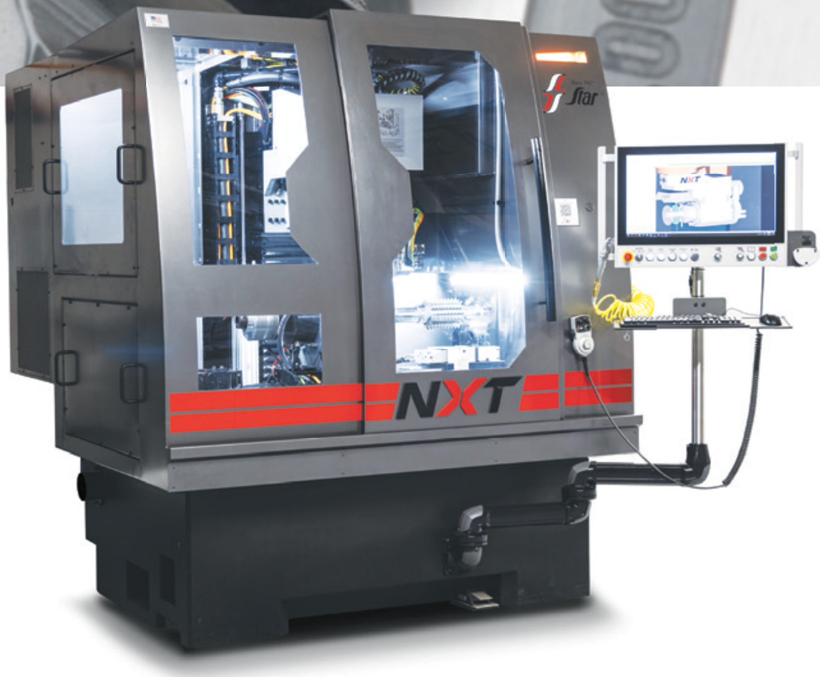
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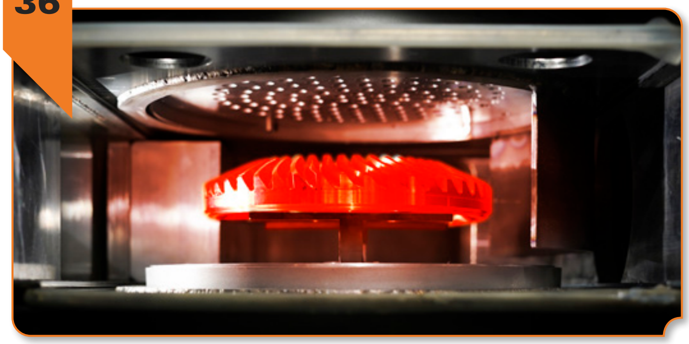

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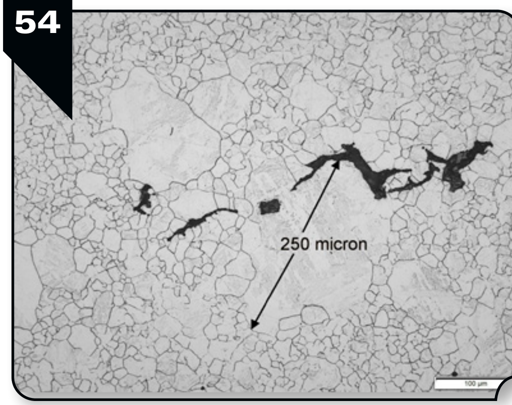

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Vol. 40. No.6 GEAR TECHNOLOGY. The Journal of Gear Manufacturing (ISSN 0743-6858) is published monthly, except in February, April, October and December by The American Gear Manufacturers Association, 1001 N Fairfax Street, Suite 500, Alexandria, VA 22314, (847) 437-6604. Cover price $7.00 U.S. Periodical postage paid at Arlington Heights, IL, and at additional mailing office (USPS No. 749-290). The American Gear Manufacturers Association makes every effort to ensure that the processes described in GEAR TECHNOLOGY conform to sound engineering practice. Neither the authors nor the publisher can be held responsible for injuries sustained while following the procedures described. Postmaster: Send address changes to GEAR TECHNOLOGY. The Journal of Gear Manufacturing. 1001 N Fairfax Street, Suite 500, Alexandria, VA 22314.

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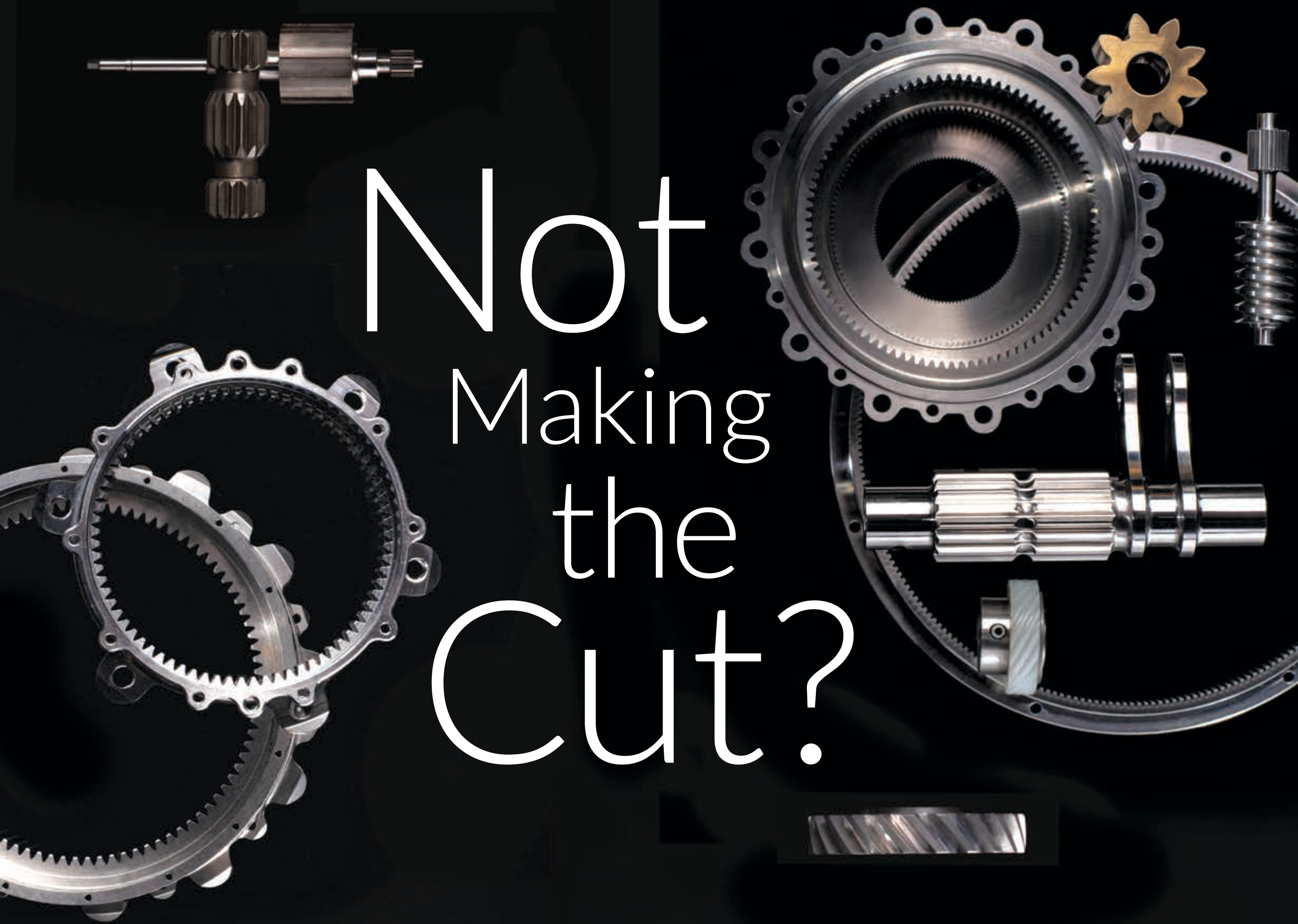
Vol. 40. No. 6


Not
Making
the
Cut?

GT Revolutions

AGMA President Matt Croson on the Manufacturing Talk Podcast

There are countless amazing stories that emerge from the manufacturing world—and Manufacturing Talks, hosted by Jim Vinoski, helps draw those stories into the light of day. As Jim states, "Manufacturing is where the rubber meets the road. There's no hiding. You're either making good products people will buy for enough to keep you in business, or you're not. Period." Nowhere is that more evident than in the gear industry. Check out Episode 51 with Matt Croson, president of the American Gear Manufacturers Association, sharing all about what the AGMA does.

geartechnology.com/blogs/4-revolutions/post/30377-agma-president-matt-croson-on-the-manufacturing-talks-podcast

GT Videos

EMAG VSC 400 PS Skiving

Power skiving has been turned into a highly efficient process for the production of internal and external gear teeth by the VSC 400 PS machine. The VSC 400 PS can accommodate up to four different power skiving tools on two spindles, plus up to six turning tools. Check out the EMAG video here:

geartechnology.com/media/videos/play/264

Graetz Mfg Increases Productivity with Mazak Machine Tools

The Pound, Wisconsin, Graetz Mfg. began as a family-run sawmill and blacksmith shop that made equipment and repair parts for the local farming community. To support both equipment and part manufacturing, Graetz Mfg. gradually expanded its machine shop capabilities to make gears, sprockets and shafts, and today the shop produces components and entire machines used in agricultural, marine, logging and packaging applications.

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WORKHOLDING TECHNOLOGY

EVerybody Pay Attention

Publisher & Editor-in-Chief
Randy Stott

Electric vehicles are changing the gear industry. If your business is at all attached to the manufacture of automobiles, construction equipment, motorcycles, aircraft, I hope you're paying attention.

The gears you used to make are going to be changing, if they haven't already. E-mobility isn't going away anytime soon.

In fact, it's clear that the major players in all those industries now consider that e-mobility will need to be a significant core competency over the next several decades. Major automotive manufacturers are investing heavily to ensure their supply chains will be able to support their plans (see Senior Editor Matt Jaster's article, "The Changing Face of Battery Manufacturing in North America," on p. 42).

I'm not telling you anything you don't know. The push for electrification has been steady and well-publicized over the last decade. While it may at first have seemed like automakers were announcing their participation in e-mobility as a publicity stunt, those days are long over. The shift is happening. Real investments have been taking place, and they'll continue.

Are you worried about your gear manufacturing operation? Are your processes and technologies capable of producing the gears of tomorrow?

IF YOU WANT TO LEARN MORE, I HAVE SOME IDEAS FOR YOU.

Gear Technology will be hosting a session of our "Ask the Expert Live" at the Motion + Power Technology Expo in October (see our show preview article on p. 33). We'll have a panel of experts discussing the technology required to manufacture EV gears. We'll be talking about things like NVH and how to control gear whine both through the design process and via gear grinding. We'll also talk about gear skiving and gear inspection.

In addition to the EV gear manufacturing session, we'll also have a panel discussing "The Future of Gear Manufacturing." In addition to electrification, you can expect our experts to talk about things like artificial intelligence, Industry 4.0, cybersecurity, additive manufacturing, and many other trends that will affect the way gears are manufactured over the coming decades.

The "Ask the Expert" sessions will be recorded and become part of our video library on *geartechnology.com*.

Lastly, and perhaps most importantly, AGMA will be hosting an EV Town Hall at MPT Expo. Amir Aboutaleb, AGMA's VP, Technical Division, will lead the discussion, both explaining how AGMA's current standards intersect with the EV space but also to get feedback from the community about whether we as an industry need to develop additional standards and information sheets to address the e-mobility space (for full details about the EV Town Hall, see Phillip Olson's article about the EV Town Hall on p. 53).

So I hope you'll join us in Detroit. MPT Expo takes place October 17–19. I guarantee it will be three days well spent.

Randy Stott

Hainbuch

DELIVERS PRECISION WORKHOLDING TO SEW-EURODRIVE

Frank Burke, Burke & Towner, Ltd.

From amusement park rollercoasters to cranes, mining equipment, conveyors, automotive assembly lines, and many other applications, SEW-Eurodrive manufactures the gearmotors, electronics, and software that keep things moving. Based in Bruchsal, Germany, the company maintains a network of 16 production plants and 79 Drive Technology Centers in 50 countries around the world. The plant in Lyman, South Carolina, one of the four facilities in the U.S., is staffed by the 300 employees and incorporates more than 100 robots in its automated production processes.

One of the principal products produced at the Lyman plant is the K series helical-bevel gear motor line, designed to deliver maximum efficiency and with low maintenance requirements with optimum ratio and torque.

Larry Neely, toolroom supervisor at SEW-Eurodrive, comments, "Because our K box line is extremely popular and is used in many diverse industries, everything we have made for the last couple of years has been for customer orders. We don't retain any inventory. In fact, demand is so high that, in the near term, we're looking to double our production and, at present, we're delivering more than 600,000 gear sets and housings per year."

Quality control is critical to the manufacturing process, and tolerances are measured in microns (µm). Robots are used to ensure maximum efficiency and accuracy.

"Among the most challenging applications is the turning of the high-ratio pinion. Machined from 8620 steel, the process involves two separate chucks—one for holding bar stock, where we turn the bearing journals, and the other for finishing the head. Parts are run on two Okuma twin-spindle turning centers. Because we are turning the bearing journals and the head on two different chucks, given our tolerances the machining process is exacting and complex," said Neely. "When we initially evaluated the Hainbuch system of precision workholding, we reviewed our entire production strategy and realized extensive benefits in both time and money."

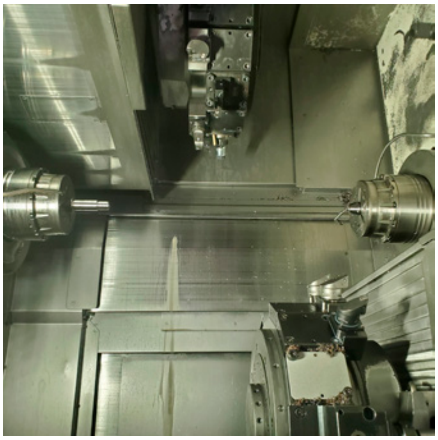
Originally, parts were produced from individual 2-in. diameter blanks that were held between centers. This required the cutting and facing of each part. Because parts were held by the pinion faces, using face drivers, they would have inconsistencies on runout and need to be processed after heat treat, after which a press was used to correct runout.

"Subsequently, we went with a quick-change collet system. Because the clamping force was not sufficient, we had to use a carbonite coating to ensure rigidity while turning. The addition of foreign material also adversely impacted our tolerances. We had to chamfer the bars when bar feeding, and this, of course, increased our cost," explained Neely.

Edward Reames, southeast regional sales manager at Hainbuch America Corp., explained, "When we first saw the setup being used at SEW-Eurodrive, we knew that we could help. We recommended the Hainbuch TOPlus chuck and clamping heads. The superior clamping capability eliminated the need for carbonite, and the unique hexagonal design allows quick-change capability with maximum repeatability. The geometry provides superior resistance to contamination and absorbs vibration. Larry agreed to a trial run, and we shortly discovered benefits that extended well beyond conventional workholding."

"Thanks to the Hainbuch TOPlus system," stated Neely, "we were able to eliminate the need for individual blanks and replace them with bar stock. This eliminated cutting, facing, and chamfering, as well as the need for carbonite. We also eliminated runout and could change the tolerance from a 20-µm tolerance to 10 µm. The carbonite we previously used resulted in excessive wear on our collets, requiring frequent replacement, and we no longer have that experience. We've also been able to increase speed and feed and extend tool life.

"Because we turn the bearing journals on the bar stock side, we use serrated collets on the main spindle/bar feed side and smooth collets on the sub spindle side for the finished surface to prevent the part from getting marked up. All of the collets are from Hainbuch's standard product line, so we don't have to incur the cost of special tooling. All in all, the incorporation of the Hainbuch system and the many advantages we derived is one of the most dramatic improvements I've been able to make—and the most painless and least disruptive."



Main/Sub Spindle TOPlus mini chucks showing (left side pinion shaft, right side pinion head).

Automated cell w/robot unloading finished pinions.

The finished pinion blank.

"By taking the 'long view,' Larry was able to visualize changes that would impact not just workholding but the entire production process. Two of the machines at SEW-Eurodrive are now equipped with the Hainbuch TOPlus system, and another is on order," Reames added.

Thanks to the improvements realized in part turning, Neely and his team are considering incorporating Hainbuch workholding equipment in generating high-precision gears, while eliminating expensive fixturing.

"We manufacture a series of high-performance gearmotors. The more accurate the gears, the more efficiently the motor can perform from an energy standpoint. That is critical as a means of cost savings," Neely said. "We plan to incorporate the Hainbuch system in the process because Hainbuch products have quality that meets our own exacting standards, and quality is always worth more. The numbers prove it."

seweurodrive.com

hainbuch.com

ANCA

SHOWCASES LATEST INNOVATIONS AT EMO 2023

ANCA will showcase their latest products and industry-specific grinding and automation solutions at EMO at Booth F52, Hall 6 in Hannover, Germany in September. The eagerly awaited winner of the renowned Tool of the Year competition will be announced live Wednesday, September 20th at 4:30 pm (GMT)—and all are welcome to join the celebrations and witness for themselves the ultimate range of cutting tools.

Edmund Boland, ANCA CNC Machines general manager said, "We are excited to bring not one but several world premieres to EMO, promising premium value, higher productivity, and extended capabilities. Visitors can see firsthand ANCA's latest technology that spans tool precision, integrated manufacturing systems, industry focus applications and optimization across the process chain."

Highlights include:

ANCA's unique vertical integration is key to its success - where machines, controls, drives and precision components are all designed and manufactured in-house. Successfully introduced to the industry last year on the MX machine platform, it boasts the highest accuracy and quality cutting tools in the world. The MX7 ULTRA achieves one nanometer axis resolution and can maintain better than +/- 0.002 mm line form accuracy of any profile which includes ball nose and corner radius endmills.

The FX7 ULTRA introduces technologies, including ANCA's unique nanometer control, that offers precision grinding for small and micro tools down to 0.1 mm diameter.

The AIMS automation package is a modular and growing system, spanning across the tool production process. ANCA is set to include additional operations like blank preparation or laser marking in the automated process. The system's intelligent design allows for progressive steps of automation, including an automated laser marking station AutoMarkX. The versatile laser marking station is tailored to meet the needs of tool manufacturers. It provides reliable and high-quality marking, ensuring traceability, identification, and branding of tools, while eliminating repetitive tasks to free up time for skilled staff.

The AutoMarkX's new, retrofittable rotary workholding system allows for unlimited index marking around the tool, with automatic Z-axis focus and compatibility with tool shanks from 3 to 32 mm. Moreover, the AIMS Autoline Basic, the standard interface for easy loading at the AutoMarkX enables customers to experience smoother material transfer between machines. By utilizing a manual trolley system, combined with AIMS pallet carriers, Autoline Basic streamlines the transfer of heavy tool pallets between machines, reducing labor-intensive processes.

ANCA'sn expertise in grinding solutions also extends to blank grinding and integrated complete machining of gear tools, including in-process measuring and compensation. The CPX blank preparation machine will feature productivity-enhancing features in Hannover, including automated loading of tools up to 32 mm, a flip station for grinding from both ends, tailstock, and extensive probing enabling statistic process control. The machine has been designed to give users high material removal rates and save time and money on unattended production.

The rising demand for gear cutting tools has led ANCA to enhance its product program with the GCX, the turnkey solution for manufacturing and resharpening gear cutting

tools. The Integrated Gear Tool Measurement (IGTM) and ANCA's expertise in grinding wheel dressing gives customers the benefit of full control over the high precision skiving cutter grinding process.

anca.com

United Grinding

OFFERS EFFICIENCY IMPROVEMENTS WITH DIGITAL ASSISTANCE SYSTEMS

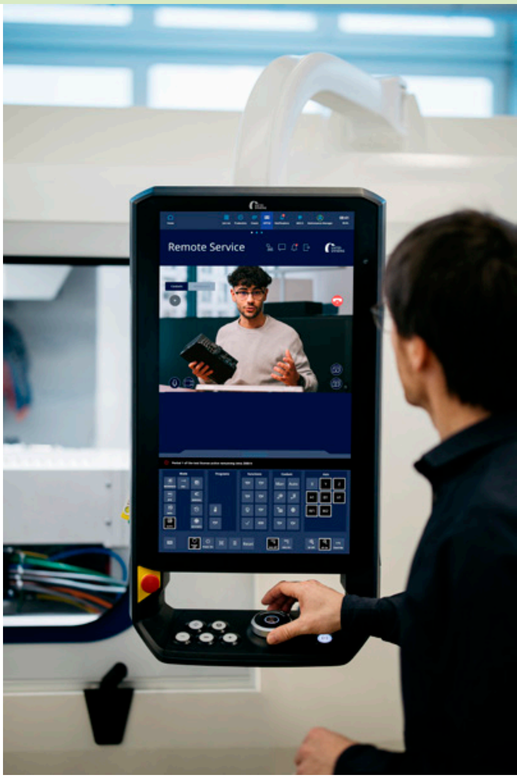
United Grinding Group offers digital assistance systems that make work easier for users of all kinds in areas like remote service, service monitoring, production monitoring, and digital solution technologies.

Remote Service offers simple and fast assistance. For example, in the event of machine downtime, United Grinding North America customers can request service with the press of a button. This service request can be submitted by the customer via a smartphone and the corresponding Digital Solutions app, or via the Customer Cockpit.

Service Monitor relieves those responsible for maintenance by clearly displaying all the important maintenance tasks based on the current machine's operating hours. The Service Cockpit can be used to centrally manage, monitor, and document maintenance due dates for several connected machines.

Production managers can monitor the production output of the machinery at any time using the Production Monitor. Production benchmarks, such as operating and non-productive times, production quantities and downtimes, are displayed in real-time. The latest version also supports the global communication standard Umati UA4MT (Universal Machine Technology Interface for Machine Tools).

United Grinding machines and machines from other manufacturers can be easily integrated into the Production Monitor—from anywhere and at any time—thanks to the Digital Solutions app. This overview makes it possible to discover optimization potential in the production and operation of the machines.



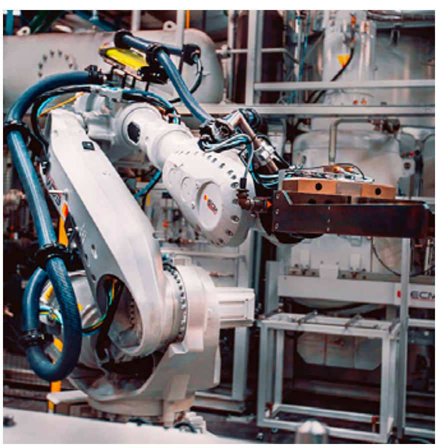
The trend towards flexible working models and working from home or on the road has also driven the demand for app-based solutions. Digital assistance systems are already an indispensable part of everyday life, and demand will continue to rise. The United Grinding Group is continuously expanding the functionalities of current products and constantly adding to the range of available digital solutions.

grinding.com/en/digitalization/digital-solutions

ECM

PROVIDES INTEGRATED ROBOTICS VACUUM FURNACE SYSTEM TO SEW-EURODRIVE

ECM USA has partnered with the prominent global manufacturer, SEW-Eurodrive, to commission a modular NANO vacuum furnace system completely integrated with advanced automation for their Lyman, South Carolina facility. It is the third ECM NANO system with integrated robotics and advanced capabilities for the US heat treat market within the last two years. This six-chamber, 20-bar quench NANO vacuum furnace system provides maximum flexibility and integration utilizing the addition of 16 tempering positions, advanced solvent-based washer (both oil and water-based contaminants), and robotic workload assembly/disassembly. Dunnage management is also provided and fully automated within the robotics configuration. The system was specifically designed to run multiple materials (including carburized grades and tool steels) and has the modular flexibility to adapt to an increase in production for various load scenarios and processes. SEW-Eurodrive Movitrans (SEW-Eurodrive's patented inductive energy power transfer supply system) will also be incorporated within ECM's vacuum furnace transfer system.



ecm-usa.com

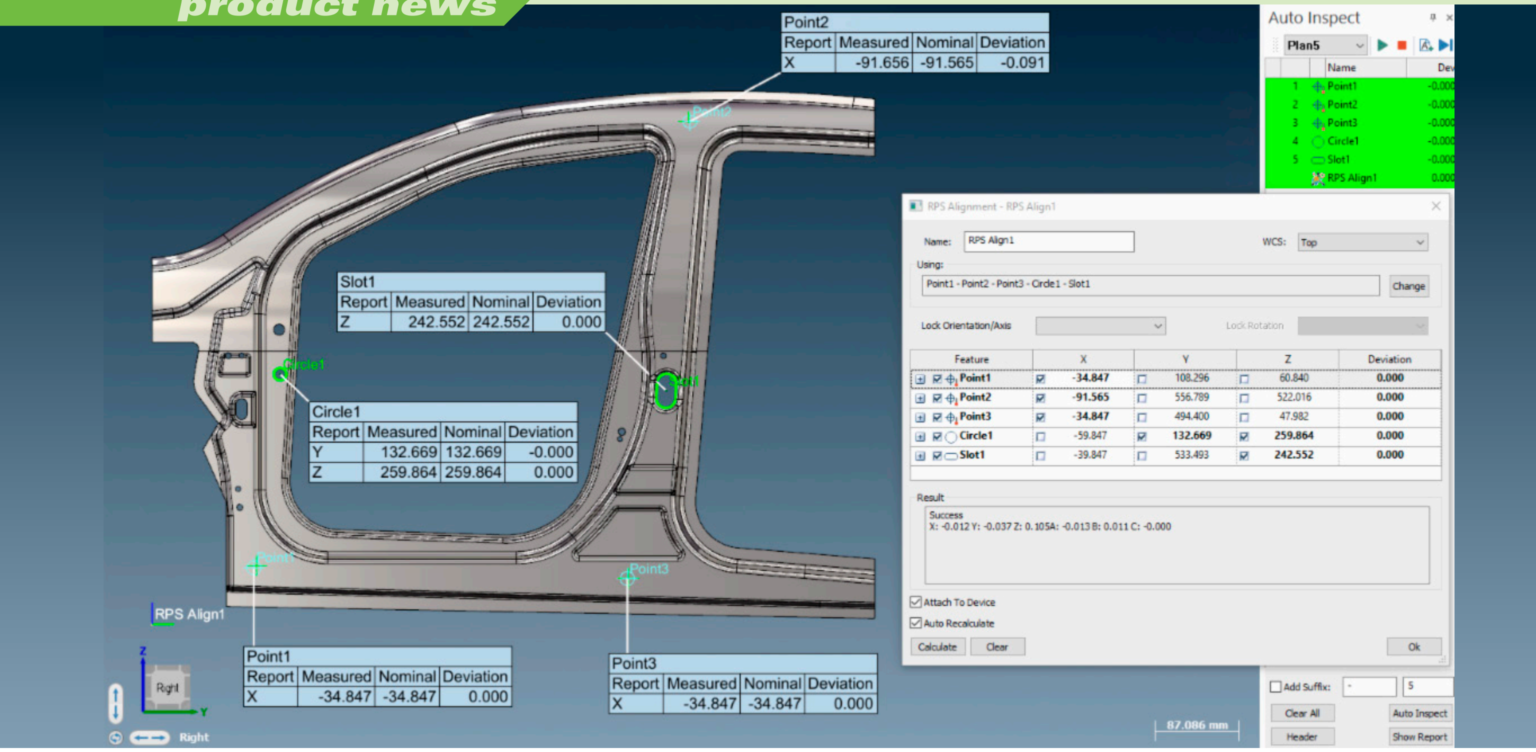
Dillon

JAW BORING RINGS INSTALL WITHOUT TOOLS TO SPEED SET-UPS

Dillon self-centering Jaw Forming Rings, or Jaw Boring Rings, attach to the front of jaws without tools so installation is fast and simple, and set-up times are slashed. Use of this device will provide a jaw surface true to the machine centerline, reduce set-up times, and increase up-times for running machined parts. They provide uniform pressure on jaws for a more consistent bore on large-diameter chucks. Soft jaws, round jaws, and full-grip jaws can be precisely machined for a firmer grip on the workpiece. They compensate for "jaw lift" even in worn chucks, which yields better part concentricity. Available in diameter-specific models or adjustable models to bore a range of chuck diameters.

Chuck-diameter-specific versions and adjustable boring rings are available from 6–18 in. in diameter. Both styles feature no-tools attachment. Dillon jaw-forming rings are a high-quality product that will ensure years of quick, stress-free set-ups when paired with Dillon jaws.

dillonmfg.com



Verisurf 2024

MEASUREMENT SOFTWARE NOW AVAILABLE

Verisurf Software, Inc. announces its 2024 software release providing new productivity workflows, powerful tools, enhanced functions, and expanded sensor and device compatibility, all designed to better connect metrology and manufacturing for global success. With the release of *Verisurf 2024*, the company continues its commitment to user-friendliness, stability, flexibility, and intelligent workflows, enhancing efficiency, quality, and throughput while keeping pace with emerging technologies and growing industry requirements.

Verisurf 2024 includes nearly one hundred new productivity workflows, enhancements, and additions. The software empowers users with a universal solution that supports all 3D metrology applications, complemented with expert technical support, training services, and application consulting for seamless integration, optimal process improvement, and better resource utilization.

"At Verisurf, our goal is to provide metrology solutions that help improve efficiency. Our intelligent workflows enable customers to add value to their products with improved quality without adding time. We take pride in the efficiency of our solutions, and ensuring the highest quality is vital to our customer promise. Regardless of the application or device, our solutions are renowned for their user-friendliness, stability, flexibility, intelligent workflows, and enhanced efficiency, quality, and throughput," said Nick Merrell, executive vice president of Verisurf Software, Inc.

verisurf.com

Liebherr

HIGHLIGHTS AUTOMATION TECHNOLOGIES AT AUTOMATICA 2023

Liebherr offered visitors the opportunity to experience a wide range of innovative products during Automatica 2023 in Munich. One of the main attractions was the Cobot Cell, a functional and reliable application that enables customers to realize bin picking.

Another highlight was the workstation, which combines part setup and recognition with a focus on the LHRobotics.Vision technology package. This incorporates AI capabilities, ease of use, and intuitive user guidance.

Furthermore, Liebherr also presented the “Kostal” cell, an automated solution for mating high-voltage battery module connectors.

In addition, the company presented the Battery Pack Dummy, which offers an insight into battery assembly processes. A live presentation of the *LHRobotics.Vision* software for bin picking allowed visitors to see the software in action. They also had the opportunity to bring their own workpiece and explore the optimization potential of their production technology.

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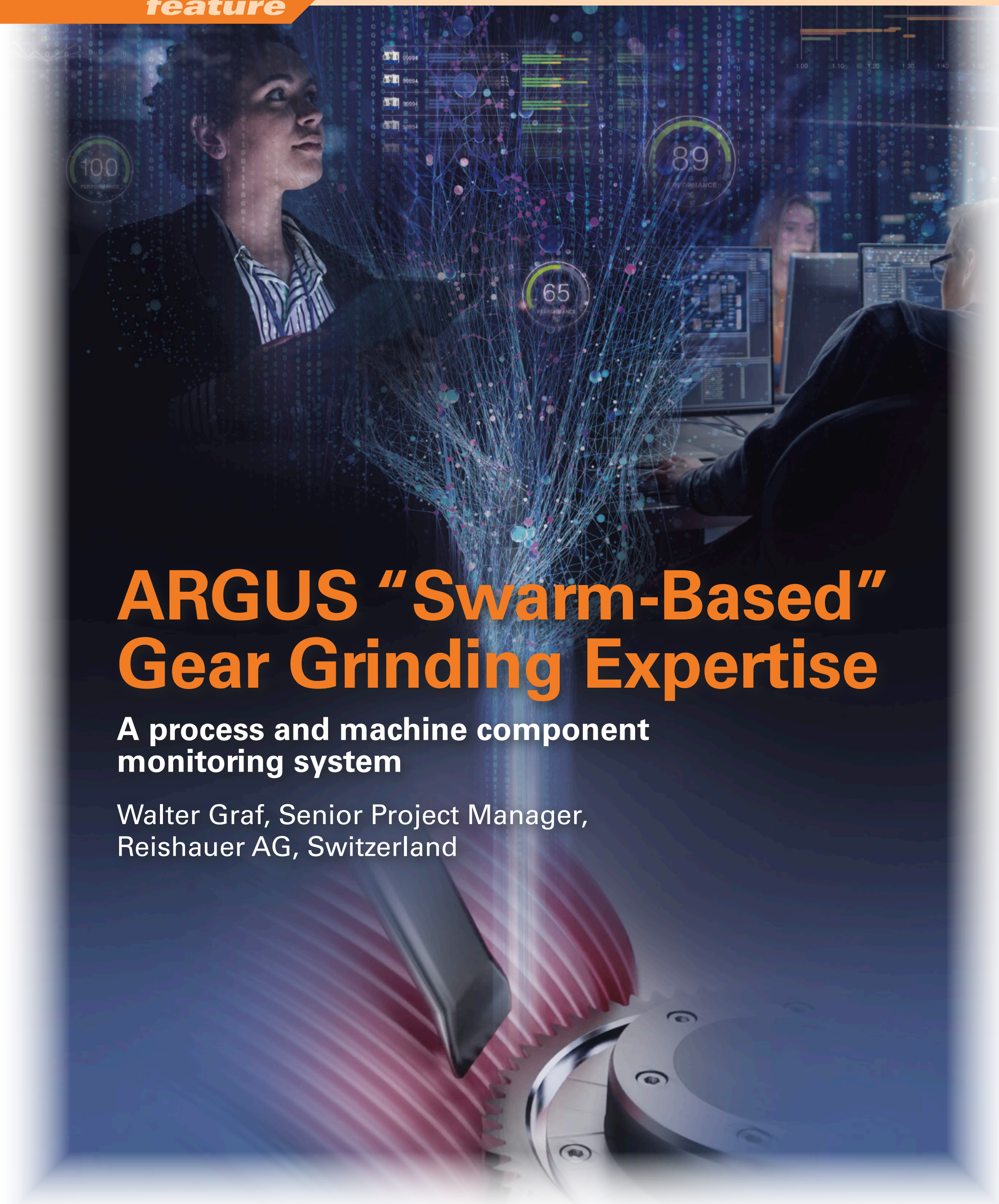


ARGUS "Swarm-Based" Gear Grinding Expertise

A process and machine component monitoring system

Walter Graf, Senior Project Manager,
Reishauer AG, Switzerland

This article describes a cloud-based process and machine component monitoring system called ARGUS. The term "swarm" is used for a large population of gear-grinding machines of individual and independent customers connected to the ARGUS system and the ARGUS cloud. These "swarm" machines permanently feed their anonymized process data into a common cloud database. Reishauer uses this database for big data analytics to discover patterns that indicate successful process and machine component

behavior patterns worth integrating into the ARGUS algorithms and propagate them across the complete ARGUS customer base. Of course, should the system also discover detrimental process patterns, such patterns are eliminated by adjusting the algorithms accordingly. While the system can operate as a standalone version at one customer plant, and even if this customer had some 50 machines, their data would never suffice to gain the insight that the much larger cloud-based Reishauer database can. First, an individual customer does not have the range of workpieces that would be stored collectively in the ARGUS cloud. Second, individual customers, for better or worse, have their ideas of an efficient grinding cycle. Within a large group of customers, there are always those who push boundaries and may discover new approaches which, once proven by ARGUS, would enrich the data to benefit all subscribers. This article argues that using the cloud-based variant, which is subscription-based, offers many benefits to individual customers. As a subscription to ARGUS entails automatic updates containing all insights gained, the subscriber constantly benefits by safely making full use of the grinding machines' potential by grinding close to the top performance limits.

Reishauer is continuously expanding its knowledge base. In July 2023, Reishauer already had around 21 million grinding cycles and stored all the associated data points. Moreover, every one of these 21 million cycles encompasses around a million data points each. At this point, it is important to repeat that all the data is anonymous and not linked to any specific customer. With complete parameter data, twenty-one million grinding operations is a large enough data pool to apply Data Science and use artificial intelligence (AI) for pattern recognition and adaptation of algorithms.

These data sets provide tremendous insights into processes with different grinding parameters. For example, Reishauer can gain insights into the optimal setting of grinding intensity limits. At the same time, the individual data sets remain anonymous, which is important for our customers and Reishauer. However, any general insights Reishauer gains from analyzing the data can be continuously fed into ARGUS updates. This way, all the subscribed customers gain a deeper knowledge of the generating grinding process.

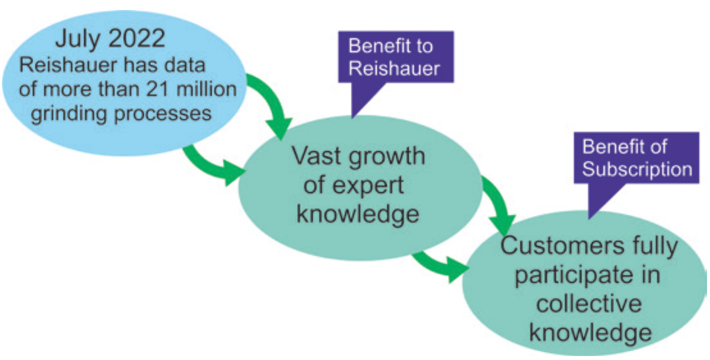
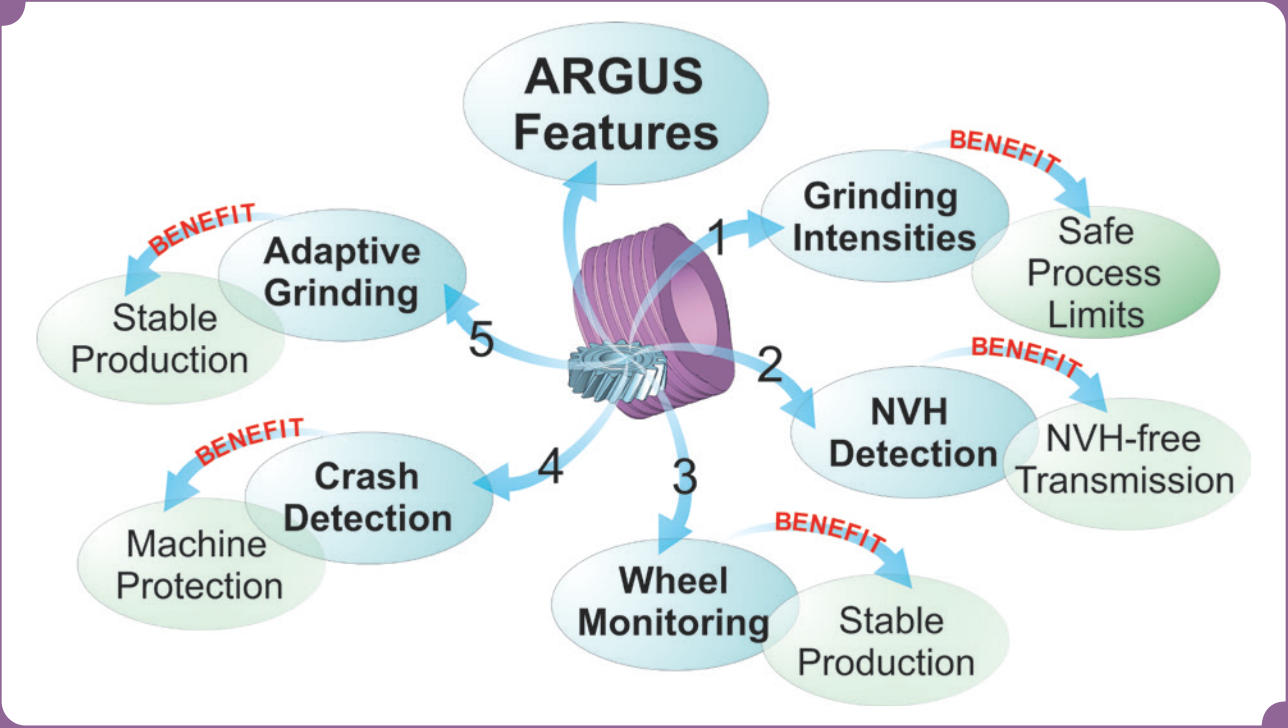


Figure 1—Benefits of large database model.

ARGUS Features



1» Grinding intensities:
These parameters are based on a force model describing the Reishauer process's contact condition. Once the grinding intensities of the roughing and finishing process are established, the parts ground within the limit have been proven accurate. In line with the quality requirements, all subsequent parts that are ground within the grinding intensity limits are also acceptable. For example, faulty pre-machined parts would generate grinding intensities that exceed the limits, and the Reishauer machine would automatically identify these parts and remove them from the process. This feature allows 100 percent part-quality control.

2» NVH detection:
ARGUS has proven invaluable in detecting and preventing NVH issues. In the best case, ARGUS can detect parts using spectral analysis that may generate NVH once they are put into transmissions. In a second case, ARGUS can be used—via Automatic Component Monitoring or analysis of the grinding data—to pinpoint the origin of the NVH problem.

3» Grinding Wheel Monitoring:
In the past, individual operators assessed grinding wheels subjectively. ARGUS offers a clear analysis and monitoring of the performance of a grinding wheel across its full tool life.

4» Crash Detection:
This ARGUS safety feature protects the machine tool. If, for example, a workpiece bore is too big and, consequently, cannot be clamped properly, it may move its position. When meshing with the threaded wheels, the out-of-position workpiece may collide with the threaded wheel. However, as ARGUS instantly picks up excessive grinding intensities, the machine immediately retracts into a safe position. This feature also protects the threaded wheel and ensures that only little damage on the threaded wheels occurs and can be easily dressed off.

5» Adaptive Grinding:
Adaptive grinding is an effective way of stabilizing the grinding process if the pre-machining is low quality. Varying material allowances and heat treatment distortion often lead to nonlinear and unstable contact conditions. An adaptive grinding process maintains the grinding forces constant, offers safety against overload, and reduces tool wear.

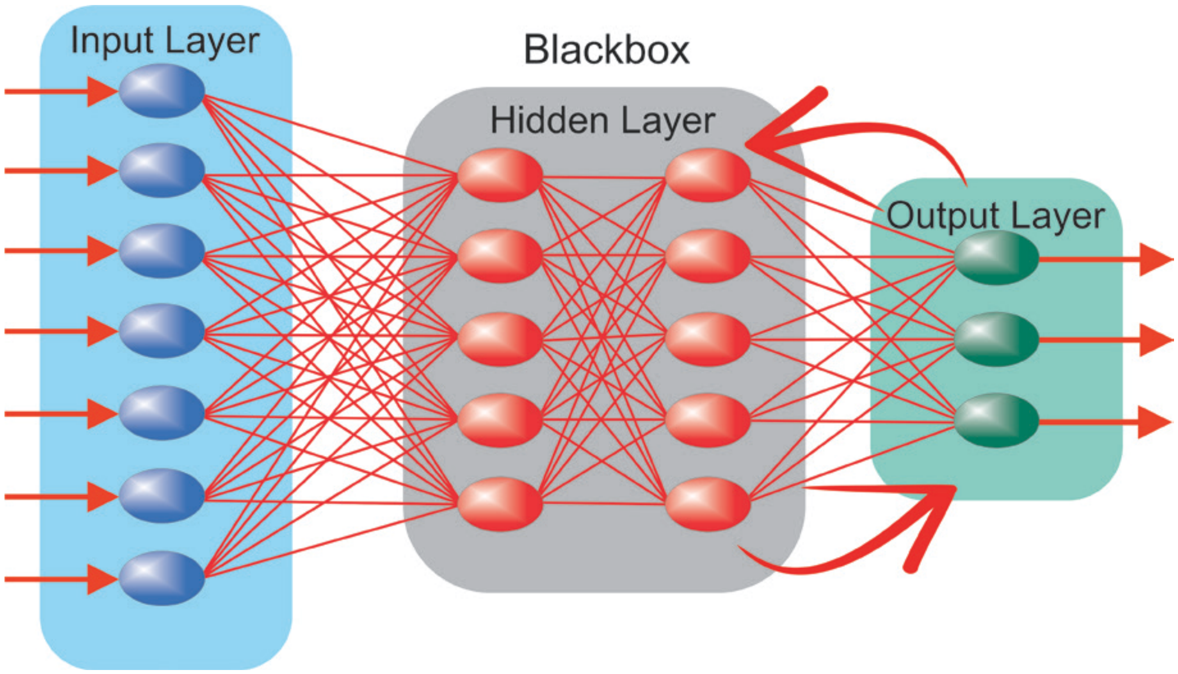


Figure 2—Neural network and AI.

For this purpose, Reishauer developed the ARGUS system based on AI. Several prerequisites must be met for artificial intelligence to be effectively used in the first place. First of all, a large amount of curated data is needed, based on which it becomes possible to derive physical regularities on which to design algorithms. In this context, there is also a need for experts and professionals from the gearing industry who can program the algorithms required for AI. In a nutshell: AI must be hard-won! What is called "intelligence" in AI is based on lengthy processes of sending reviewed and curated data sets through neural networks. Subsequently, the data output results must be checked, revised, and sent backward through the neural network. In this manner, the AI system continuously learns, constantly corrects itself, and adjusts the algorithms accordingly. This process is also called deep learning. So, what can artificial intelligence do much better than human intelligence? AI can find the proverbial needle in a haystack at lightning speed. AI is based on pattern recognition, uncovering unusual correlations in enormous amounts of data that would usually escape human intelligence. AI is, first and foremost, a decision-making technology. In the context of component monitoring, speed and accuracy of decision-making are imperative, and AI is lightning-fast.

Automated component monitoring requires a cloud structure for data storage to cope with the large volumes of data continuously generated by countless grinding machines around the clock, as shown in Figure 3.

Furthermore, it requires overarching machine algorithms that can evaluate the anonymized data about the states of the machine components in real-time with AI with the Automatic Component Diagnosis (ACD) feature. The grinding machine runs autonomous cyclic tests that reflect the components' conditions. Since grinding machines generate enormous quantities of signals, the signal quantity is only useful if it can be interpreted. It has been necessary to bring in a highly skilled person who knows how to interpret and analyze signal

Figure 3—Cloud structure of large machine tool population.

changes—especially in real time—because it is paramount to interpret the data when any critical process condition occurs. No matter how experienced, this person cannot interpret the multiple problems in the volumes of data generated by the equipment today. The ACD does not wait for errors but is constantly evaluating and thus uncovering tendencies in the deviations. It is only based on analyzing these tendencies that preventive maintenance is possible. Due to the large amount of data, the ACD finds even the smallest errors or deviations. The detected errors can then be traced back to a bearing of a machine axis, to name one example.

Only enormous amounts of data, available anonymized in a cloud, make it possible to train the corresponding algorithms. It is important to mention that the legal regulations concerning data protection must be strictly observed. The machine can be checked as often as required without needing personnel, without interrupting the production cycle, enabling preventive maintenance, and saving user costs, as machine downtimes can now be planned.

Over time, the precision of the algorithms continues to improve as the knowledge gained leads to further developments and refinements. In addition, since sensor technology is constantly evolving and always integrated into the ARGUS system, this also continuously upgrades the analyses and the algorithms. Whereas failure analyses took a huge amount of time, with the help of ARGUS, the Reishauer experts can perform a failure analysis at lightning speed. For example, the specialists can predict a potential NVH problem (disturbing transmission noise) from the signals, preventing faulty parts from being installed in the finished transmission. Previously, such problems required an expensive and time-consuming trip to the user's site.

In addition to Automatic Component Diagnosis (ACD), ARGUS breaks down the previously mentioned million data points per grinding cycle into the following five main features:

Conclusion

It is very important to understand that the foundation of ARGUS is a sophisticated, properly functioning gear grinding machine. The Reishauer gear grinding machine has proven itself with thousands of machines worldwide. Every other feature of Reishauer's circle of competence, tooling, automation, or grinding technology, is an add-on to the successful machine concepts. This approach also applies to the ARGUS system. ARGUS is an add-on, a part of digital services, and makes the machine even better; it offers transparency and control on a level never seen before. This transparency and control, plus its continuous improvement, offered by subscription as an ever-expanding database, provides the customers with a powerful tool to get the maximum benefits from their gear grinding processes.

reishauer.com

Hot Technologies to Help Cool the Planet

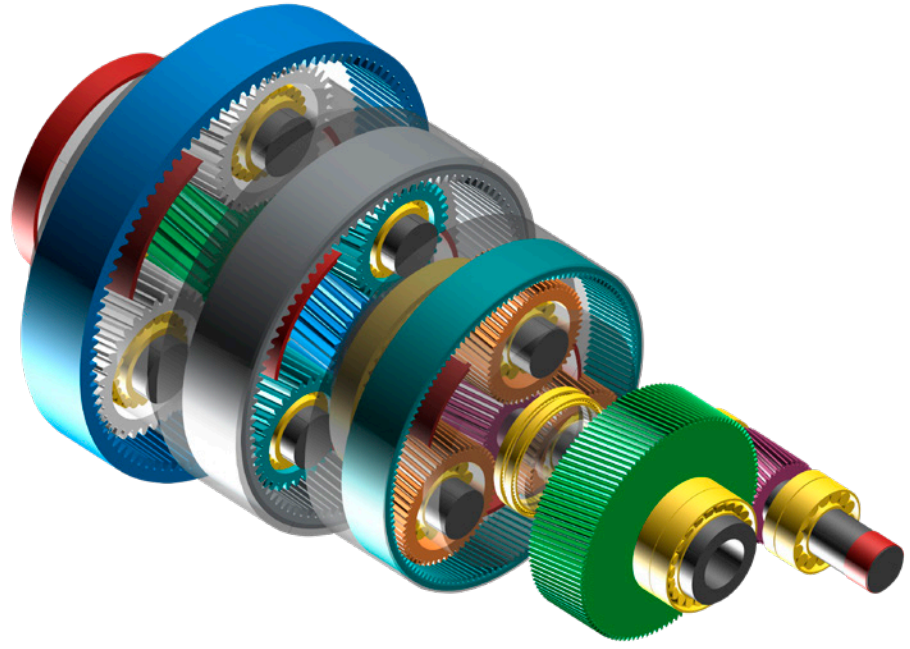
With global wind turbine demand set to quadruple by the end of the decade, manufacturers are seeking new technologies to ramp up production of gears that can operate in any environment, around the clock, for years to come.

Dr. Antoine Tuerich, Director of Product Management Hard Finishing Solutions, Gleason Corporation; Gottfried Klein, Director of Product Management, Soft Machining Solutions, Gleason Corporation; and Hanspeter Dinner, Deputy General Manager, KISSsoft AG

2023 is shaping up to be our planet's hottest year on record, and the wind energy industry is feeling the heat. The GWEC (Global Wind Energy Council) says that the rate of wind turbine installations will need to quadruple globally by the end of the decade if we're to achieve the IRENA's (International Renewable Energy Agency) goal of net zero carbon emissions by 2050—and keep the average annual temperature worldwide from increasing more than the predicted 1.5° C. Fortunately, "net zero" commitments are gathering global momentum. Before year's end, total global windpower is expected to reach a historic milestone of 1 TW of installed capacity, eliminating 1.2 billion tons of CO_2 annually, roughly the equivalent of all the carbon emissions of South America.

These are indeed interesting times for wind turbine manufacturers, now faced with unprecedented demand and backlogs stretching to the horizon. Meeting capacity challenges, while at the same time producing wind turbines that are more efficient and extremely reliable, are the most significant headwinds. In this industry, where the average lifespan of a wind turbine, onshore or offshore, can be 20 years, wear and tear take its toll, and repair and maintenance are very costly. Component quality thus becomes paramount.

Gleason is addressing these challenges with a complete array of solutions for optimizing production of the gears most commonly used in today's windpower gearboxes and, in particular, planetary gears in the 1,200 mm diameter range.



A windpower gear configuration in **KISSsoft.**

Better By Design

The design of gears and toothing for use in today's high-performance wind turbine main gearboxes poses unique challenges. Wind turbines today are much larger and capable of generating considerably more power than their predecessors. Some stand as tall as the Eiffel Tower and generate 13–15 MW, several times that of the average wind turbine in 2010. Gearbox designs have kept pace, with many more variations for low, medium, and high-speed applications and with one, two, three, or even four stages respectively. This added complexity, and the pressures of producing more power, more efficiently, while at the same time seeking greater reliability, have made it imperative that gear designs first be optimized, and their manufacturability assured well before the first gear is even cut. For that, there's *KISSsoft*. *KISSsoft* is a modular calculation program for the design, optimization, and verification of machine elements. The application ranges from individual elements to the automatic design of complete gearboxes with the add-on system *KISSsys*. It's a critically important tool when considering the challenges, and pressures, facing the wind turbine gearbox designer.

Reducing Failure in the Field

In the low-speed stage (LSS), the extremely low speed in combination with high torque poses the risk of micropitting and tooth flank fracture besides uneven load distribution and flank and root failure. While the latter examples are well manageable and covered in detail in design guidelines, e.g., IEC 61400-4, micropitting and flank fracture rating processes along ISO 6336 series still are somewhat ambiguous and field failures do not always correlate with engineering analysis. Effects of material composition and purity, heat treatment, residual stresses, and shot peening are pronounced in the LSS due to the large part size. However, these effects are difficult to quantify in the gear sizing process, while at the same time, the gear sizing process for the LSS has the highest cost impact. *KISSsoft* gear design software can assist in this process by providing hundreds, even thousands of design candidates for the experienced designer to choose from. With these options, the designer considers absolute ring gear size, torque density, risk of vibration, required hardening depths and so forth. The need to split the input torque into several power paths necessitates the use of four or five or more planets in the LSS instead of only three planets. A simulation or calculation-based estimate for the load sharing among the planets can easily be created, along with the experimental verification thereof.

Optimized for Greater Efficiency

In the intermediate speed stage (ISS), tuning the gearbox ratio is the prime objective along with further lowering the torque for the high-speed stage to be able to handle it. A relatively high ratio asks for a relatively low number of teeth on the sun gear while the pitch tube defines a lower limit for its diameter. Furthermore, the higher circumferential speeds ask for a higher contact ration to mitigate the risk of elevated vibration levels. And for involute gears, a high transverse contact ratio requires a reasonably high number of teeth. Again, requirements are contradictory and algorithms to vary multiple parameters (face width, helix angle, profile shift, tooth profile, root rounding, protuberance, final machining stock, etc.) in a very short time must be calculated. The planet gear size must be chosen such that rolling bearings with rings can be accommodated for while ensuring sufficient material below the root diameter. Technologies, such as raceways, ground into planets or the use of hydrodynamic bearings add both constraints and freedom to the planet gear design.

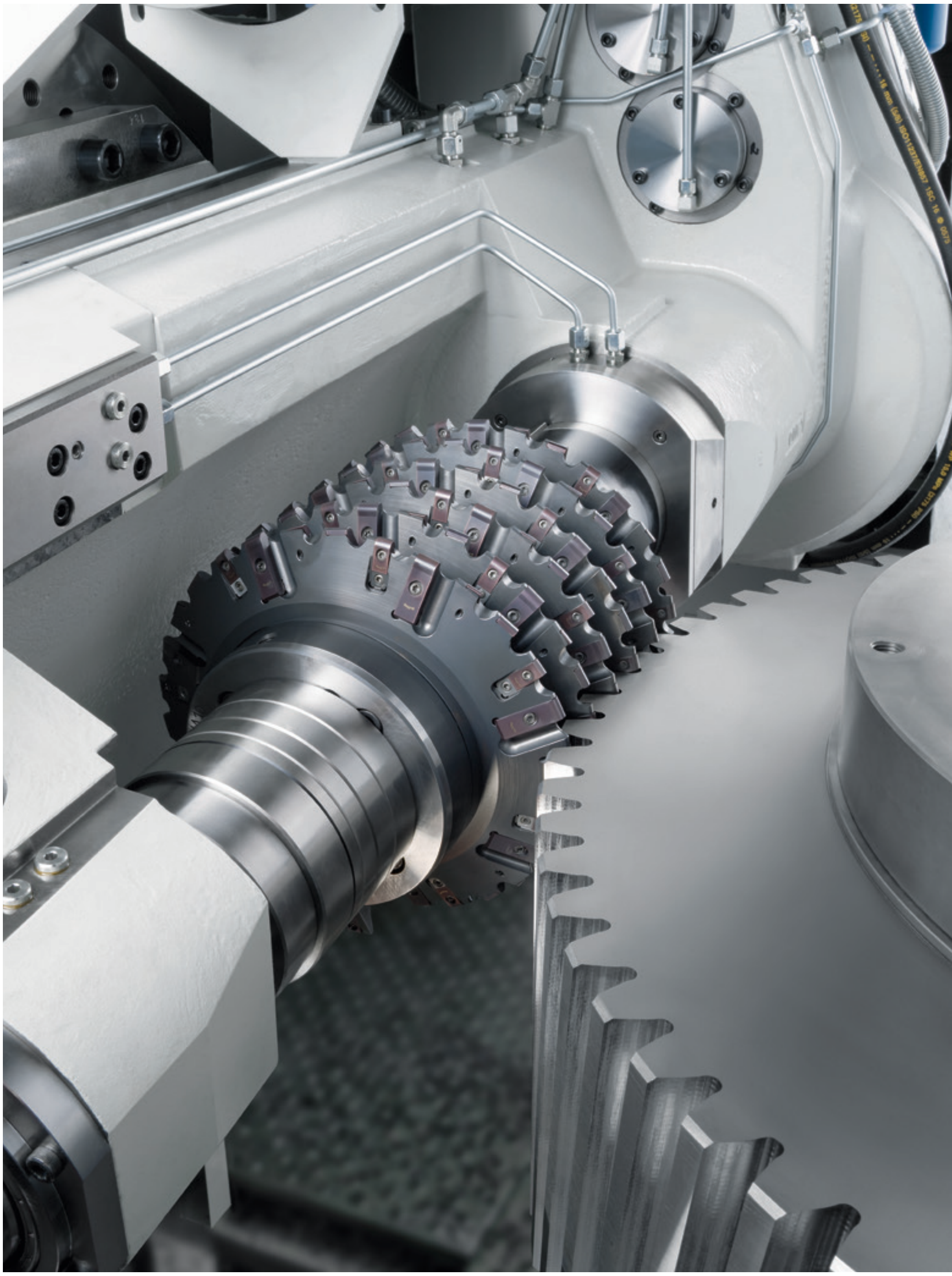
Extending Service Life by Years

Finally, the high-speed stage (HSS) reaches cycle numbers well into the high cycle fatigue range where experimental S-N curves are hard to come by. The gear rating for near infinite life much depends on the material purity, quality control and lubrication. The failure mode to base the gear design mode is pitting and the forementioned parameters are to some extent considered in the life calculations. Software based life and failure probability calculation are commonly based on load duration distribution type spectra but may nowadays also be based on torque versus time data directly. The effect of torque reversals may be considered for the flank and root rating modifications of the damage accumulation method, e.g., the use of "Haibach modification" should be considered. Finally, the Loaded Tooth Contact analysis and assessment of the transmission error in the HSS and its spectrum is an integral part of the gear design, targeting low mesh force amplitudes and pronounced higher orders in its spectrum. For all of the above, *KISSsoft* provides the gear designer with powerful tools to speed and help optimize this complex design process.

A Cut Above

Significant savings in production time, and improvements in windpower gear quality are now possible downstream in the manufacturing process as well, with the all-purpose Gleason P Series hobbing machines and the Gleason Titan hobbing machine series, combining maximum productivity and precision. For the planetary gears, external hobbing machines up to 1,200 mm workpiece size are used, with or without automation. These machines are also used for production of the sun gear shafts. For the larger internal gears, hobbing machines in the three-to-four-meter range, with powerful internal milling heads for profile milling, are necessary. All these machines need to offer maximum productivity for both rough and finish cutting.

The Gleason P-Series of hobbing machines seem almost tailor-made for the requirements of these gears. Wide guideways, with hydraulically preloaded guides, are used in combination with a separate linear guide and backlash-free roller bearing assembly to ensure precise, repeatable slide movements at any feed rate. The use of hydrostatic table bearings combined with the proven zero-backlash double worm index drive guarantees precise table travel and maximum face and radial runout accuracies for the worktable. With the Gleason Titan series, a machine concept for high performance external wind planetary and sun gear cutting is now available. Patented guideways ensure high performance when dry or wet cutting. The guideways, a combination of slideway and antifriction guideway, provide the ideal combination of stiffness and damping characteristics to help ensure substantially higher productivity and improved gear-cutting quality. Direct driven tables with



Opti-Cut Hobs (and Gear Gashers) maximize metal removal rates and cutting speeds by employing indexable carbide insert technology.

hydrostatic bearings offer new performance levels.

With both machine series, several hob head options for external and internal gear cutting are offered. Depending on the module and gear size, solid HSS hobs or Opti-Cut Hobs (and Gear Gashers) with carbide inserts can be used. The Opti-Cut design guarantees maximum metal removal rates and cutting speeds by employing indexable carbide insert technology. By eliminating the need to resharpen the tool, Opti-Cut Hobs achieve more consistent tool life and saves on the time-consuming resharpening process. Opti-Cut Hobs are available in a variety of cutter body sizes and geometries for gear milling or hobbing.

With today's higher volume production requirements for planetary gears, reductions in nonproductive load/unload and workpiece clamping times are critically important. Gleason offers a range of flexible automation and workholding solutions, all working together to make significant reductions in nonproductive time. For example, with the X-Pandisk system, workpieces weighing up to 2,000 kg can be centered and clamped automatically, thus taking significant time out of the typical process needed for an operator to manually set up and dial in workpieces of this size.

The Zero Point Clamping is intended for larger workpieces weighing up to 8,000 kg, including the pallet. Here, the setup of the clamping devices and the workpieces takes place in parallel during machining. This allows optimum quality to be achieved with minimum setup times.

In conjunction with these workholding solutions, nonproductive time can be further reduced by loading/unloading in parallel to machining using automation solutions now available for even the larger hobbing machines. These include pallet changer systems and 2-station ring loaders for disc parts.

The X-Pandisk system can handle workpieces weighing up to 2,000 kg and can be centered and clamped automatically—taking hours out of the typical manual process for operators to set up and dial in workpieces of this size.

Faster Grinding, Greater Reliability

With quality requirements now at levels rarely seen for gears of this size, hard finish grinding is mandatory. How best to deliver fine finishing, but without creating a costly production bottleneck—and adding significantly to cost? At Gleason, we've addressed this production conundrum with several new profile grinding solutions.

1200G Profile Grinding Machine

With 1,300 mm axial travel, the new 1200G covers the applications most common in this size range. For the large profile depths and high grinding performance required in wind power applications, then a performance grinding head with powerful 150 Nm torque and maximum wheel diameter of 450 mm is available. The grinding head can cover up to 80 mm profile depth, sufficient for the typical windpower gear. The 1200G's axial speed, particularly critical to ensuring short grinding times, is 10 m/min, exceeding the performance of competitive machines by up to 66%. Optionally, even 14.5 m/min is available, setting a new benchmark in this class.

Additionally, the design of the direct drive table allows for high dynamics and, through use of Gleason's proprietary Auto Servo Tuning (AST), the capability to handle a wide variety of workpiece sizes, weights and inertias.

Finally, the 1200G has an integrated inspection device for testing external and internal gears right on the machine, thus saving precious time as compared to transporting these parts to the quality lab. The inspection data can be evaluated according to all common industry standards.

Titan Profile Grinding Machines

The Titan Grinding Machines offer the ideal combination of high-performance grinding with best-in-class surface finishes. Through the use of the unique tool changer, it is no longer necessary to compromise with a single grinding wheel suitable for both roughing and finishing. Instead, individual grinding wheels can be used that are adapted to the specific tasks of roughing and finishing. This results in higher productivity, better surface finishes, and at the same time greater process reliability.

Titan's modular design covers machine models ranging from the 1200G to 1600G, with up to 1,600 mm workpiece diameter, 1,600 mm axial travel, module 40 mm, and a 100 mm maximum profile depth. For the profile grinding of windpower gears ranging in size from 1,600 mm up to 4,000 mm in diameter, Gleason offers its P-series. The P4000G, for example, is particularly well suited for hard finishing larger internal ring gears.

The new 1200G's axial speed, particularly critical to ensuring short grinding times, is 10 m/min, exceeding the performance of competitive machines by up to 66 percent.

All of these series give customers their choice of different grinding heads for external and internal grinding to cover any production requirement.

Most importantly, both the 1200G and Titan are designed to take precious minutes, even hours, out of cycle times by greatly reducing typical nonproductive time. For example:

Runout and Wobble Compensation

Time-consuming manual alignment of large and heavy workpieces on the machine table can be significantly shortened with patented runout and wobble compensation. A measuring probe detects the eccentricity position of the clamped workpiece on one or two measuring planes and compensates both the wobble and the runout of the workpiece during grinding. This feature ensures high precision with significantly reduced loading time.

Stock-Specific Grinding

Stock-specific grinding avoids air grinding caused by possible hardening distortions, especially during the first grinding strokes. During the tooth centering process, the stock allowance distribution around the circumference of the gear is determined and grinding is performed only where material removal is expected.

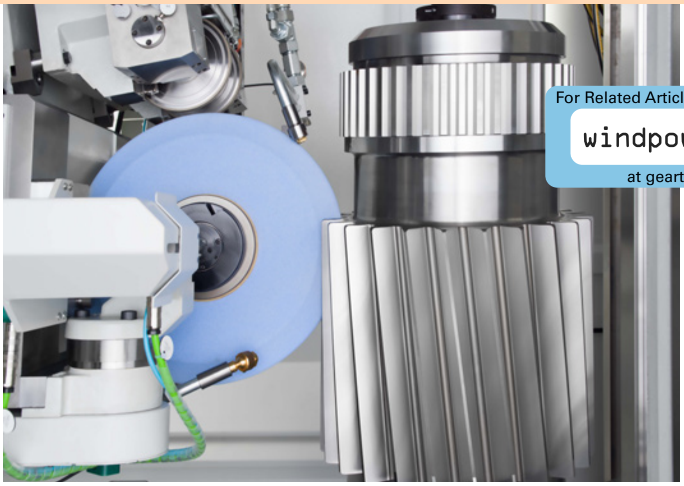
A(X) and Degressive Infeed Strategies

Innovative infeed strategies such as the patented A(X) and Degressive Infeed result in significantly better and uniform material removal along the entire profile during all grinding strokes, leading to much more effective and reliable material removal. This results in shorter grinding times, better wear behavior of the grinding wheel, and higher process reliability to avoid grinding burn.

Smart Dressing

Costly, time-consuming basic dressing for initial profiling or reprofiling of a grinding wheel is greatly reduced by the use of "Smart Dressing." The innovative software function ensures that dressing only takes place on the necessary grinding wheel areas.

gleason.com



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windpower

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New profile grinding solutions are the key to meeting the quality and reliability required of today's windpower gears, while at the same time reducing cycle times.

Motion + Power in the Motor City

MPT Expo 2023 comes to Detroit in October

Randy Stott, Publisher & Editor-in-Chief

The Motion + Power Technology Expo is a three-day show that's designed for the gear and power transmission industry, representing the entire community of professionals involved in the life of a gear, gearbox or other power transmission device—from design to manufacturing, testing, heat treating and more. You can find the suppliers of the equipment to make gears as well as gear and gear drive manufacturers themselves, along with related suppliers of things like software, tooling, lubrication, bearings and more.

Not only is MPT Expo a trade show representing the complete power transmission supply chain, but it's also an educational and networking event that seems to grow in its offerings with every iteration.

The show takes place alongside AGMA's Fall Technical Meeting (October 16-18), where experts will present research on the latest technology in gear manufacturing. MPT Expo also runs concurrently with the ASM Heat Treat and IMAT shows (see our preview article on p. 36).

On the show floor itself, you'll have plenty of opportunities to learn and interact with gear-industry colleagues, including live podcasts, exhibitor demonstrations and our own "Ask the Expert" panel discussions in booth #3136.

Come and meet the AGMA Media team in Booth #3132 and at the "Ask the Expert Stage" in Booth #3136.

Gear Technology and Power Transmission Engineering editors will sit down with technology experts throughout MPT Expo for one-on-one interviews as part of our Revolutions video series.

2023 Ask the Expert Topics

- **The Future of Gear Manufacturing (Tuesday 10/17 at 10:30 am)**
- **Manufacturing Gears for Electric Vehicles (Tuesday 10/17 at 2:30 pm)**
- **Automation for Job Shops (Wednesday 10/18 at 10:30 am)**
- **Skilled Workforce Retention and Development (Wednesday 10/18 at 2:30 pm)**

The Gear Technology *"Ask the Expert Live" panel discussions always draw a crowd of enthusiastic industry participants.*

Panelists for the "Ask the Expert" sessions will be announced soon! In addition, on the same stage in Booth #3136, our editors will be conducting live interviews with many of the exhibitors and other specialists who will be at the show, highlighting the latest technology and solutions for our industry.

Educational Opportunities

See the website at *motionpowerexpo.com/education-courses/* for information on pricing.

Basics of Gearing. Tuesday, October 17, and Wednesday, October 18, 8:00 am–5:00 pm. Instructor: William Mark McVea, KBE+, Inc. Dramatically improve your knowledge and productivity through Basics of Gearing. This course will be presented in a two-day format and will give you a comprehensive overview of standard gearing nomenclature, gear involute geometry, inspection procedures, and much more.

Integration and Trade-Offs in Gear and Bearing Systems. Tuesday, October 17, 8:00 am–5:00 pm, and Wednesday, October 18, 8:00 AM–noon. Instructor: Michael Berhan, Ford Motor Company. The purpose will be to cover the concurrent design and analyses of gears and bearings in integrated systems like gearboxes, transmissions, and electric motor drives, so as to allow for good integration and faster optimization of the overall system. This will help gear engineers and suppliers better determine the trade-offs with the bearings, help bearing engineers and suppliers similarly with the gears, and system engineers better understand both. The examples covered are generic but should be useful both within and across industries that use these components and systems.

Reverse Engineering: Why, When, and How—Avoiding Pitfalls and Litigation. Tuesday, October 17, 8:00 am–5:00 pm. Instructor: Raymond Drago, P.E. Reverse engineering a gear system is a not too unusual task and in many, but not all, cases the process goes fairly well, thus it is easy to become complacent. It is important, however, to fully understand the process and the best practice procedure for reverse engineering a gear system. This course will review the basic types of reverse engineering projects. The need for understanding the operation of the system in which the gears will be used, the conditions that led to the need for the project and especially, the specific nature of the failure that occurred, if that is the reason for the project, are key, often ignored, elements of the process.

Why Bearings are Damaged. Wednesday, October 18, 1:00 pm–5:00 pm. Instructor: ABMA. The American Bearing Manufacturers Association is offering this course on rolling element bearings for those involved in industrial equipment design, reliability, and maintenance. It will include a basic overview of rolling bearings, their selection, precision and mounting considerations, service life estimation, and lubrication-related influences. A hands-on damage analysis session will be the featured portion of this program.

Involute Spline Design and Rating. Wednesday, October 18, 8:00 am–5:00 pm. Instructor: Raymond Drago, P.E. This course will address both geometry and rating of involute splines of various types. Types of spline joints and their applications are discussed. Spline configuration variations including half depth and full depth and special function designs will be addressed. Both fixed and flexible spline configurations are treated in terms of usage and design. Lubrication methods, including grease, oil bath and flowing oil as well as coatings appropriate for various spline applications are discussed. Shear and compressive stress rating methods are discussed with analyses methodology presented in both equation and graphical methodology via various rating charts.

Modern Automated Gear Quality Assessment Technology. Thursday, October 19, 8:00 am–5:00 pm. Instructor: William Mark McVea, KBE+, Inc. This course is intended to provide you with a thorough understanding of the information contained within a typical gear inspection report. Specifically, we will look at the contents and meaning of the information contained within the gear charts, as well as the techniques used by the gear measurement system to assess gear quality. An explanation of basic gear measurement techniques, how measurement equipment and test machines implement these techniques, and how to interpret the results from these basic measurements will be covered. We will also discuss how to interpret the results and what corrective actions may be considered if the quality of a particular gear is unsatisfactory.

Materials Selection and Heat Treatment of Gears. Thursday, October 19, 8:00 am–5:00 pm. Instructors: AGMA and ASM International. Because of their unique contribution to the operation of so many machines and mechanical devices, gears have received special attention from the technical community for more than two millennia. New developments in gear technology, particularly from the materials and heat treatment perspectives, have improved gear performance. This course, developed jointly by AGMA and ASM International, will provide an overview of materials selection and heat treatment of gears. Topics covered include: Gear material selection, heat treatment, material hardenability, allow steel selection, gear failure concerns, manufacturing considerations, material form, cast iron, powdered metal, bronze and brass, and plastics.

Networking Events

FTM Networking Reception. Monday, October 16, 6:00 pm–8:00 pm. $85. Join attendees from the Fall Technical Meeting for a fun networking reception at The Yard in Corktown! The reception includes dinner, drinks, and fun activities including axe throwing, board games, shuffleboard, fire pits, and cornhole. The reception is included in registration for Full FTM attendees, but tickets are available for single-session passholders, other MPT Expo attendees, and anyone else interested in joining the fun!

Women in Manufacturing and Engineering Breakfast. Tuesday, October 17, 7:00 am–9:00 am. $50. AGMA and ASM are pleased to invite all women at MPT Expo to a networking breakfast where there will be a panel of industry experts sharing experiences and advice about how to become leaders in your field and how to avoid complacency in the workforce to advocate for your own career. Join others from all sectors of manufacturing and engineering, from new employees to high-level executives, to build new relationships, grow your network, and innovate for the future. Who should attend: All women exhibiting or attending Motion + Power Technology Expo, the Heat Treat Conference & Exposition, or IMAT events who want to network and be inspired!

Opening Night Welcome Reception. Tuesday, October 17, 5:00 pm–6:00 pm. FREE to all attendees. Join exhibitors and fellow attendees on the show floor for the Opening Night Welcome Reception. Your expo pass includes two drink tickets, and hors d'oeuvres will be served. Come meet exhibitors, network with your peers, and meet new friends as we kick off MPT Expo!

Wednesday Networking Reception. Wednesday, October 18, 7:00 pm–10:00 pm. $100. Take a night off from the tradeshow floor to unwind and network with industry professionals! Meet up with old friends or enjoy the open bar with new prospects. Enjoy local fare and drinks and get ready for an evening of fun and entertainment. More details regarding this event will be posted soon! Who should attend: All those attending or exhibiting at Motion + Power Technology Expo, the Heat Treat Conference & Exposition, or IMAT events.

AGMA Electric Vehicle Technology Town Hall

Thursday, October 19
8:00 am–10:00 am
Free

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MPT Expo
at geartechnology.com

For more than 100 years, AGMA has led discussions in standards development for the gear industry. From streetcars to wind turbine technology, AGMA has been the facilitator-in-chief bringing together stakeholders to discuss, brainstorm, share, and collaborate in the development of standards that are utilized by entire industries across the globe.

Electric vehicle technology is emerging as a mainstream technology, and to keep within its traditional role as the facilitator-in-chief, it is time for AGMA to gather experts and begin discussion on standards for this space.

The two-hour town hall style meeting will begin with a short presentation by Amir Aboutaleb, AGMA VP, Technical Division, on what current AGMA documents are available for use in the EV space. Next, attendees will be invited to share their thoughts on current state of the EV sector including areas and topics where AGMA could step in to support the gear industry. Drawing on its 100+ year experience, the goal of this event is for AGMA to gather the experts around a table to discuss outstanding issues identified by consensus and collaborate on consensus based, mutually beneficial solutions as it relates to the EV sector. Come be a part of the discussion!

This meeting is open to all interested from the gearing industry, specifically those involved in the electrical vehicle space. Participants should expect, and be ready and willing, to collaborate and share knowledge.

AGMA's Fall Technical Meeting attracts engineers and technical specialists who want to learn the latest technical information about gears from the world's leading experts.

Fall Technical Meeting 2023

AGMA's Fall Technical Meeting begins one day before MPT Expo, and it requires a separate admission (see *www.agma.org/events/fall-technical-meeting-ftm/* for details on pricing).

This meeting brings together top researchers from across the globe who will provide the latest information on their peer-reviewed gear industry research. Network with the industry experts, academics, and engineers; ask your burning questions; and see what is in the future of this industry.

Monday, October 16

Technical Session 1—Efficiency, Lubrication, Noise, and Vibration (1:00 pm–5:00 pm)

- How Many Gears for Electric Cars? One Example
- Cross-Correlation of Design Variables for Epicyclic Systems
- Particle-Based CFD Study of Lubrication in Power Transmission Systems Using Local Refinement Techniques
- Modeling Lubricant Flow and Thermal Response for Gears

Tuesday, October 17

Technical Session 2—Materials and Heat Treatment (8:00 am–12:00 pm)

- Influence of Precipitation Conditions on the Tooth Root and Pitting Load Carrying Capacity of Carbonitrided and Low Pressure Carburized Gears
- Methodology to Evaluate the Bending and Contact Allowable Stress Numbers of Gears from Rotating Bending Database
- Advanced Distortion Control for Case Hardening of Transmission Components
- 3D Printing Plastic Gears
- SPECIAL PRESENTATION: Updates to AGMA 926, Recommended Practice for Carburized Aerospace Gearing

Technical Session 3—Gear Wear and Failure (1:00 pm–5:00 pm)

- Non-Linear Analysis of Gear-Fatigue-Damage Under Variable Load
- Use of Gear Reliability Data in a Cloud-Based Gearbox Digital Twin
- Wear Behavior of Polymeric Compound Measured on a New Test Rig for Plastic Gears
- Tooth Flank Fracture—Investigations on the Influence of Overloads on the Fatigue Strength of Case-Hardened Gears
- Experimental and Analytical Study of the Effect of Shot Peening on Gear Micropitting and Contact Fatigue Failure

Wednesday, October 18

Technical Session 4—Manufacturing, Inspection, Testing, and Quality Control (8:00 am–12:00 pm)

- Laser Material Processing for the Production of Bronze Coatings for Tribological Applications
- Influence of Tooth Root Contour Deviations on the Tooth Bending Strength
- Power Skiving Tool Offsets and the Feasibility of Using a Calculator for Manipulating the Resulting Geometry
- Virtual End of Line Test—Prediction of the Acoustic Behavior of Gearboxes Based on Topographic Deviations Using Neural Networks

Technical Session 5—Application, Design, and Rating (1:00 pm–5:00 pm)

- Holistic Assessment of Drive Systems with Gears, Shafts and Bearings Using Measured Torque-Speed Data
- Local Load Capacity Analysis for the Design of a Balanced Flank Modification for Cylindrical Gears According to Bevel Gear Procedures
- Determination of the AGMA J-Factor for Internal Spur Gears
- Flexible Planet Pins for High Torque Epicyclic Gears: Experience with Design, Manufacturing and Application
- Numerical Approach to Account for Actual Tooth Root Geometry

Feel the Burn

Heat Treat 2023 is right around the corner

Aaron Fagan, Senior Editor

Credit: SECO/Vacuum

Heat Treat 2023 is the Heat Treating Society's 32nd conference and expo for heat treating professionals featuring three days of face-to-face networking opportunities with approximately 200 heat treat exhibitors/companies. All the top heat-treating companies will offer the latest research and industry insights during more than 100 technical programs. This year's show includes a VIP-guided industry tour, as well as student/emerging professionals initiatives, including free college student registration, Fluxtrol Student Research Competition, and the ASM Heat Treating Society Strong Bar Student Competition. Heat Treat 2023 is colocated with Motion + Power Technology Expo 2023 with access to additional exhibitors. The event takes place October 17–19, 2023 at Huntington Place in Detroit.

The largest of its kind in North America, the Heat Treat Conference and Expo bridges the gap between research with industry—bringing together heat-treating professionals, materials experts, global innovators, researchers, influencers, and decision-makers from around the globe. Below are a few booth previews along with a sidebar featuring some select networking and educational opportunities to look out for.

Networking and Educational Opportunities

The show features 100+ technical presentations and networking opportunities
—(please note that details and times are subject to change)—
including the following:

Tuesday, October 17

7:00 am–9:00 am
ASM Women in Engineering Breakfast (Joint with IMAT and AGMA)

9:00 am–10:00 am
Applied Technology / Processes and Applications: Energy Consumption and Efficiency
Session Chair: *Mr. Dennis Beauchesne*

Atmosphere Technology and Surface Engineering I
Session Chair: *Prof. Mei Yang*

Microstructural Development / Characterization I
Session Chair: *Prof. Robert L. Cryderman*

10:30 am–11:30 am
Applied Technology / Processes and Applications: Quality Control

Microstructural Development / Characterization II
Session Chair: *Prof. Robert L. Cryderman*

1:00 pm–1:40 pm
New Trends in Global Heat Treating

1:00 pm–2:20 pm
"Green" Heat Treating / Low Carbon I

"Green" Heat Treating / Low Carbon II

Vacuum Processes and Technology

2:30 pm-4:30 pm
Keynote, Dr. Stefanie Tompkins, Defense Advanced Research Projects Agency (DARPA)

4:00 PM–5:30 PM
FLUXTROL STUDENT RESEARCH COMPETITION—PHASE 1—POSTER PRESENTATIONS

HTS STRONG BAR STUDENT COMPETITION—PHASE 1—POSTER PRESENTATIONS
Session Chair: *Mr. Robert C. Goldstein*

6:00 pm–9:30 pm
ASM ANNUAL AWARDS RECEPTION AND BANQUET (Marriott)

9:30 pm–11:00 pm
ASM PRESIDENT'S RECEPTION (Marriott)

Wednesday, October 18

9:15 am–10:00 am
Keynote, Dr. Iver Anderson, FASM, Ames Laboratory presents
"Heat Treatment Effects on Sintering of Highly Grain-refined Dy-free Nd-Fe-B Anisotropic Magnets"

10:30 am–11:30 am
FLUXTROL STUDENT RESEARCH COMPETITION—PHASE 2—ORAL PRESENTATIONS
Session Chair: *Mr. Robert C. Goldstein*

11:45 am–12:30 pm
HTS STRONG BAR COMPETITION—BEND TESTING

1:00 pm–2:40 pm
Simulation & Modeling I: Process Simulation (CFD/FEA)
Session Chair: *Mr. Andrew L. Banka, P.E.*

1:00 pm–3:00 pm
Materials Durability / Mechanical Testing / Non-Destructive Testing
Session Chair: *Mr. Jason Orosz*

Residual Stress / Panel Session
Session Chair: *Dr. Lesley D. Frame*

3:30 pm–4:50 pm
Industry Internet of Things
Session Chair: *Ms. Trisha Rouse*

Quenching Technologies I: High Pressure
Session Chair: *Dr. Mohammed Maniruzzaman*

3:30 pm–5:10 pm
Heat Treating: Induction Heat Treating
Session Chair: *Mr. Robert J. Madeira, President*

6:00 pm–9:00 pm
Networking Event at the Waterview Loft

Thursday, October 19

9:15 am–10:00 am
Keynote, Dr. Marvin Barnes, NASA presents
"Ordinary Materials, Extraordinary Applications"

10:30 am–12:10 pm
Atmosphere Technology and Surface Engineering II: Nitriding and Cleaning
Session Chair: *Dr. Olga K. Rowan*

Quenching Technologies II
Session Chair: *Mr. David A Guisbert*

Simulation & Modeling II: Process Simulation (CFD/FEA)
Session Chair: *Mr. Stefan Habean*

SECO/Vacuum—Booth 2101

At the ASM Heat Treat Show, SECO/Vacuum will feature technologies for "the future of heat treating":

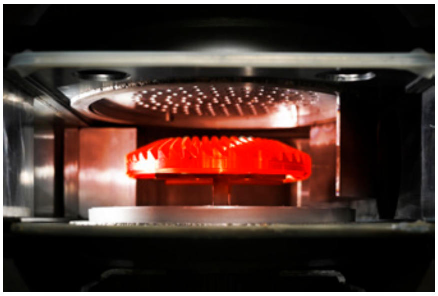
Vector Single-Chamber High-Pressure Gas Quench Vacuum Furnace

Vector is SECO/Vacuum's single-chamber gas quenching vacuum furnace using high-pressure quench (2 to 25 bar) which can be applied to a wide variety of heat-treating processes and applications. It provides important capabilities for producing high uniformity in heat-treated parts, high consistency in workloads, and high speeds in batch processing with low consumption of power and process gases.

Casemaster Evolution Multichamber Gas or Oil Quench Vacuum Furnace

SECO/Vacuum offers two configurations of its CaseMaster Evolution. The two-chamber furnace, called D type, is a dual-chamber furnace with one chamber for vacuum heat processing and a second chamber for oil or gas quenching. The three-chamber furnace, called T type, provides the same chambers as the D type plus a third pre-heating (and/or pre-oxidation chamber) which increases productivity through semi-continuous batch processing. In the three-chamber approach SECO/Vacuum's PreNitLPC process can be added for even higher productivity.

4D Quench Single-Piece Flow Vacuum Furnace



SECO/Vacuum 4D Quench for single-piece quenching with distortion control and prediction.

SECO/Vacuum's 4D Quench furnace is a vacuum heat treatment solution for single-piece quenching with distortion control and prediction. It is designed to heat or re-heat products such as gears on a single conveyor deck. It consists of a vacuum heating chamber and a high-pressure nitrogen quench chamber equipped with transportation mechanisms. It enables customers to replace oil quenching with a clean, environmentally friendly, cost-effective nitrogen quenching technology. 4D Quench was designed for those who want to significantly increase the production quality and economy of high-volume gears and power transmission components to produce totally uniform parts in a completely hands-free environment.

Pit-LPC Vacuum Furnace

The new SECO/Vacuum Pit-LPC vacuum furnace.

The new Pit-LPC vacuum furnace from SECO/Vacuum is another innovation designed for clean, uniform processing of large or parts requiring deep case depths. As a modern alternative to 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.

The LPC vacuum Pit 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.

secovacusa.com

AFC/Holcroft—Booth 2219

Thermal processing is critical to producing the materials of modern life, yet they are unavoidably energy-intensive. But that doesn't mean that heat treatment systems are impervious to ways to reduce their environmental impact. In fact, there are already many climate-aware improvements to traditional heat treatment systems that can be implemented, today. AFC-Holcroft is continually developing solutions to lessen the heat treatment carbon footprint and offers many forward-thinking ways to help safeguard the environment. In addition to their newly renovated manufacturing and offices reducing their own footprint—their Green Equipment Initiatives encompass options that can offer specific benefits towards energy savings, operating efficiencies, environmental safeguards, reduced carbon footprint, and general climate protection.

When it comes to the manufacturing of complex components such as gears, controlling distortion is a difficult, but necessary consideration for reducing the post-heat treat grinding process. There are opportunities to use various heat-treating processes to help reduce distortion and thereby reduce the overall grinding time, resulting in lower manufacturing costs and improvements in overall quality—but where are those opportunities? What is the best choice for your gear manufacturing operation?

AFC Holcroft UBQA (Universal Batch Quench—Austemper) System.

AFC-Holcroft uses molten salt during the quench portion of the heat-treating process in their UBQA (Universal Batch

Quench—Austemper) System, which can be an effective, safe, and environmentally friendly solution to help overcome the problem of part distortion resulting in the quench process.

Salt quench systems are playing a major role in the next generation of IC powertrains, the xEV market, and industrial power transmission systems worldwide. AFC-Holcroft's proven designs have been adopted by major multinational corporations across the globe, with greater acceptance than ever before.

afc-holcroft.com

Gasbarre Thermal Processing Systems—Booth 1928

Gasbarre Thermal Processing Systems' continuous vacuum furnaces utilize the latest in control technology and offer repeatability and modular flexibility to meet the needs of virtually any vacuum heat-treating process. With temperature capabilities up to 2,650°F, they are designed to meet AMS 2750G requirements with uniformity up to Class 2 (±10°F) and instrumentation configuration Types D and E. They can be equipped with oil or gas quenching modules with gas pressure capabilities up to 10 bar, making them ideal for hardening applications. Modular equipment design allows low-pressure carburizing dwell times and index rates to be fine-tuned to meet process and production requirements, optimizing the return on value for your investment.

In addition to their robust design and modular flexibility, Gasbarre's continuous vacuum furnaces offer several unique advantages over other types of vacuum heat treat equipment. Concurrent processing reduces the effective duration of the heat-treating cycle by eliminating work staging and vacuum pumping from floor-to-floor time. The resulting higher throughput allows for smaller load sizes which help overcome challenges with uniformity and repeatability associated with larger workloads required to achieve production rates in batch equipment.

Because heating and cooling are performed in dedicated sections of the furnace, thermal efficiency is dramatically improved over batch-style furnaces where the entire insulation assembly must be heated and cooled every cycle. Similarly, dedicated sections of the furnace reduce

Gasbarre continuous vacuum oil quench.

process gas requirements for cooling and partial pressure. In addition to reduced utility consumption, the lack of thermal cycling and oxygen exposure dramatically improves the life of refractory consumables within the furnace, reducing maintenance costs and downtime.

Continuous vacuum isn't right for every gear-treating process which is why Gasbarre Thermal Processing Systems designs, manufactures, and services a full line of thermal processing equipment for virtually any process. Gasbarre's offering includes continuous and batch atmosphere and vacuum equipment, serving customers in the automotive, aerospace, industrial equipment, energy, and commercial heat-treating industries.

Gasbarre provides products and services that combine value and design flexibility through knowledge and understanding of your process. For each piece of equipment, Gasbarre takes a 360-degree approach. From sales and applications engineering to equipment design, manufacturing, commissioning, and aftermarket support, Gasbarre's team of engineers, metallurgists, and technicians aims to understand your process from all angles.

gasbarre.com

Nitrex—Booth 2138

As a respected leader in surface treatment, Nitrex draws upon 40 years of expertise to deliver innovative thermal processing solutions to the gear manufacturing industry. With an extensive portfolio of end-to-end heat treatment solutions and a network of 15 global sites, Nitrex focuses on maximizing results for gear manufacturers and diverse industries alike.

At the forthcoming ASM Heat Treat 2023 exhibition, colocated with Motion and Power, Nitrex will showcase their esteemed thermal processing. From turnkey heat-treating furnace systems and process control solutions to software/digitalization and heat-treating services, they collaborate closely with gear manufacturers worldwide. Their support spans the entire journey—from prototyping to process refinement, low- to high-volume heat treat orders, and even new installations or retrofit applications. The result is superior quality, bolstering gear manufacturing operations in diverse sectors, such as automotive, aerospace, defense, and mining.

Among their groundbreaking innovations, NITREG gas nitriding technology stands out. A vanguard in controlled gas nitriding, this technology remains a frontrunner in surface hardening today. The NITREG-controlled gas nitriding process optimizes gear properties, enhancing tribological characteristics, minimizing distortion, and eliminating post-finishing steps. Beyond its technical prowess, this process champions sustainability, a dual benefit for both efficiency and environmental well-being. Nitrex has further expanded their capabilities with technologies like NITREG-C controlled nitrocarburizing, ONC post-oxidation, and NITREG-S controlled nitriding of stainless steels, offering enhanced wear and corrosion properties and broadening its range of treatable steels. Additionally, their heat-treat service centers provide Low-Pressure Carburizing for special gears.

Nitrex's solutions bolster gear manufacturing operations in diverse sectors, such as automotive, aerospace, defense, and mining.

Using eco-friendly clean heat treatment technologies, Nitrex nitriding and vacuum furnaces not only ensure the highest standards of sustainable processing but also contribute to a reduced environmental footprint during the treatment of components. Their commitment to efficiency and sustainability is further evident in the UPC-Marathon product lines, which include oxygen probes, process control solutions, flow solutions, and endothermic/exothermic gas production systems. These not only future-proof assets for a longer service life but also optimize resource utilization while meeting the latest quality and safety standards.

Representing the latest in digitalization, QMULUS drives gains for both industry and the environment. As a holistic IoT solution, QMULUS digitizes the heat-treat shop floor, enabling remote management, real-time visibility, and optimized operations and resources through advanced AI and machine learning—achieving a triple-bottom-line impact.

Located at booth number 2138, you can explore how their solutions can bring your manufacturing operations and gear performance to new heights. Don't miss their presentation on "Nitrided White Layer—Formation, Function, Usefulness, Variations, and Challenges: How is this helping Electric Vehicle Engineering?" on Thursday, October 19 at 11:50 am.

nitrex.com

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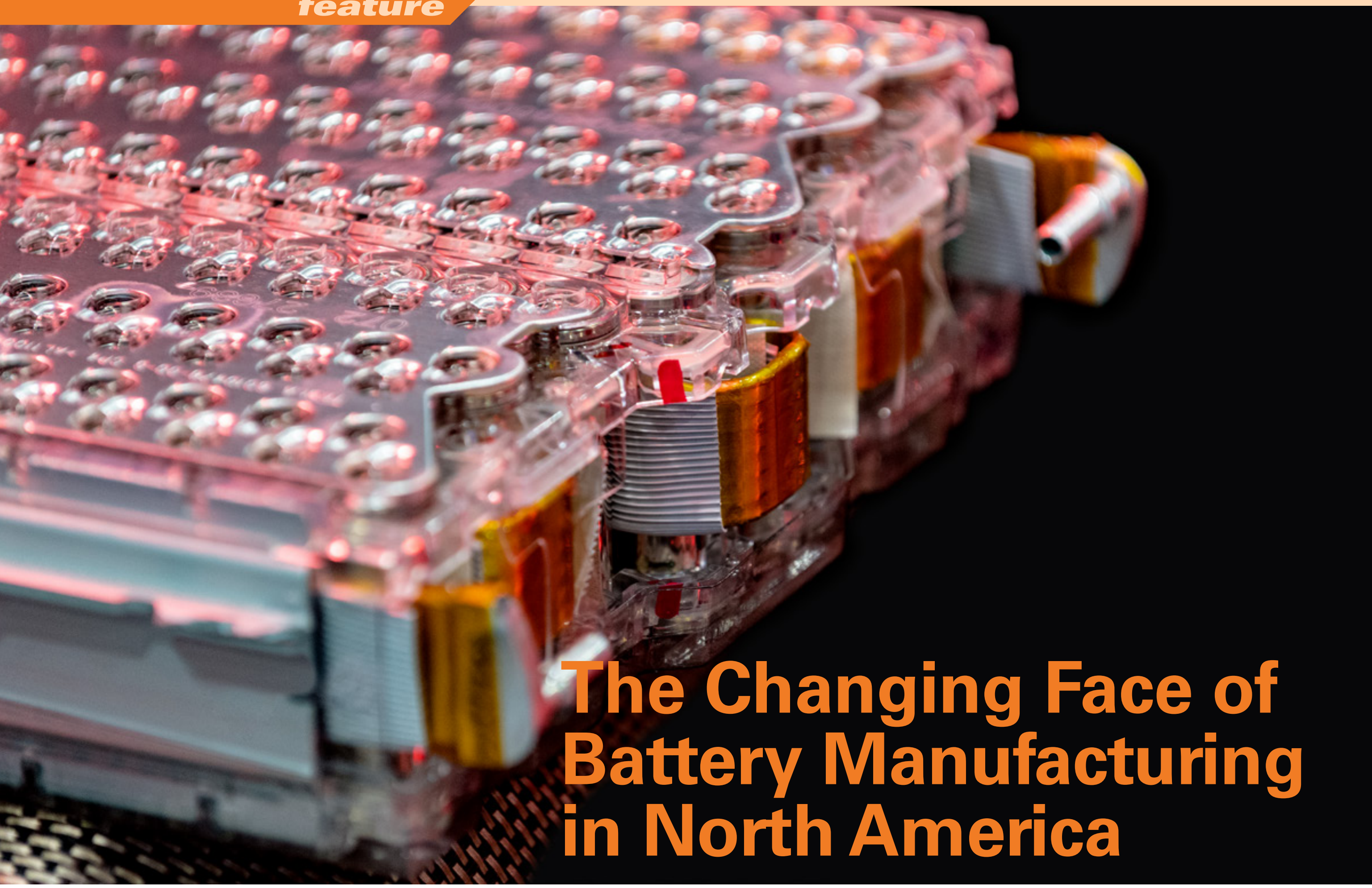

The Changing Face of Battery Manufacturing in North America

Battery technology starts and stops with the raw materials. North America is bypassing traditional suppliers to meet electrification requirements.

Automotive companies add "mining" to their growing field of interests in the age of e-mobility

Matthew Jaster, Senior Editor

The manufacturing version of Indiana Jones is much more interested in lithium, cobalt, and nickel than arks, grails or "Dials of Destiny." So much so that the current administration is doing its part to keep up with China in the dramatic supply chain cold war taking place across the globe. We've all read and reread the headlines, electrification is imminent for our carbon-neutral future—the path toward electrification, however, is quite complicated.

The EV Battery Supply Chain

Steps involved in producing and using an EV battery fall into four general categories, according to the Rocky Mountain Institute (RMI).

Upstream: Mines extract raw materials; for batteries, these raw materials typically contain lithium, cobalt, manganese, nickel, and graphite.

Midstream: Processors and refiners purify the raw materials, then use them to create cathode and anode active battery materials; commodities traders buy and sell raw materials to firms that produce battery cells.

Downstream: Battery manufacturers assemble the battery cells into modules and then pack and sell them to automakers, who place the finished batteries in EVs. Some automakers like Ford and Stellantis have formed partnerships with battery manufacturers to produce their own batteries for the vehicles they sell.

End of Life: When batteries no longer serve their original purpose, they can be reused or recycled.

RMI recently reported that China continues to dominate this supply chain. As broader geopolitical issues affect economic and trade relationships, the stability of the global supply chain is increasingly at risk when extracting, refining, processing, and assembling an outsized share of EV battery components occurs in any single country.

Several critics have described American efforts to increase domestic EV battery supply chain capacity as an attempt to "decouple" from China, which is an oversimplification. A more accurate assessment is provided by US Trade Representative Katherine Tai, who labels the current administration's approach "de-risking." As the market for EV batteries and other advanced energy technologies expands, there will be plenty of growth opportunities for all producing nations, even as that production capacity diversifies.

Case in point: The United States Geological Survey (USGS) has spent recent years studying potential domestic resources for the following minerals: aluminum, cobalt, graphite, lithium, niobium, platinum group elements (PGE), rare earth elements, tantalum, tin, titanium, and tungsten. The USGS has identified broad areas within the United States to target acquisition of geologic mapping, geophysical data, and (or) detailed topographic information to aid research, mineral exploration, and evaluation of mineral potential in these areas.

It is important to recognize that strengthening the EV battery supply chain is not a zero-sum game with winners and losers. Creating a robust supply chain will benefit people around the world by creating jobs and making it easier for consumers to purchase EVs.

Developments in North America

Talon Metals Corp. submitted its Environmental Assessment Worksheet ("EAW") to the Minnesota Department of Natural Resources to begin the State's Environmental Impact Statement scoping process for the Tamarack Nickel-Copper-Cobalt Project (the "Tamarack Nickel Project"), a proposed small-footprint, high-grade underground nickel mine that would be located near the City of Tamarack in Aitkin County, Minnesota.

"Our team in Tamarack is excited to have reached the milestone of submitting the initial worksheet form to begin Minnesota's Environmental Review process, the starting point for any project seeking a permit in the state," said Henri van Rooyen, CEO of Talon. He continued "We have worked very hard and invested millions of dollars to understand the environment and cultural resources in the area where we are proposing the Tamarack Nickel Project outside the City of Tamarack. Environmental data collection started in 2006 and today includes data from the deep bedrock where the high-grade nickel deposit is found, to the surface water in the glacial till layer that contains wetlands, streams, rivers, lakes, and homestead wells. This baseline data has helped the team to design the proposed project to safeguard the environment."

An update in July 2023 noted that the drill team at Tamarack hit a new area of semi-massive nickel sulfide signaling that there is more nickel left to find in America.

Reuters recently reported that lithium iron phosphate (LFP) is gaining traction as the EV battery material of choice. The popularity of this compound is due partly to environmental and geopolitical concerns. But technological advances have also reduced the performance gap with more widely used materials such as nickel and cobalt.

LFP, embraced by EV industry leader Tesla two years ago, has sparked new interest especially in the United States, where a clutch of domestic and overseas manufacturers has pledged more than $11 billion in new production facilities.

Toyota Motor and Hyundai Motor, have both recently announced plans to equip their future vehicles with LFP batteries.

Michigan-based Our Next Energy—a proponent of LFP according to founder and chief executive Mujeeb Ijaz—is building a $1.6 billion battery manufacturing complex in Van Buren Township because the materials are more abundant and sustainable, with far less risk of fire. "We've also demonstrated that you can match the range of cobalt cells with no compromise," he said.

The Southwest is home to several mines that are receiving a "second look" in order to assess the availability of certain minerals for battery production.

More than 90 percent of LFP materials and components still come from China, said battery expert Shirley Meng, a University of Chicago professor, and head of Argonne National Laboratory's Collaborative Center for Energy Storage Science.

The rapidly increasing adoption of LFP by EV manufacturers including Tesla and Hyundai suggests those companies "are not ready to decouple from China," Meng said.

Earlier this year, Michael Matz wrote an article for Argonne National Laboratory titled, "Investigating battery failure to engineer better batteries." This study explored how a class of gemstone materials could be a key ingredient in next-generation batteries. The research team included the US Department of Energy's (DOE) Argonne National Laboratory, DOE's Oak Ridge National Laboratory, Princeton University and Purdue University. The study used cutting-edge X-ray techniques at Argonne's Advanced Photon Source, a DOE Office of Science user facility.

Michigan Tech University has also been in the news this year for transportation and sustainability endeavors.

"Michigan Tech is committed to advancing new technology and sustainability solutions—in its work on campus at the Keweenaw Research Center and Great Lakes Research Center, in the Grand Traverse region with the Freshwater Research and Innovation Center, and in Ann Arbor at the Michigan Tech Research Institute. These impressive footprints strongly position the University and its talent throughout the state. The mobility industry provides an annual economic contribution to the state of Michigan of over $300 billion. It is our signature industry," said Glenn Stevens Jr., executive director, MICHauto.

Early 2023, the DOE awarded grants to develop rapid carbon mineralization and critical mineral extraction technology to 16 projects nationwide, totaling $39 million. Michigan Tech's project is the only one in the state of Michigan to receive funding from Mining Innovations for Negative Emissions Resource Recovery (MINER), a new initiative through the

A copper mine located in British Columbia, Canada.

DOE's Advanced Research Projects Agency-Energy (ARPA-E). The MINER initiative funds technology research that increases mineral yield, while decreasing required energy and subsequent emissions, to mine and extract energy-relevant minerals.

Michigan Tech's project is titled "Energy Reduction and Improved Critical Mineral Recovery from Low-Grade Disseminated Sulfide Deposits and Mine Tailings." It seeks to permanently and cleanly mineralize and store carbon dioxide, potentially enabling the mining industry in Michigan's Upper Peninsula and Minnesota to achieve net carbon zero while extracting critical minerals from low-grade ores, said principal project investigator (PI) Lei Pan, an associate professor in Michigan Tech's Department of Chemical Engineering.

The American Three: Motors, Miners and E-Mobility

This focus on battery minerals has led GM, Ford and Stellantis to partner with a variety of suppliers to support battery production in North America.

Ford Motor aims to open a $3.5 billion LFP cell manufacturing plant in western Michigan, leveraging technology licensed from China's CATL, the world's largest EV battery maker. The goal, Ford CEO Jim Farley said in a press release, is to lower the automaker's cell costs to less than $70 a kilowatt-hour, from more than $100/kWh for current NCM cells.

Stellantis and Canada-based miner NioCorp Developments Ltd (NB.TO) recently signed a supply deal for rare earth minerals critical to electrical vehicles. The preliminary agreement establishes a 10-year offtake contract for minerals like neodymium-praseodymium oxide, dysprosium oxide, and terbium oxide that NioCorp aims to produce at its Elk Creek Critical Minerals Project in southeast Nebraska.

General Motors and Element 25 Limited announced an agreement for Element 25 to supply up to 32,500 metric tons of manganese sulfate annually to support the annual production of more than 1 million GM EVs in North America.

Under the agreement, GM will provide Element 25 with an $85 million loan to partially fund the construction of a new facility in the state of Louisiana for production of battery-grade manganese sulfate—a key component in lithium-ion battery cathodes—starting in 2025. Element 25 will produce manganese sulfate at the facility by processing manganese concentrate from its mining operations in Australia. It is expected to be the first facility of its kind in the United States.

"GM is scaling EV production in North America well past 1 million units annually and our direct investments in battery raw materials, processing and components for EVs are providing certainty of supply, favorable commercial terms and thousands of new jobs, especially in the United States, Canada and free trade agreement countries like Australia," said Doug Parks, GM executive vice president, global product development, purchasing and supply chain. "The facility E25 will build in Louisiana is significant because it's expected be the first plant in the United States to produce battery-grade manganese sulfate, a key component of cathode active material which helps improve EV battery cell cost."

A Renewed Focus

Minerals for battery production exist here in North America just as they do around the globe. Today, it's a question of building the production facilities, infrastructure, and supply chain to onshore these processes here at home. According to the International Energy Agency (IEA), mineral demand will likely triple by 2040. The transportation industry can debate electric vehicles, charging requirements, battery costs and regulations, etc., but without the minerals to power these batteries it won't matter—North America's clean energy ambitions will come down to building (and digging) its own e-mobility roadmap.

Additional Resources

Interested in learning more about the mineral arms race? Check out the following resources:

Ewing, J., Krauss, C., "Lithium Scarcity Pushes Carmakers into the Mining Business," *The New York Times,* July 2, 2023.

Bednarski, L., 2021, *Lithium: The Global Race for Battery Dominance and the New Energy Revolution.*

Pitron, G., 2020, *The Rare Metals War: The Dark Side of Clean Energy and Digital Technologies.*

Bridges, A., Mamula, N., 2018, *Groundbreaking! America's New Quest for Mineral Independence.*

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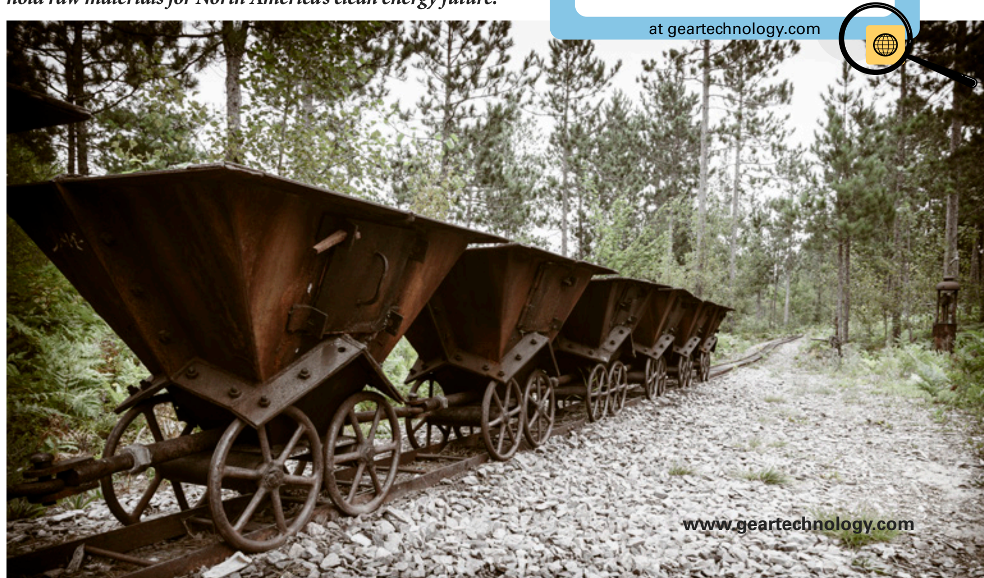
An abandoned mine in Michigan's Upper Peninsula may still hold raw materials for North America's clean energy future.



Precision Workholding for Gear Production

Custom clamping for challenging requirements

Emuge-Franken USA

A range of gear manufacturing applications such as planetary carriers and gear wheels with strict tolerances demand comprehensive, reliable clamping solutions. Whether the objective is to reduce vibrations or ensure concentricity of only a few microns, the clamping must meet challenging requirements.

Planetary Gear Wheel Clamping Device—designed, engineered, and manufactured by Emuge-Franken.

A first example is a planetary gear carrier—an essential component of an automatic transmission because it carries the planetary gears, which are needed to couple the sun and ring gears. It is interesting to know that its name "planetary gear" is based on the solar system. The central point of an automatic gearbox is the sun wheel, which is orbited by several shafts. These shafts have gear wheels, the so-called planetary gears, and the movement which is similar to that of planets orbiting a central sun. This structure is surrounded by a ring gear. As the name suggests, the planetary gear carrier carries the planetary gears.

By changing gears in the gearbox, the interaction of the various gears previously mentioned changes so that the drive operates at the optimal speed and load range.

Precise Clamping for Planetary Gear Carriers

There are significant and demanding technical clamping challenges on a "bulky" planetary gear carrier being used in milling operations with high machining forces. Requirements include clamping with low distortion and fixed with low vibration by means of enormously high torques.

Collaborating as a "team," Emuge-Franken worked closely with its customer and machine manufacturer to design, engineer, and manufacture a planetary gear carrier clamping solution. The goal was not to achieve the highest possible accuracy but to be able to run a demanding machining operation with great forces that have to be absorbed by a massive clamping device and high levels of torque. This also has an impact on the machine, which had to be considered during the project process.

To meet the requirements, the best of two worlds were combined in a clamping concept. First, primary clamping featured a diaphragm chuck with clamping jaws. Second, a traditional concept of a collet chuck and hydraulically actuated clamping piston was incorporated for the additional internal clamping. Emuge chose this design to best accommodate a relatively short clamping surface on the workpiece and a large working space required for the tools.

We know the diaphragm has high inherent tension and provides good holding torque. Add in hydraulic back pressure and the holding torque is greatly increased, which theoretically might have been suitable for the machining process. However, a collet chuck was a necessary addition to achieve vibration-free clamping and withstand the high holding forces. This was especially key to offset the high cutting forces, which can cause significant vibration and possibly reduce machining quality.

An alignment unit was another important design element of this clamping device. The first function is the insertion lock, ensuring the workpiece is inserted correctly during manual loading. The alignment sleeve has pins that can be extended and retracted, giving the workpiece the correct angular alignment for machining.

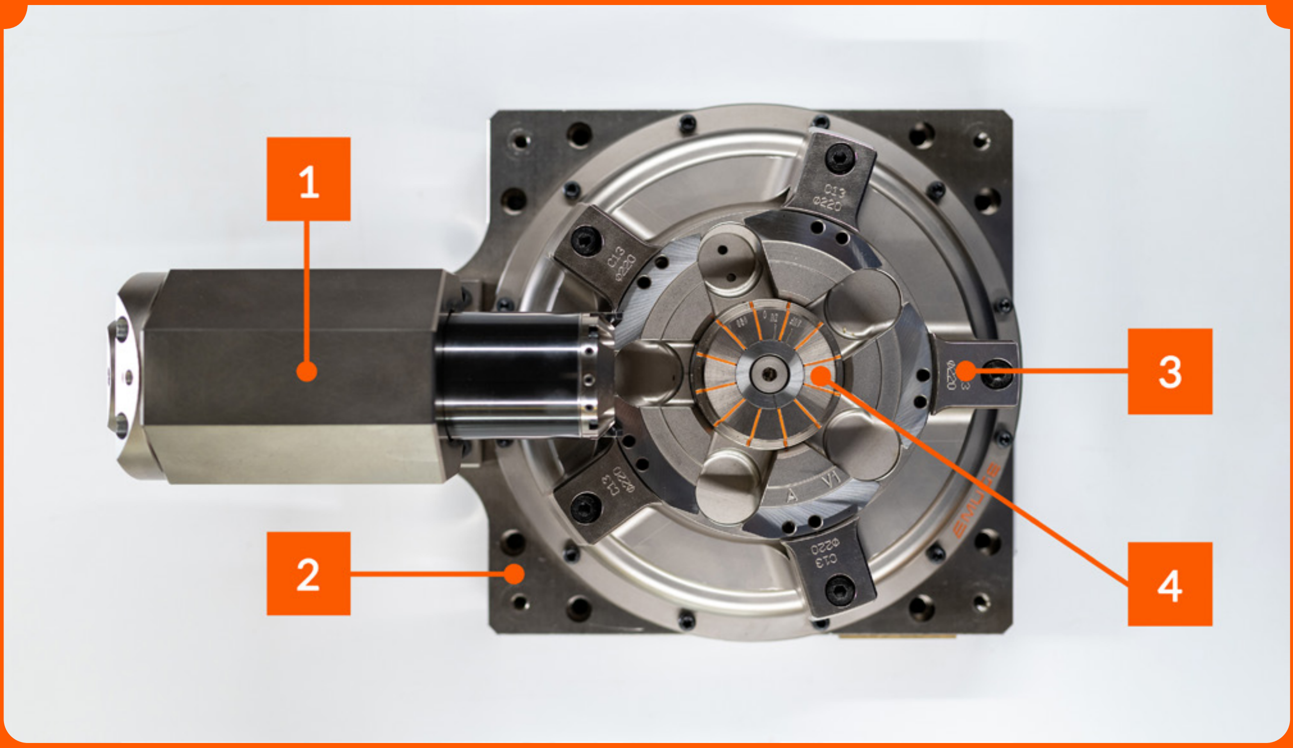
A movable sleeve also sets the final position during alignment, freeing up enough space for the added tools by retracting away from the workpiece. The clamping device is actuated hydraulically with a maximum of 200 bar. Precisely controlled clamping sequences were matched to the workpiece, precisely defined by a complex hydraulic circuit. The hydraulic circuit was limited by the number of hydraulic channels available on the machine side.

The completed clamping solution was about more than just clamping and unclamping. It was about the coordination of many movement sequences, a complex control system and finally the huge size of the clamping device which has a base plate of 23 x 14 inches (580 x 360 mm) and weighs in at over 353 lbs. (160 kg).

It is interesting to note that the required holding torque could not be easily checked. A 6.5-ft. (two-meter) long torque wrench had to be used. Once the holding torque was verified, the customer setup the six clamping devices on the machine. The configuration had three devices inside the machine and three devices outside the machine -- all on palletized tables. This setup allowed the three clamping devices in the machine to be operated simultaneously, which significantly increased the volume of machined workpieces. The other three clamping devices, which are located outside the machine, can be unloaded/ loaded concurrently, which also increases production volume.

Emuge-Franken's Planetary Gear Wheel Clamping Device was designed to meet demanding clamping technical challenges.

The planetary gear carrier clamping device has a solid foundation that is a specially designed plate (2) on which the other components are installed. All hydraulic and pneumatic lines, including the external connections, are connected to this plate. There are distinctive hydraulic connections and mounts for the load bars which are necessary due to the total weight of over 353 lbs. (160 kg).



The external clamping concept forms a diaphragm. The five clamping jaws (3) are screwed to the diaphragm and rest against the workpiece due to its inherent tension. This torque is massively reinforced by hydraulic pressure. The orange slots of the collet (4) are clearly visible through the clamping jaws. The alignment unit (1) is located in an outboard position above two of the clamping jaws.

High Accuracy Hollow Wheel-Clamping Technology

Diaphragm clamping devices are also an excellent choice for the demanding holding requirements when power skiving to produce external and internal gears, as well as spur and helical gears when modern power skiving. The machining process is highly productive, but only if the machine, the tool, and the workpiece are perfectly matched.

These clamping devices are subject to enormous demands regarding design, clamping force, and accuracy. In addition to the sophisticated design, the complex production of the clamping diaphragm also plays an essential role.

Diaphragm clamping devices are used in the gearing of ring gears for use in commercial vehicle transmissions. High-precision production of gears is an important factor in these transmissions, and Emuge-Franken diaphragm clamping devices are ideally suited for these applications. The repeatable concentricity on the workpiece is often in the range of less than 10 µm, depending on the clamping diameter, as is the axial run-out.

The design also makes diaphragm clamping devices low-maintenance and resistant to contamination in addition to the guaranteed clearance and run-down for the machining tool.

Diaphragm clamping devices are able to achieve excellent concentricity or roundness in machining, even with finely detailed workpieces with strict tolerances. Accuracies in concentricity or roundness of 10 to 30 µm can be obtained, depending on how large and how thin-walled the workpiece is. And even though many diaphragm clamping devices are suitable for workpieces with a diameter of 5 to 20 in. (130 to 510 mm), a compact design is possible.

A clamping diaphragm has a high internal tension due to its design, so the forces adapt perfectly to the contour of the workpiece. For thin-walled workpieces, the clamping diaphragm is designed accordingly. The clamping force can be increased by the tractive force of the machine for robust workpieces.

Clamping jaws, which are a typical element of diaphragm devices, ensure that the workpiece is clamped securely, without deformation, and at defined points. An optional face clamping additionally clamps the workpiece. Six or eight clamping jaws are used depending on the clamping diameter. Also, the clamping force is independent of the rotational speed due to centrifugal force compensation.

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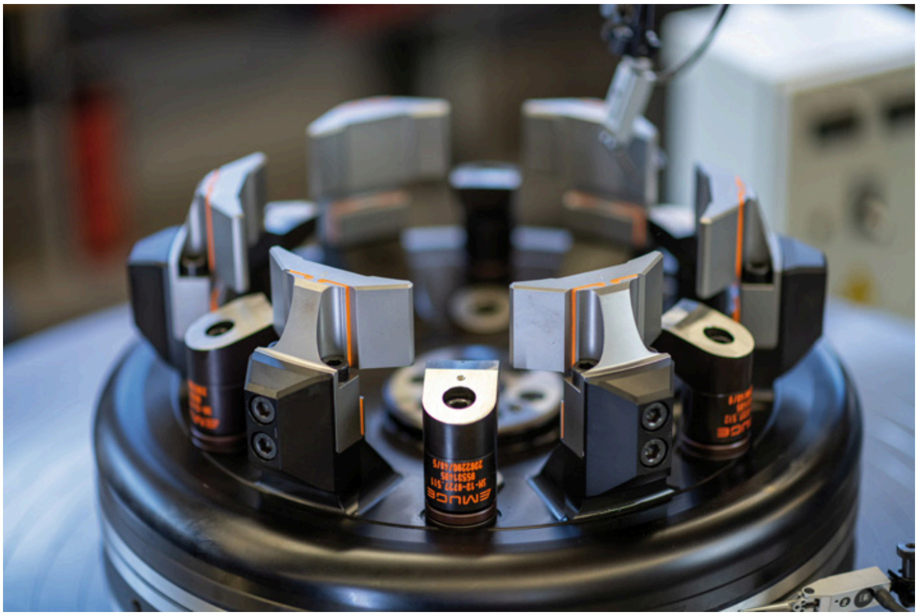
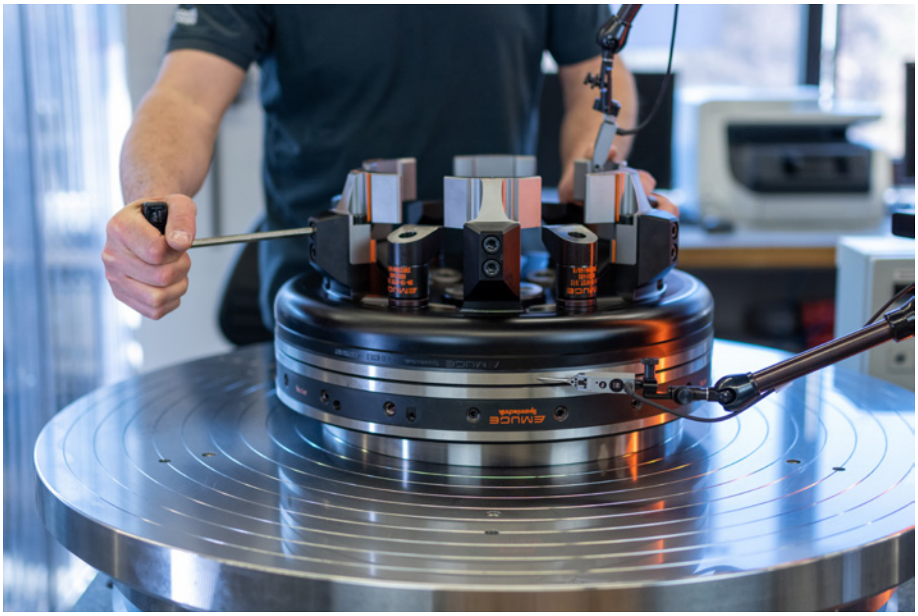


Emuge-Franken's Diaphragm Clamping Device provides excellent concentricity or roundness in machining, including parts with fine details.



Designed with indicating in the base and jaws on a diaphragm for perfect runout correlation between the two.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Town Hall: Is It EV-Standards Time?

Phillip Olson, Director, AGMA Technical Services

For 107 years, AGMA has been the go-to place for gear standards. We have been bringing together engineers and leaders from across our industry to keep our standards updated and in line with new technologies. We started with noise issues on electric street cars in the early 1900s, and today we lead the global ISO TC 60 committee on standards including wind-turbine gear-box development. As new technologies and gear applications emerged, AGMA has gathered experts to discuss, brainstorm, share, and collaborate on the topics of the day such as plastic gears, epicyclic gears, marine gears, wind turbine gearboxes, and, of course, gear sets for internal combustion vehicles. We have also kept updated standards on gear accuracy, materials, and lubrication. This work has led to standards that reduce costs, improve quality, and make safer products for manufacturers and consumers worldwide.

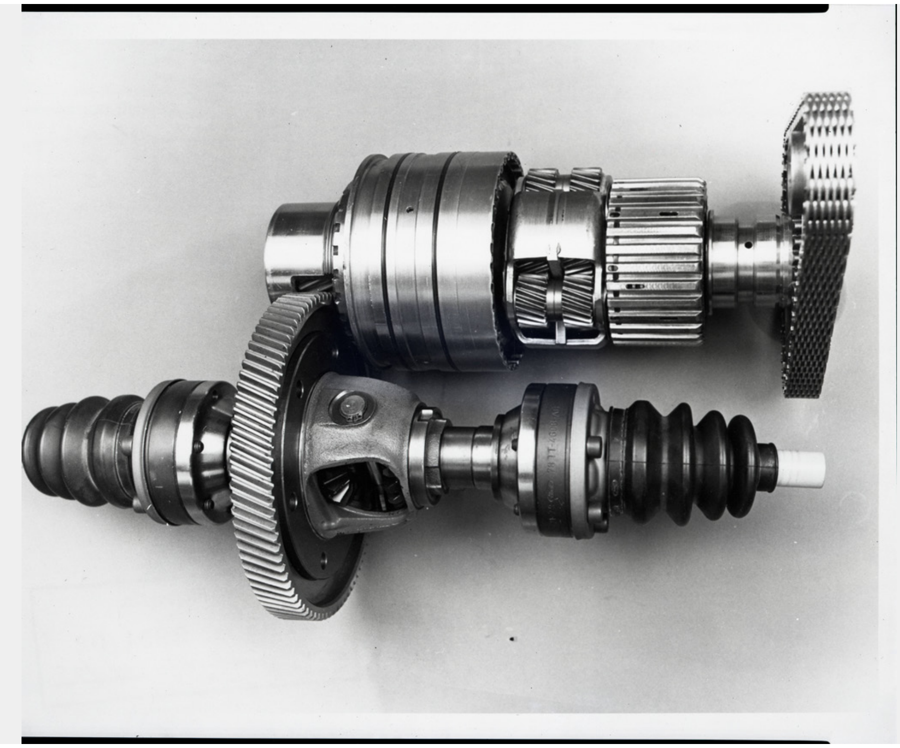
Today, electric vehicle (EV) technology is an exponentially growing sector with many opportunities for standardization. Specific to gears, areas of standardization may include gear noise, vibration, and harshness (NVH), gear designs for higher RPMs, or design considerations for regenerative braking—*just to name a few*. To keep within its traditional role as the facilitator-in-chief, AGMA is calling for a gathering of experts to begin discussions toward the possible development of standards in the EV space. We invite you to the table!

AGMA will host an EV Town Hall from 8:00–10:00 am on October 19 during the Motion + Power Technology Expo (MPT Expo) at the Detroit Convention Center on October 17–19, 2023. Attendance for this event is free and just requires registration through the MPT Expo website.

During the meeting, you will be introduced to the current leaders of AGMA and its Board. They will provide updates on our work in the EV space including education, events, emerging technology work, and other resources. Amir Aboutaleb, AGMA VP, Technical Division will outline current AGMA standards and information sheets that intersect with and are currently used in the EV space. Relevant design documents to be discussed include, ANSI/AGMA 6002-D20 which covers internal combustion vehicle spur and helical gears, ANSI/AGMA 6123-C16, Design Manual for Enclosed Epicycle Gear Drives, and ANSI/AGMA ISO 23509-B17, Bevel and Hypoid Gear Geometry. Also, of note are three published NVH documents that could be applied to EV gears, AGMA 914-B04, Gear Sound Manual, ANSI/AGMA 6000-C20, Specification for Measurement of Linear Vibration on Gear Units, and ANSI/AGMA 6025-E19 Sound for Enclosed Helical, Herringbone and Spiral Bevel Gear Drives. In addition to these, other documents with broad applications beyond EV, but which may have relevant sections, such as ANSI/AGMA 1010-F14 Appearance of Gear Teeth—Terminology of Wear and Failure will be discussed. Amir will outline the process for new standards development. He then will open the floor for attendees to share their thoughts on the industry's current state, including areas and topics where AGMA should consider developing standards or information sheets. All are welcome and encouraged to attend.

This discussion will provide us with the next steps for AGMA in the EV space. One outcome is the formation of a group—or multiple groups—to work on new standards. Another possibility is reviewing and updating current standards. We also may find the need for more education in this area as another outcome. Regardless, we are here to listen to your feedback and facilitate the next steps in response to industry needs. Come be part of this discussion to have your voice heard.

Register today at:
register.rcsreg.com/r2/mpt2023/ga/clear.html



Electric Vehicle Eaton Transaxle, NASA Technology, 1980.

Influence of Grain Size on Metallurgical Properties

Robert Errichello, Rainer Eckert, and Andrew Milburn

This report discusses grain size and its influence on metallurgical properties including its effect on yield strength, ultimate strength, fatigue strength, and fracture toughness. Also discussed are manufacturing issues such as heat treatment, hardenability, and machinability. Figures 1 through 4 in this report are from Ref. 1. For figure credits see Ref. 1.

	Austenitic Grain Size	
Property	**Fine**	**Coarse**
Hardenability	Lower	Higher
Hardening depth	Shallow	Deep
Retained austenite	Less	More
Distortion in quenching	Less	More
Depth of carburizing	Less	More
Risk of quench cracks	Less	More
Risk of grind cracks	Less	More
Residual stress	Lower	Higher
Embrittlement by cold working	Less	More
Hardness	Higher	Lower
Yield strength	Higher	Lower
Ultimate strength	Higher	Lower
Fatigue strength	Higher	Lower
Fracture toughness	Higher	Lower
Machinability after normalizing	Lower	Higher
Machinability after heat treat	Higher	Lower

Table 1—Influence of Grain Size on Metallurgical Properties.

Influence of Tensile Strength on Fracture Toughness

Figure 1 shows that fracture toughness decreases with increasing tensile strength and increasing sulfur content.

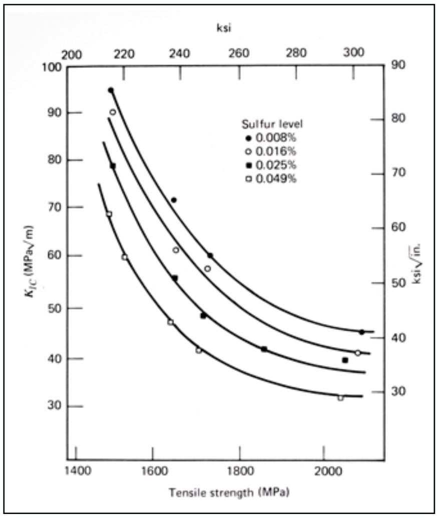


Figure 1—Influence of tensile strength and sulfur content on fracture toughness.

Influence of Grain Size on Tensile Strength and Fracture Toughness

Figure 2 shows that grain refinement represents a unique opportunity where steel may be both strengthened and toughened. This is a particularly attractive strengthening mechanism in view of the generally observed inverse relationship between strength and toughness as shown in Figure 1. Note that weldability and ductility are not adversely affected.

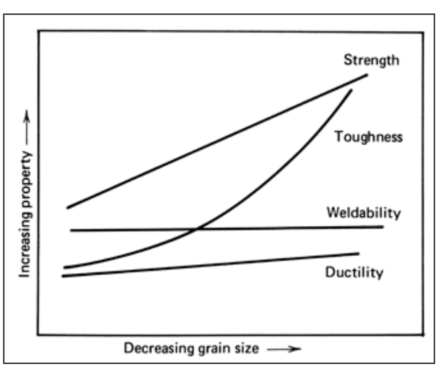


Figure 2—Improvement of tensile strength and toughness with decreasing grain size.

Influence of Grain Size on Yield Strength

Plastic deformation is caused by dislocations moving on a slip plane within a grain. The grain boundary acts as an obstacle to dislocation movement and a group of dislocations pile up at the grain boundary creating a back pressure (pile-up stress) that resists further dislocation movement. Because the grain boundary totally encompasses the slip plane of the dislocations, the dislocations within the grain cannot go around the obstacle as they could with a point obstacle. The stress required to force a dislocation across a grain boundary is so high that the probability of slip propagating from one grain to the next is remote. However, stress concentration at the tip of a slip band can be high enough to activate dislocation sources in the neighbor grain across the boundary. The magnitude of the stress concentration caused by the dislocation pile-up depends on the number of dislocations in the pile-up, which is a function of the length of the active slip plane; larger grains have larger slip planes and more dislocations in the pile-up. Therefore, larger grains lead to lower yield strength. In the case of irregular grain shapes, the longest dimension of the grain is the relevant grain size for yield strength.

Hall-Petch Relation

Small grains have greater ratios of surface area to volume, which means a greater ratio of grain boundary to the number of dislocations, and since grain boundaries impede dislocation movement, fine grains increase yield strength, which is expressed by the Hall-Petch relation (Refs. 2–3):

$$S_y = S_i + k_y d^{-1/2} \tag{1}$$

Where:

S_y = yield strength;
S_i = lattice resistance to dislocation movement;
k_y = dislocation locking term;
d = average grain diameter.

Influence of Grain Size on Fracture Strength

The fracture stress is related to grain size by Equation 2:

$$S_f = \frac{4G\gamma_m}{k_y} + d^{-1/2} \tag{2}$$

Where:

S_f = true fracture stress;
G = shear modulus;
γ_m = plastic work done around a crack as it moves through the crystal;
k_y = dislocation locking term from Hall-Petch relation Equation 1;
d = average grain diameter.

Figure 3 shows that the fracture stress S_f is more sensitive to grain size than the associated yield strength S_y. For grains smaller than ASTM E112 number 3, yielding occurs first and is followed by eventual fracture after a certain amount of plastic flow, the amount increasing with decreasing grain size. Since S_f and S_y are both temperature-sensitive properties, the critical grain size for the ductile-brittle fracture transition varies with temperature. See Figure 4 for more information.

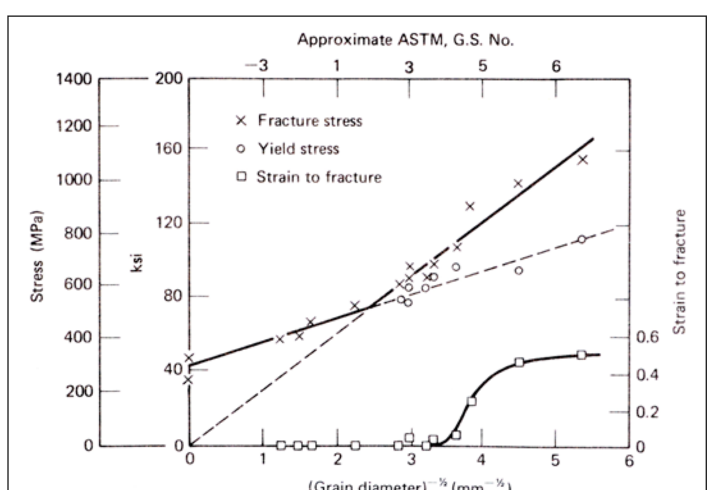


Figure 3—Yield and fracture strength, and fracture strain dependence on grain size in low carbon steel at -192 °C.

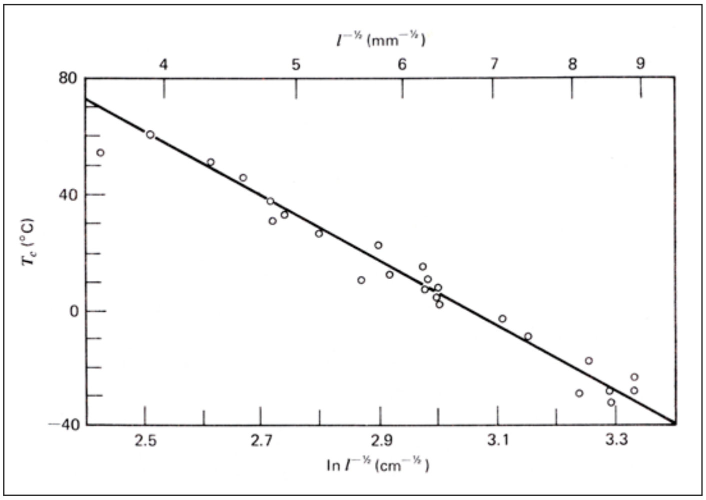


Figure 4—Dependence of ductile-brittle transition temperature on grain size.

Figure 4 shows the dependence of ductile-brittle transition temperature T_c on grain size. The ductile-brittle transition temperature decreases strongly with decreasing grain size (increasing ASTM grain size number).

Influence of Grain Size on Hardenability and Machinability

Very fine grain size reduces hardenability and consequently gives lower tooth core hardness and gives less case depth. Furthermore, very fine grain size reduces machinability. Depending on the steel alloy, grain size should be no finer than ASTM E112 number 9.

Summary of Influence of Grain Size

Small grain size increases yield strength and fracture strength (Figure 3). Small grain size also increases fatigue strength because fatigue strength is a function of yield strength. Furthermore, small grain size decreases the ductile-brittle transition temperature, which increases fracture toughness (Figure 4). On the other hand, very fine grain size (finer than ASTM E112 number 9) reduces hardenability and machinability.

Measuring Grain Size

ASTM E112 (Ref. 9) specifies standard test methods for estimating average grain size. There are three methods:

1. Standard series of graded chart images.
2. Planimetric method.
3. Intercept method.

The planimetric or Zay Jefferies method (Ref. 6) uses a test circle superimposed over the microstructure. All the grains that are completely inside the test circle are counted, plus all the grains that are intercepted by the circle. It is assumed that, on average, half of the intercepted grains are inside the test circle and half are outside. The number of grains per square millimeter N_A and grain size G are calculated from:

$$N_A = f\left(N_{inside} + \frac{N_{intercepted}}{2}\right)$$

$$f = Jeffries' \ multiplier$$
(from ASTM E112 Table 5)

$$G = 3.31928 \log N_A - 2.954$$

The Heyn lineal intercept method (Ref. 7) was suggested by Heyn in 1903 and revised by Halle Abrams in 1974. It uses a three-concentric circle test grid superimposed over the microstructure. The grain boundary intersections are counted, and the count is divided by the true line length, which is the line length divided by magnification. This yields the number of intersections per unit length. The reciprocal of the intersections is the lineal length L3. The average grain size is given by the equation:

$$G = (-6.6457 \log L3) - 3.298$$

Failure Mode Relevant Grain Size and Critical Area

The use of the mean (average) grain size is difficult to justify, since yield, fatigue, and fracture are "weakest link" phenomena that are controlled by the largest grain size (Ref. 4). Furthermore, the location of the critical largest grain is dependent on the failure mode. For example, the critical areas for each failure mode of gear teeth are:

Failure mode	Critical area
Macropitting	On the tooth flank at the lowest point of single tooth contact (LPSTC) at a depth of the maximum shear stress.
Subcase fatigue	On the tooth flank at the LPSTC at a depth of 2.5 times the effective case depth.
Bending fatigue	On the surface of the tooth root at the 30-degree tangent to the root fillet.
Subsurface initiated bending fatigue	On the tooth flank near mid-height of the tooth usually at the depth of a nonmetallic inclusion.
Tooth interior fatigue fracture (TIFF)	On the tooth flank near mid-height of the tooth and on a flat plateau at a depth near the case/core boundary.
Case/core separation	Below the top land at a depth near the case/core boundary.

Table 2—Location of critical area versus failure mode.

Controlling Grain Size

For optimal properties, it is essential that the grain size of carburized and hardened components is both uniform and fine (Ref. 5). Grain refinement is accomplished by adding certain elements, for example, aluminum or vanadium to the molten steel in the ladle after a thorough deoxidation treatment, usually with silicon. Additions of aluminum, vanadium, or both, encourage the formation of compounds, for example, aluminum nitride AlN or vanadium carbide V_4C_3 that, because of their extreme fineness and relative stability can mechanically restrain grain boundary movement during subsequent austenitizing heat treatments. A normalize heat treatment, or a normalize, quench, and temper treatment, before carburizing favors an initially uniform and small grain size. The duration of the austenitizing treatment is important, for example, steel with 0.020 percent Al was fine grained (ASTM 7) when austenitized at 927 °C for one hour, whereas at 10 hours at the same temperature the average grain size increased to about ASTM 3 (see Figure 5.3b in Ref. 5). Grain size is influenced by the chemical composition, mechanical and thermal history, and the carburizing temperature. Re-heat quenching from near the Accm temperature favors a fine-grain structure.

Increasing the temperature at which low-pressure carburizing is performed runs the risk of abnormal grain growth (Ref. 8). Steels that contain aluminum and nitrogen with aluminum to nitrogen ratio of Al/N > 2.1, and preferably 2.2, have AlN particles that pin the grain boundaries and prevent or minimize grain growth during austenitizing (Ref. 8). The optimal Al/N ratio depends on the specific steel alloy, forging reduction ratio, cold working prior to heat treatment, heat treatment prior to carburizing, heat treatment during carburizing, and method of quenching and tempering. However, Al and N can have harmful effects when added excessively, Therefore, the optimal Al/N ratio can range from 2.0 to 3.5 depending on the variables listed, and it is best to experimentally determine the optimal Al/N ratio for the actual conditions.

Subcase Fatigue Caused by Large Grain Size

Figure 5 shows a large grain size that was located below the case/core boundary, which was the root cause of a subcase fatigue failure of a carburized gear. The depth of the cracks was 2.5 times the effective case depth. The grain size of the largest grain was ASTM 2. However, the longest length within the grain was about 250 µm, which was probably the length of the longest slip plane and was associated with high-stress concentration due to a dislocation pile-up; that is, the weakest link. Note that the next largest grain corresponds to ASTM 3 grain size.

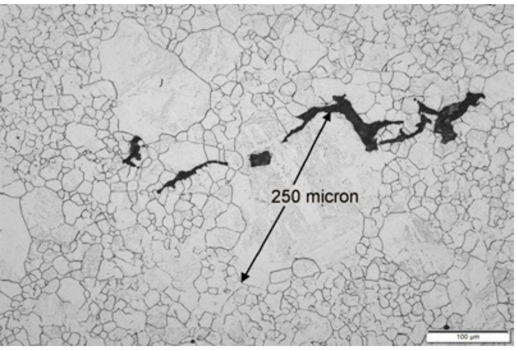


Figure 5—Large grain size below case/core boundary.

Conclusions

1. Grain refinement represents a unique opportunity where steel may be both strengthened and toughened.
2. Small grain size increases yield strength, ultimate strength, fatigue strength, and fracture toughness.
3. Yield, ultimate, fatigue, and fracture strength are "weakest link" phenomena that are controlled by the largest grain size in a critical area of the gear tooth.
4. The location of the critical largest grain is dependent on the failure mode.
5. To maintain hardenability and machinability, the grain size should be no finer than ASTM E112 number 9.
6. Steels that contain aluminum and nitrogen with aluminum to nitrogen ratio of Al/N = 2.0 to 3.5 have AlN particles that pin the grain boundaries and prevent or minimize grain growth during austenitizing.

Recommendations

1. AGMA 923 grain size specification should be 90% of the grains ASTM E112 number 5-8 and no grain larger than ASTM E112 number 3 and no grain smaller than ASTM E112 number 9.
2. Metallographic inspection of grain size should be performed at all critical areas on a representative coupon of a gear tooth.
3. For failure analyses, the metallographic inspection should be performed at the crack initiation point.
4. The optimal Al/N ratio can range from 2.0 to 3.5 depending forging, cold working, and heat treatment, and it is best to experimentally determine the optimal Al/N ratio for the actual conditions.

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Robert Errichello heads a gear consultancy called GEARTECH, is a member of several AGMA Committees, and is a technical editor for *Gear Technology.* Errichello is a recipient of a variety of honors including the AGMA Lifetime Achievement Award, the STLE Wilbur Deutch Memorial Award, and the AWEA Technical Achievement Award.

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Andrew Milburn is currently president of Milburn Engineering, Inc., a consulting firm located near Tacoma, Washington and has 45 years' experience in the design and analysis of gears and gearboxes. As a consultant he has investigated numerous gear and bearing failures, and helped clients improve their gear products.

Enhanced Calculation Method for Tooth Flank Fracture Risk with Consideration of Tensile Residual Stresses in Larger Material Depths

Daniel Müller, Thomas Tobie and
Karsten Stahl

Introduction and Motivation

Residual stresses are a major influencing factor on the load-carrying capacity of case-carburized gears. For the gear failure modes, tooth root breakage, and pitting, a significant improvement of the load-carrying capacity is possible with higher compressive residual stresses. The crack initiation for tooth root breakage at the surface of the tooth root fillet can even be prevented with shot peening. In these gears, the crack initiation is shifted to the material depth. The gear fatigue failure mode tooth flank fracture (TFF) is usually initiated in a larger material depth, where higher compressive residual stresses are not present anymore or are possibly tensile. It is very likely that the residual stresses have a similar effect on the TFF strength as for pitting and bending strength. However, neither the residual stresses in this larger depth are known yet, nor the effects of them on the TFF load carrying capacity. For these reasons, the tensile residual stresses have not yet been considered in the calculation of tooth flank fracture load capacity according to ISO/TS 6336-4.

This paper deals with the residual stress depth profiles in case-carburized gears, their effects on the fatigue behavior as well as the enhancement of ISO/TS 6336-4 to include the consideration of tensile residual stresses in the tooth core area. For this purpose, an equation is also presented with which these tensile residual stresses can be estimated so that they can be used in the enhanced evaluation of TFF risk.

Nomenclature

Parameters

ρ_{rel}	radius of relative curvature	mm
A_{FF}	material exposure according to ISO/TS 6336-4	
A_{max}	maximal material exposure in larger depth ($y \geq b_H$) according to ISO/TS 6336-4	
b_H	half of the Hertzian contact width	mm
CHD	case hardening depth at 550 HV	mm
M	mean stress sensitivity	
M_{RS}	residual stresses sensitivity	
p_H	Hertzian pressure	MPa
R	stress ratio	
y	material depth at the flank	mm

Used Abbreviations

CHD	Case hardening depth
FVA	Forschungsvereinigung Antriebstechnik (German Drivetrain Research Association)
HV	Vickers hardness
ISO	International Organization for Standardization
RS	Residual Stresses
TFF	Tooth flank fracture
TS	Technical specification

State of the Art

Failure Mode Tooth Flank Fracture

Tooth flank fracture (TFF) is a gear fatigue failure mode with subsurface crack initiation. The crack characteristic is shown in Figure 1 (left). The breakage of the tooth, which consequently leads to the failure of the gear stage, occurs usually after several million load cycles. The crack initiation is mainly caused by the contact stresses, which can be described by the Hertzian theory. Hereby the maximal shear stress is placed in deeper material depth for larger relative radii of curvature. In addition, material conditions favor crack initiation at larger depths. In the near-surface region, the higher hardness and the compressive residual stresses prevent the formation of cracks, see Figure 1 (right), whereas in larger depths the hardness is decreased, and less compressive residual stresses are obtained. Consequently, the crack is initiated where the load-bearing capacity is reduced but the contact stresses are still sufficient to initiate the failure. Crack initiation can also be significantly promoted by inhomogeneities, defects, or non-metallic inclusions in the material.

Residual Stresses in a Larger Depth of Case-Carburized Gears

Neutron and X-Ray Diffraction Measurement in Larger Material Depth

Residual stresses can be reliably measured with various methods in the near-surface region down to a limited component depth (Ref. 9). Reliable residual stress measurements at larger component depths are currently only possible with complex and expensive measurement methods, such as e. g. neutron diffraction. There are only a few neutron beam measurements of case-carburized parts or especially gears known.

In Tobie or Witzig (Refs. 2–3) the residual stresses in the cross-section of a module 8 mm gear for two different case hardening depths are published. The measurements show tensile residual stresses up to approximately 150 N/mm² in the core of the tooth. For the larger CHD the transition from compressive to tensile residual stresses is in larger material depth. Other measurement results also generally show tensile residual stresses in the core of case-hardened gear teeth (Ref. 4).

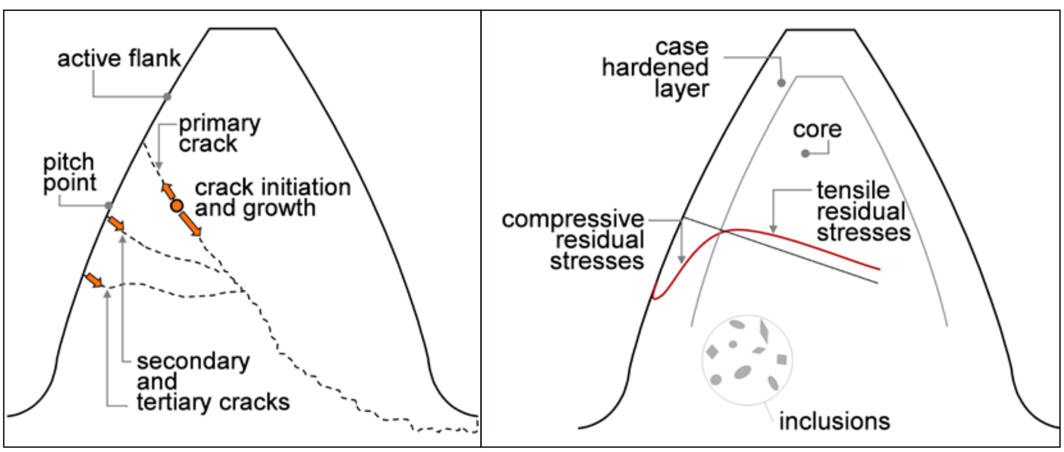

Figure 1—Schematic representation of a characteristic tooth flank fracture (left) and influencing factors depending on component material (right) (Ref. 1).

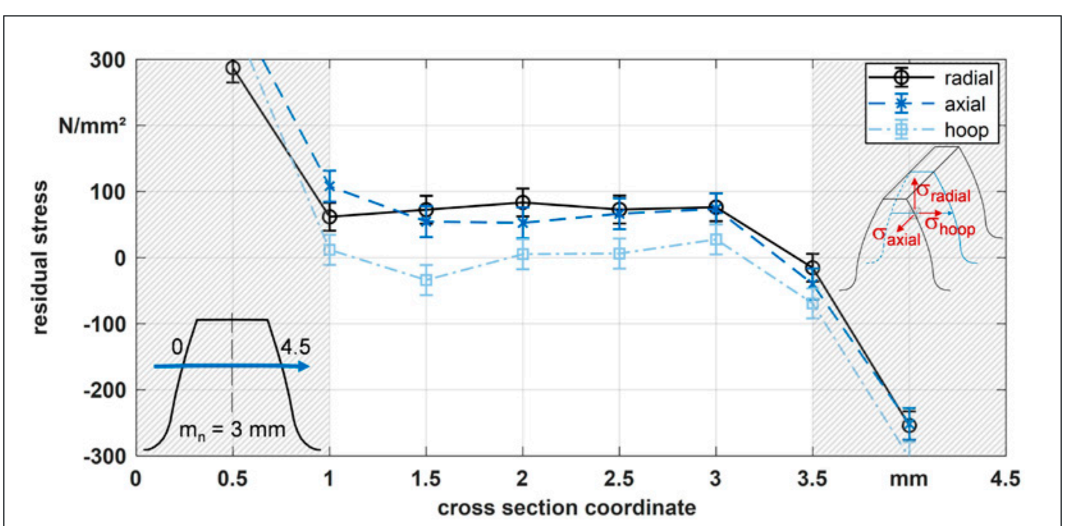

Figure 2—Measured residual stresses in a case-carburized gear of m_n = 3 mm with neutron diffraction (Ref. 5).

In Schwienbacher (Ref. 5), the module 3 mm gear (z_1 / z_2 = 67/69), which preferentially fails due to flank breakage was also measured at the cross section of a tooth. The measured residual stresses are shown in Figure 2. Tensile residual stresses in the core area are also evident here. The axial and radial stresses are between 50 N/mm² and 100 N/mm², whereas the stresses in the direction of the cross-section are near zero. The first and last measured values (in the marked area) can be neglected (Ref. 5).

By X-ray measurements, residual stresses can be reliably determined up to a component depth of approx. 0.3–0.5 mm. A residual stress depth profile is determined by material layer removal (etching) and measuring the surface residual stresses. For X-ray measurements at larger component depths, the influence of this layer removal on the residual stress state must be considered. Various proposals exist for this correction of the measured residual

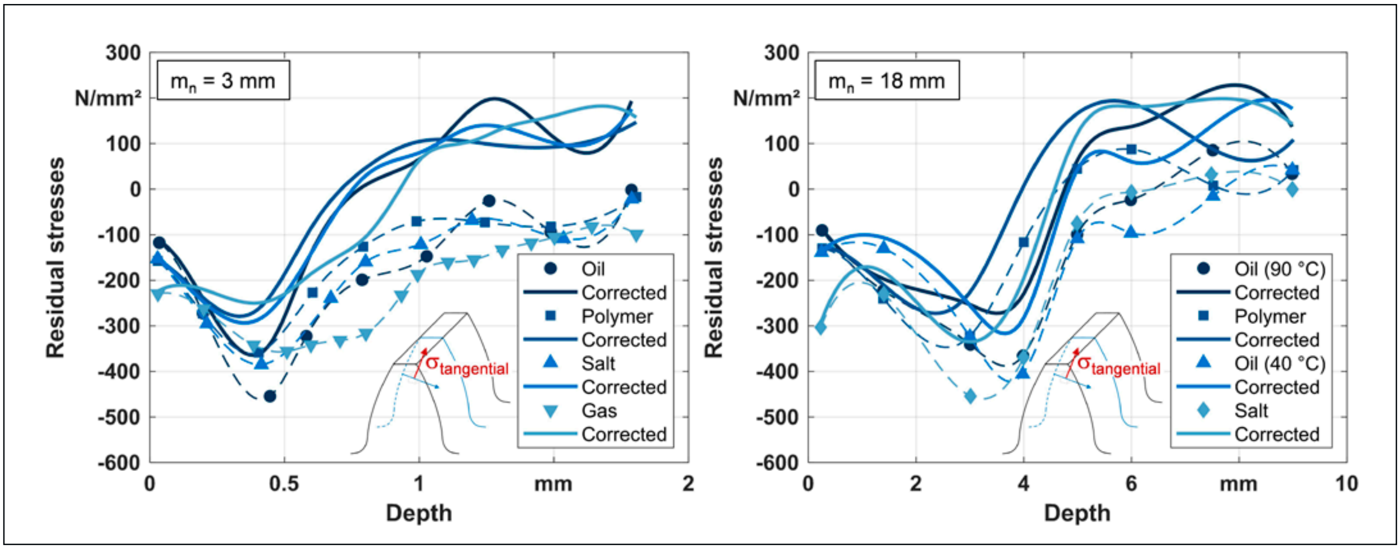

Figure 3—Measured and corrected residual stresses in case-carburized gears of m_n = 3 mm, CHD ≈ 0.5 mm (left) and m_n = 18 mm, CHD ≈ 3 mm (right) with X-ray diffraction (Ref. 10).

stresses, which have not yet been fully validated for residual stress measurements in case-hardened gears. Besides FE methods, the correction theory of Ref. 6 is the most widely used. This method was used on gears, for example, in Refs. 7–9.

In FVA 835 (Ref. 10), X-ray measurements of different-sized gears (m_n = 3 mm and 18 mm) were carried out by the Leibniz Institute for Material-Oriented Technologies—IWT in Bremen. The case carburizing process differs in each case in the quenching medium (Oil at 90°C and 40°C), Polymer and Saltwater). All measurements show tensile residual stresses of approx. 100–200 N/mm² in depths larger than 2 CHD. The measured and corrected (correction of Moore and Evans [Ref. 6]) profiles are shown in Figure 3.

Calculation Approaches for Residual Stresses in Case-Carburized Gears

To date, only a few equations exist to estimate residual stress depth profiles. The residual stress depth profile is mostly derived from the hardness depth profile according to Lang (Ref. 11).This calculation approach shows good agreement with measured values for the compressive residual stresses near the surface and is used in the standard calculation methods of ISO 6336. The calculation of the residual stress depth profile from the hardness depth profile is comparatively simple and can also be performed with only the heat treatment parameters: surface hardness, core hardness and CHD. In this case, the hardness depth profile must first be measured or calculated, e.g., according to Lang, from the above-mentioned parameters. However, the hardness and residual stresses are decisive influencing variables in the TFF risk calculation and in some cases, it is disadvantageous to calculate the residual stresses from the hardness, since differences in hardness that are not significant from a measurement point of view can cause significant changes in the calculated risk of TFF.

The tensile residual stresses inside the tooth are not considered by the approach of Lang (Ref. 11). According to Lang, the tensile residual stresses are negligible for sufficiently large core cross-sections. However, in the case of small core cross sections (with a large case hardening depth, slender teeth, or near the tooth tip), significant tensile residual stresses may be present in the core area based on the presumed mechanical stress equilibrium. For case-hardened gears, extensions to Lang's calculation approach have therefore already been proposed, in which the actual tensile residual stresses in the tooth core are considered.

Residual stress depth profiles with tensile residual stresses inside the tooth can be calculated, for example, according to Weber (Ref. 9), Konowalczyk (Ref. 12), or Böhme (Ref. 13). The principle of this calculation is shown schematically in Figure 4. Most calculation approaches are based on the compressive residual stresses calculated with the approach of Lang up to a certain depth (mostly 0.5 CHD) but show in part significant differences in their iteratively calculated tensile

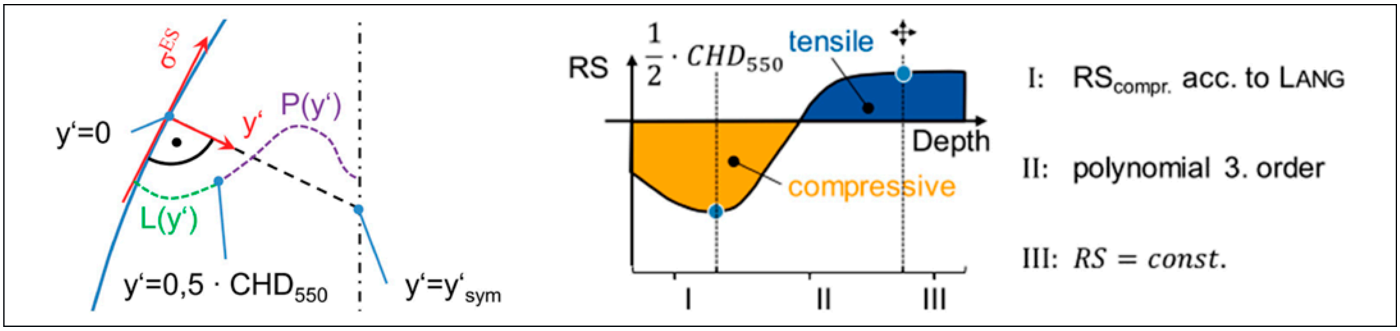

Figure 4—Schematic representation of calculation approaches with consideration of tensile residual stresses (left: Weber [Ref. 9]; right: Konowalczyk [Ref. 12]).

residual stresses based on a mechanical equilibrium. In addition, these approaches are not sufficiently verified. However, the authors address the problem of the unknown tensile residual stresses in the core of a case-carburized tooth.

Influence of Residual Stresses on Fatigue Strength

Compressive residual stresses have a significant positive influence on the fatigue limit. For case-hardened gears, this influence is investigated in various research projects regarding pitting damage (Refs. 12, 14–15) or tooth root breakage (Refs. 16–20). With shot peening (and other additional treatments), high compressive residual stresses can be induced up to a certain depth. For reference-sized shot-peened gears, the increase of permissible torque is often stated as approximately up to 50 percent compared to the unpeened variant (Refs. 19, 21). The influence of tensile residual stresses on the load-carrying capacity is less researched except in the context of the influence of grinding burn (Ref. 22), which causes tensile residual stresses in the near-surface region. However, it is generally assumed that tensile residual stresses lower the fatigue limit (Ref. 23).

The influence of the residual stresses on the fatigue limit strongly depends on the material (tensile) strength. In [24] is stated that residual stresses have a greater effect on the fatigue limit in higher-strength steels than in steels of medium tensile strength. In material conditions with low strength, the influence of residual stresses can be negligibly small [24]. Each increase of static strength increases the sensitivity to mean stress (Ref. 25). This effect is quantified by the residual-stresses sensitivity and can differ from the mean stress sensitivity according to Ref. 24 (compare Figure 5 [right]). For the influence of residual stresses, Macherauch and Wohlfahrt (Ref. 24) propose a residual-stresses sensitivity that depends on the tensile strength of the material. They do not assume vibration-stable residual stresses but consider a reduction of residual stresses by replasticization (Ref. 26).

In Fig. 5, the residual stress sensitivity and the mean stress sensitivity according to Ref. 24 are shown. The residual stress sensitivity describes the influence of residual stresses on fatigue strength in the same way that the mean stress sensitivity describes the influence of mean stresses on the alternating fatigue limit (see Haigh Diagram or Goodman diagram). Higher values indicate a greater effect. It should be noted that the relationship in Fig. 5 was determined for axial oscillating load. In the experimental determination of the sensitivity of the residual stress, too-low values can be measured due to the reduction of the residual stresses. If it is assumed that the residual stresses are stable and act like local mean stresses and that the local alternating strength is directly influenced only by the local residual stresses, then according to Winderlich (Ref. 25) the local residual stress sensitivity should not differ from the local mean stress sensitivity. Also, according to Bomas (Ref. 27), for example, stable residual stresses can be equated to mean stresses in their effect. According to Refs. 28–29 the mean stress sensitivity can be even higher for case-hardened steels under torsional loading e.g., M = 0.7 for Rm = 1,000 MPa.

Various equations exist for calculating the mean stress sensitivity from the tensile strength as plotted in Fig. 5. The mean stress sensitivity can also be described from the ratio of the alternating strength and the oscillating strength. According to Liu and Zenner (Ref. 31), the mean stress sensitivity for smooth specimens under multiaxial loading can be calculated according to Equation 1.

$$\beta = \frac{2\sigma_w}{\sigma_{sch}} - 1 \quad (1)$$

where

- β is the mean stress sensitivity acc. to Liu and Zenner (Ref. 31);
- σ_w is the normal stress fatigue limit for completely reversed loading (R = -1);
- σ_{sch} is the fatigue limit for oscillating loading (R = 0).

According to Dang Van (Ref. 32), the mean stress sensitivity depends on the ratio of the shear fatigue strength and the tension-compression fatigue strength:

$$M_\sigma = 1 - \frac{1}{2}\frac{\sigma_w}{\tau_w} \quad (2)$$

where

- M_σ is the mean stress sensitivity for normal stresses;
- σ_w is the normal stress fatigue limit for completely reversed loading;
- τ_w is the shear stress fatigue limit for completely reversed loading.

In addition, the mean stress sensitivity depends on the type of stress. In the Haigh diagram, the mean stress sensitivity for the effect of normal stresses also depends on the stress ratio R (Ref. 33) and for shear stresses, the influence of mean stresses

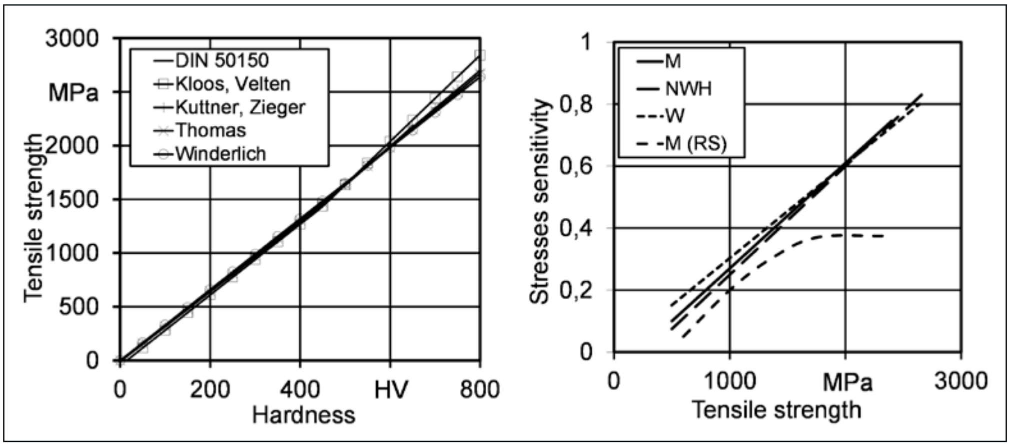

Figure 5—Relationship between hardness and tensile strength: DIN 50150; Kloos, Velten; Kuttner, Ziegler; Thomas; Winderlich (left). Relationship between tensile strength and mean stress sensitivity: Macherauch (M); Niemann, Winter, Höhn (NWH); Winderlich(W); Macherauch for residual stresses (M); (right). According to Ref. 30.

is lower according to the FKM guideline (Ref. 34). The mean stress sensitivity for shear stresses is reduced by the ratio of the fatigue strength for shear and tension-compression after Equation 3 (Ref. 35).

$$M_\tau = \frac{\tau_w}{\sigma_w} M_\sigma \tag{3}$$

where

M_τ is the mean stress sensitivity for shear stresses.

Conclusion: Various empirical equations have already been proposed for calculating stress sensitivity. However, the various influencing factors make it difficult to determine the stress sensitivity in experiments. For the complex stress state in the volume beneath the flank contact the influence of residual stresses is not known in detail to the author and probably impossible to determine exactly experimentally.

In summary, it can be stated that the following applies to the most commonly used methods or equations:

- The stresses sensitivity is in the range between 0 and 1.
- The material strength influences the stresses sensitivity. Higher stresses sensitivities are specified for higher-strength materials.
- The stresses sensitivity depends on the existing stress condition.

The mean stress sensitivities determined experimentally or calculated using various approaches (for a comparable strength) are similar for simple stress conditions.

A local residual stresses sensitivity is required for the TFF risk evaluation, since the stress state and the strength change with increasing material depth. A residual stresses sensitivity for flank fracture evaluation is not known. Therefore, it is assumed that:

- The residual stresses are oscillatory stable and act like local mean stresses.
- The residual stresses sensitivity for the multiaxial loading condition over the entire component depth is comparable to the residual stresses' sensitivity for axial tension/compression loading.

Calculation of the Risk of TFF

Higher Order Calculation Model

The higher order calculation model was developed at the author's institute about 40 years ago and has been continuously refined and enhanced. In the following, the basic concept of the model is described. Further descriptions of the model can be found in Refs. 2 and 36.

The higher-order model represents the rolling contact. In a stationary coordinate system, normal and shear stresses are calculated according to Föppl (Ref. 37). The occurring rotation of the principal stress axis system results in a change of the direction of the maximum shear stresses depending on the surface load relative to the considered volume element. After determining the individual components of the contact stresses and the (compressive) residual stresses, these are superimposed and the total stress components σ_x, σ_y, σ_z and τ_{xy} are obtained for each volume element over the material depth of each considered contact point.

The residual stress depth profile of tangential residual stresses is used as an input. The residual stresses in the axial direction are then calculated from the tangential residual stresses. When evaluating the TFF risk with the higher-order model, all residual stresses of the stress tensor can be taken into account. If the residual stresses normal to the flank are negligibly small, the axial residual stresses are calculated by default using the Poisson's ratio $\nu = 0.3$ according to Equation 4. The axial and tangential residual stresses correspond to the principal residual stresses of the plane strain state. This simplification is permissible due to the lower influence of the axial residual stresses.

$$\sigma_{RS_{axial}} = \sigma_{RS_{tangential}} - \nu \cdot \sigma_{RS_{tangential}} \tag{4}$$

where

$\sigma_{RS_{axial}}$ is the residual stress in axial direction;
$\sigma_{RS_{tangential}}$ is the residual stress in tangential direction;
ν is the Poisson's ratio.

The choice of the equivalent stress hypothesis plays an important role in the calculation of the decisive stress. For the stress states resulting from rolling contact, the shear stress intensity hypothesis (SIH) acc. to Ref. 38 is a suitable and proven hypothesis. Equivalent stress hypotheses such as the octahedral shear stress hypothesis and the von Mises yield criterion are special cases of the SIH and are only conditionally suitable for complex multiaxial stress states with a rotating principal stress axis system. Other equivalent stress hypotheses can be found in the literature, such as the hypothesis according to Dang Van (Ref. 39).

According to Liu (Ref. 40), the SIH provides generally better accuracy in predicting the fatigue strength under multiaxial loading for all loading cases. This stress hypothesis of the integral strain, as well as the hypothesis of the critical plane can be derived from the Weakest-Link model. In the SIH, all section planes are considered and thus the requirement of invariance from the body-fixed coordinate system and the principal stress system is fulfilled. The decisive advantage is the accuracy for equal-frequency, frequency-differentiated and arbitrarily periodically oscillating stresses. Thus, for example, the consideration of a downstream stress state due to tooth deformation is made possible.

The shear stress intensity τ_{eff} is obtained by integrating the shear stresses $\tau_{\gamma\alpha}$ of the individual section planes over the spherical volume element with Equation 5. According to Oster (Ref. 41), the root mean square of the maximum stresses of all section planes is used. In this integral stress hypothesis, the stresses in all sectional planes on the spherical volume element are considered to be collectively relevant to damage (Ref. 31).

$$\tau_{eff} = \sqrt{\frac{1}{4\pi} \int_{\gamma=0}^{\pi} \int_{\alpha=0}^{2\pi} \tau^2_{\gamma\alpha,max} \sin\gamma \, d\alpha \, d\gamma} \tag{5}$$

where

τ_{eff} is the effective shear stress;
$\tau_{\gamma\alpha,max}$ is the maximal shear stress in all planes;
α, γ are the polar coordinates for the spherical volume element in a certain depth beneath the flank.

In the variant of SIH used, mean stresses or residual stresses are not directly considered. However, the effective shear stress, calculated from the residual stresses present, is subtracted from the effective shear stress, calculated from the load and residual stress condition. This double amplitude $\tau_{eff\ DA}$ is calculated according to Equation 6 and is to be understood as the alternating stress (stress amplitude).

$$\tau_{eff\ DA} = \tau_{eff\ Load,\ RS} - \tau_{eff\ RS} \tag{6}$$

where

$\tau_{eff\ DA}$ is the local equivalent stress (double amplitude);
$\tau_{eff\ Load,\ RS}$ is the local equivalent stress of load and residual stresses (upper total stress state);
$\tau_{eff\ RS}$ is the local equivalent residual stress (lower total stress state).

The effective shear stress (double amplitude) calculated in this way, is then compared with an allowable shear stress. The allowable shear stress is proportional to the hardness. The empirical proportionality factor is composed of the factor for converting the hardness profile into a shear strength profile and the factor for considering the material. The hardness conversion factor was chosen empirically especially for the calculation of TFF risk. Thus, the local shear strength is derived from the local hardness according to Equation 7.

$$\tau_{per}(y) = K_{\tau_{per}} \cdot K_{material} \cdot HV(y) \tag{7}$$

where

τ_{per} is the local material shear strength;
$K_{\tau_{per}}$ is the hardness conversion factor;
$K_{material}$ is the material factor;
HV is the local Vickers hardness.

Practical Calculation Approach (of ISO/TS 6336-4)

Witzig (Ref. 3) has developed a standard-compliant, practice-oriented and non-iterative calculation approach for determining the risk of TFF for case-hardened cylindrical gears as part of the project FVA 556 I "Flank load capacity in larger material depth" (Ref. 42). This practical calculation approach is derived from the higher-order model for calculating the TFF risk. The simplified method has the advantage of numerous simplifications in the calculation equations, which ultimately allow a closed-form solution and thus enable industrial application. Both methods show comparable material exposure depth profiles especially in larger material depth ($y \geq b_H$). The practice-oriented calculation approach according to Witzig that is also the basis of ISO/TS 6336 4 was validated with the aid of the higher-order model with several million calculations. Overall, the results showed very good agreement for material depths $y > 1 \ldots 9 \cdot b_H$ and within the following application limits:

- 500 N/mm² $\leq p_H \leq$ 3000 N/mm²
- 5 mm $\leq \rho_{rel} \leq$ 150 mm
- 0.3 mm $\leq$ CHD $\leq$ 4.5 mm

Both methods are also calibrated by load carrying tests in test rigs and recalculations of failures and non-failures in different applications

The loading input variable represents the local Hertzian pressure to consider influences from flank corrections, shaft deformation, bearing stiffnesses and can be calculated using a suitable load distribution program, e.g., RIKOR (Ref. 43) or the equations in ISO 6336-4.

The material exposure AFF results from the comparison of the effective shear stress with a shear strength τ_{per}. In Eq. 8, the effective shear stress is composed of the total stress state $\tau_{eff,L,pA}$, the influence of residual stresses on the total stress state $\tau_{eff,L,RS,stat.,pA}(y)$ and the residual stress state $\tau_{eff,RS,pA}(y)$. In the calculations of the effective stresses only compressive residual stresses can be considered. The consideration of tensile residual stresses is not yet possible with this calculation approach.

$$A_{FF}(y) = \frac{\tau_{eff,L}(y) - \Delta\tau_{eff,L,RS}(y) - \tau_{eff,RS}(y)}{\tau_{per}(y)} \tag{8}$$

where

A_{FF} is the material exposure;
$\tau_{eff,\ L}$ is the effective shear stress is composed of the total stress state without residual stresses;
$\Delta\tau_{eff,\ L,\ RS}$ is influence of residual stresses on the total stress state;
$\tau_{eff,\ RS}$ is the residual stress state;
τ_{per} is the local material shear strength.

The shear strength is derived from the hardness depth profile, taking into account empirical factors in accordance with the higher-order model according to Equation 7.

The practice-oriented calculation approach according to Witzig was transferred with some minor changes into the technical specification ISO/TS 6336-4. This technical specification contains some guidance for the practical application of the calculation method. For example, procedures for estimating the hardness depth profile according to Lang (Ref. 11) and for estimating the residual stress depth profile (Ref. 44) are mentioned.

The result of the calculation, the material exposure depth profile $A_{FF}(y)$ indicates the risk of a subsurface failure. In reference fatigue tests with test gears, the fatigue limit for 50 percent failure probability regarding TFF correlates reproducibly with values of the maximum material exposure in larger material depth of $A_{FF,\ max} \approx 0.8$. However, due to further influencing factors for TFF risk in applications, such as variable torque, overloads, a significantly lower failure probability, size effects or longer lifetimes than previously investigated, the maximum allowable material exposure is lower. Further information and notes on the use of the ISO/TS 6336-4 and the interpretation of a material exposure depth profile can be found in Ref. 45.

Aim of the Investigation

From the state of the art, it is clear there are tensile residual stresses present in the core of a case carburized gear. So far, these tensile residual stresses are not considered in the calculation of TFF risk. It is also known that compressive and consequently possibly tensile residual stresses have a major influence on fatigue strength. In experimental investigations of tooth root breakage high compressive residual stresses lead to improvement of up to 50 percent in applicable torque. For the failure mode TFF a more complex stress condition is present beneath the flank. For this complex stress state there are various proposals of multiaxial fatigue criteria and on how to consider the residual stresses in them. But so far, the residual stresses in larger depth cannot be predicted with any certainty, which makes the evaluation of fatigue criteria for TFF even more difficult.

The aim of this work is first to predict residual stress depth profiles with tensile residual stresses present in the core of case carburized gears and second to consider the tensile residual stresses in the higher order calculation model of the TFF risk within the SIH and subsequent for the practical calculation approach of ISO 6336-4. This leads to an enhanced calculation method, that improves the current method and opens up new calculation possibilities.

Estimation of Residual Stresses in Case-Carburized Gears

In FVA 835 (Ref. 10), a simulation model for the residual stresses formation in the case carburizing process was built by the Chair and Institute for Materials Applications in Mechanical Engineering—IWM at RWTH Aachen University. The model is based on extensive simulative as well as experimental research. To characterize the material behavior of 18CrNiMo7-6 (1.6587), investigations with dilatometer specimens were carried out. These include the determination of flow behavior, transformation kinetics, transformation strains and thermal strains, quenching and tempering behavior. These properties were determined for samples with carbon contents between 0.18 and 0.82 mass percent carbon as a function of the relevant microstructural compositions and thermal conditions. The simulation model was validated with residual stresses measurements of module 3 mm and module 18 mm gears.

With this simulation model the residual stresses were simulated in different gear geometries for several CHDs. In addition, the influence of the carbon content depth profile and the quenching medium were simulated. Based on the simulated residual stresses a practical approach for the calculation of residual stress depth profiles in larger material depth was developed.

First, characteristic points of the simulated residual stress depth profile were defined. These characteristic points can be described by the component depth and the residual stress value. Figure 6 shows an example of the characteristic points for a simulated residual stress depth profile. The residual compressive stresses at the component surface are described by σ_0. Since several simulations showed a compressive residual stress maximum below the surface, an additional characteristic point was defined here. The pressure maximum is described by a residual compressive stress σ_D at a component depth y_D. These points near the surface are not directly relevant for the TFF evaluation, since the crack origin is located at a larger depth. However, using these points showed a higher agreement to the simulated residual stress depth profile in the region between compressive maximum and compressive to tensile residual stress transition. The transition from compressive to tensile residual stresses, where the residual stresses are zero, is described by y_{DZ}. The tensile residual stresses inside the tooth are described by σ_Z, which indicates the maximum tensile residual stresses inside the tooth. The position of the maximum tensile residual stresses is usually in the center of the tooth.

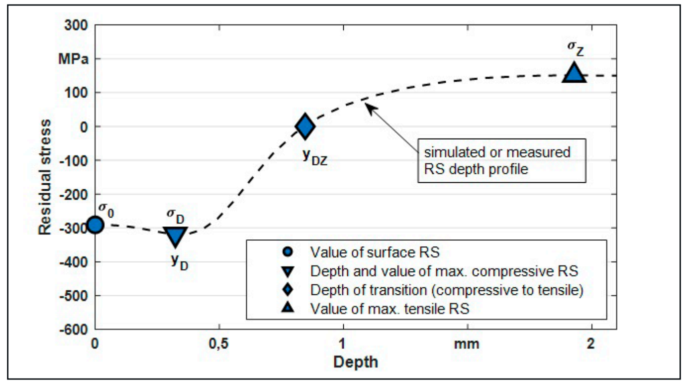

Figure 6—Chosen characteristic points for the description of a simulated residual stress depth profile.

With the characteristic points, the depth profile of the tangential residual stresses can be easily calculated over the component depth y. A logistic function was adapted in such a way that the characteristic points can be inserted directly or via the parameters α, δ, k. The adjusted equation is given by Equation 9.

$$\sigma_{RS,\tan}(y,\alpha,k,\delta,\sigma_z) = \alpha + \frac{\sigma_z - \alpha}{1 + e^{-k(y+\delta)}} \tag{9}$$

where

$\sigma_{RS,tan}$ is the tangential residual stress at the depth y;
σ_Z is the tensile residual stress in the tooth core;
α,k,δ are parameters of the equation that are calculated.

The depth y is given in millimeters and the residual stress in N/mm². The parameter α defines the compressive residual stresses at the surface. If the maximum residual compressive stress is directly at the surface, the following applies:

$$\alpha(\sigma_D) = \sigma_D \tag{10}$$

where

σ_D is the maximal compressive residual stress near the surface.

For a compressive residual stress maximum below the surface, it is suggested to use the average of σ_0 and σ_D for the residual stresses at the surface.

$$\alpha(\sigma_0,\sigma_D) = \frac{\sigma_0 + w \cdot \sigma_D}{1 + w} \tag{11}$$

where

σ_0 is the compressive residual stress at the surface;
σ_D is the maximal compressive residual stress near the surface;
w is the parameter to adjust the compressive residual stresses.

The parameter k is calculated as follows:

$$k(\alpha,\sigma_z,y_D,y_{DZ}) = \frac{1}{y_D - y_{DZ}} \cdot ln\left(\frac{(r-1)\cdot\sigma z}{r\cdot\alpha - \sigma_z}\right) \tag{12}$$

where

y_D is the depth y of the maximal compressive residual stresses;
y_{DZ} is the depth of the transition from compressive to tensile residual stresses;
r is the parameter for the slope in the transition from compressive to tensile residual stresses.

The parameter δ can be calculated from all other parameters and characteristic points as follows:

$$\delta(\alpha, k, \sigma_z, y_{DZ}) = -\frac{1}{k} \cdot ln\left(-\frac{\sigma_z}{\alpha}\right) - y_{DZ} \tag{13}$$

In this calculation of tangential residual stresses, a residual stress depth profile can be calculated by specifying the characteristic points. The values of the surface residual stresses can be adjusted as desired without changing the further residual stress depth profile at larger depth. Thus, the approximation equation can be used to generate arbitrary residual stress depth profile by specifying the five values σ_0, σ_D, y_D, y_{DZ}, and σ_Z. The parameters r and w can be used for a better fit to the desired depth profile. Reasonable residual stress depth profiles usually result for 0.4 < r < 1.0. For the value w, which is used to weight the surface residual stresses, values between 0 and infinity can be selected.

In Figure 7 a residual stress depth profile calculated with Equation 9, as well as the used input parameters are shown. In addition, the residual stress profile calculated with Lang's approach is shown, where no tensile residual stresses are considered. This simulated residual stress depth profile applies for a heat treatment with oil quenching and a carbon depth profile with 0.7 mass percent carbon content at the surface (Ref. 10).

If the characteristic points are unknown, they can be calculated based on the simulated residual stresses for different gearings and CHDs. For this purpose, correlations were derived from the simulated residual stresses. In FVA 835 (Ref. 10), these equations were derived to calculate the inputs for the shown equations (σ_0, σ_D, y_D, y_{DZ}, σ_Z, w, r) based on only the module m_n and the CHD. Thus, residual stress depth profiles can now be estimated for case-hardened gears based on module and CHD.

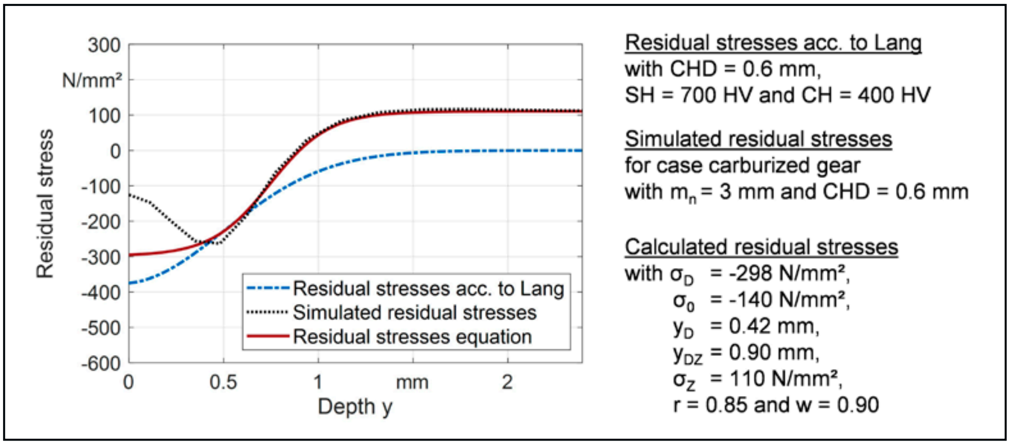

Figure 7—Comparison of residual stress depth profiles for a case carburized m_n = 3 mm gear with CHD = 0.6 mm: Calculated with Lang's approach based on the calculated hardness profile, result of simulation in FVA 835 and calculated with Equation 9.

Enhancement of the Calculation Methods for Tooth Flank Fracture Risk

First, the higher order calculation model for tooth flank fracture was extended to consider tensile residual stresses in larger material depth. After that, the practical calculation approach (of ISO 6336-4) was adapted as well. The modifications are described in the following.

The effective shear stress calculated with SIH is, by definition, without a sign, so that the sign of the existing residual stresses must be considered when calculating the double amplitude. The calculation of the double amplitude is based on the concept of subtracting the effective residual stress state from the effective loading and residual stress state. If the residual stresses change the sign at transition from compressive to tensile residual stresses some adaptations are necessary. The higher-order model has been extended so that tensile residual stresses can be taken into account in a material-physical way. In the extension, the tensile and compressive residual stresses are considered via a residual stresses sensitivity. Up to now, residual stresses were considered without residual stresses sensitivity. This corresponds to the extended calculation with a residual stresses sensitivity $M_{RS} = 1$. Equation 15 shows the enhanced calculation of the double amplitude in the higher-order model. In Equation 15, the residual stress state is multiplied by the residual stresses sensitivity M_{RS}. In addition, the sign of the effective shear stress calculated from the tensile residual stresses is therefore adjusted.

$$\tau_{eff\ DA} = \tau_{eff\ L,RS} - M_{RS} \cdot \tau_{eff\ RS} \tag{14}$$

where

$\tau_{eff\ DA}$ is the decisive equivalent stress (double amplitude);
$\tau_{eff\ L,RS}$ is the equivalent stress of loading stresses and residual stresses acc. to the SIH;
$\tau_{eff\ RS}$ is the equivalent stress of the residual stresses acc. to the SIH;
M_{RS} is the residual stresses sensitivity.

This residual stresses' sensitivity M_{RS} is also used in the calculation of the equivalent stress of loading stresses and residual stresses $\tau_{eff,\ L,\ RS}$. Here, the residual stresses are multiplied by the residual stresses sensitivity before superimposing with the load stresses. By extending Equation 6 and by adding a residual stresses sensitivity to the calculation of the total stress state, the influence of residual stresses on TFF load capacity is considered.

In the extended higher-order model, the residual stresses are considered via a proposed residual stresses sensitivity. The residual stresses sensitivity is calculated from the tensile strength, which is calculated from the hardness depth profile. Various approximations exist in the literature for calculating the tensile strength from the hardness. However, most approximations show a comparable relationship between hardness and tensile strength. For the calculation of the tensile strength, the calculation (Equations 16 and 17) according to Velten (Ref. 46) (compare Fig. 3) for case-hardened steels is proposed. Comparable relations are stated in various works.

$$Rm\,(y) = 4.02 \cdot HV(y) - 374 \text{ for } HV(y) > 445\ HV \tag{15}$$

$$Rm\,(y) = 3.29 \cdot HV(y) - 47 \text{ for } HV(y) \leq 445\ HV \tag{16}$$

where

$Rm\ (y)$ is the local tensile strength;
$HV(y)$ is the local Vickers hardness.

Since no data for residual stresses sensitivities for the flank fracture evaluation are known in the literature, it is suggested to consider the residual stresses as mean stresses with the mean stress sensitivity for axial load. The residual stresses sensitivity can thus be derived from the tensile strength Rm using, for example, Equation 18 according to NWH (Ref. 47) (compare Figure 3).

$$M_{RS} = 0.00035 \cdot R_m(y) - 0.1 \tag{17}$$

where

M_{RS} is the residual stresses sensitivity;
$Rm\ (y)$ is the local tensile strength.

The resulting relationship between hardness and residual stresses sensitivity is shown in Figure 8. The tensile strength was calculated from the hardness according to Velten (Ref. 46) and the residual stresses sensitivity from the tensile strength according to NWH (Ref. 47). Thus, it is assumed that the residual stresses are vibrationally stable and act like local mean stresses. Furthermore, it is assumed that the residual stresses sensitivity for the flank fracture evaluation is comparable to the residual stresses' sensitivity for axial loading.

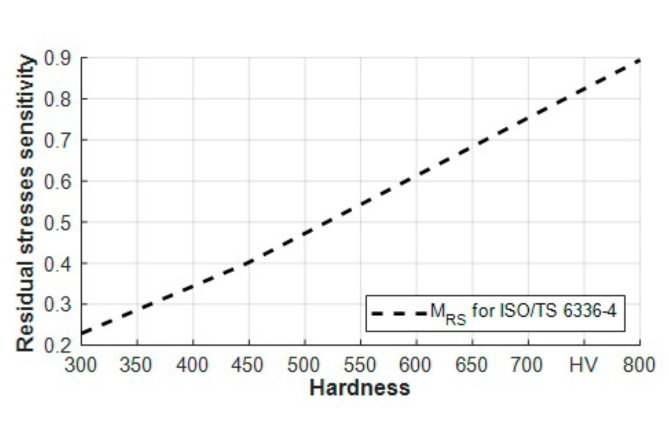

Figure 8—Plot of residual stresses sensitivity M_{RS} ***for the tooth flank fracture evaluation as a function of hardness.***

For the adaption of the practical approach some changes in definitions and in the equations are necessary. The adjustments described for the proposed expansion are listed below:

I. $|\sigma_{RS,\,max}|$: Is defined as the absolute value of the maximum compressive residual stresses, which is used for the calculation of K_{pH} (and K_2)

II. For the calculation of the influence of the residual stresses on the local equivalent stress $\Delta\tau_{eff,L,RS,CP}$ the factor $K_2 = 0$:

$$\Delta\tau_{eff,L,RS,CP}(y) = K_1 \cdot \frac{|\sigma_{RS}(y)|}{100} \cdot 32 \cdot \tanh\left(9 \cdot y^{1.1}\right) \tag{18}$$

where

$\Delta\tau_{eff,L,RS,CP}\,(y)$ is the influence of the residual stresses on the local equivalent stress;
$|\sigma_{RS}\,(y)|$ is the absolute value of the residual stress.

III. For the calculation of the local equivalent stress $\tau_{eff,\,CP}$, the local residual stresses sensitivity $M_{RS}(HV(y))$ (acc. Eq. 17) is added. In addition, a distinction is made between component depths with compressive and tensile residual stresses. This results in the following extended equations:

$$\tau_{eff,CP}(y) = \tau_{eff,L,CP}(y) - M_{RS}(y) \cdot \Delta\tau_{eff,\,L,\,RS,\,CP}(y) - M_{RS}(y) \cdot \tau_{eff,RS,CP}(y) \text{ for } RS(y) \leq 0 \text{ with } M_{RS} = 1 \tag{19}$$

$$\tau_{eff,CP}(y) = \tau_{eff,L,CP}(y) + M_{RS}(y) \cdot \Delta\tau_{eff,CP}(y) + M_{RS}(y) \cdot \tau_{eff,L,CP}(y) \text{ for } RS(y) > 0 \text{ with } M_{RS}(HV) \tag{20}$$

where

$M_{RS}\,(HV)$ is the local residual stresses sensitivity calculated from the local hardness.

For the calculations according to ISO/TS 6336-4 the hardness depth profile of the investigated gearing should be approximated with a hardness calculation approach, such as Thomas' approach. In some cases, another hardness approach such as Lang's approach may be more suitable. The use of a measured profile is not recommended because the usually unsmoothed profile affects the material exposure curve and makes its interpretation difficult. However, this approximation should also be done for the residual stresses' depth profile when tensile residual stresses should be considered. Therefore, the approximation with Equation 9 is recommended.

The use of a residual stresses sensitivity of $M_{RS} = 1$ in the range of compressive residual stresses and a residual stresses sensitivity derived from the hardness $M_{RS}(HV)$ in the range of tensile residual stresses leads to a discontinuity in the stress depth profiles at the transition from compressive to tensile residual stresses. This discontinuity can be eliminated if, for example, $M_{RS} = 1$ is used in the range $y < 1 \cdot b_H$, $M_{RS}(HV)$ is used in the range of tensile residual stresses and interpolation is performed in between. However, in the investigated cases the choice of M_{RS} in the area of compressive residual stresses does not affect the maximum material exposure in larger depth but has the advantage, that the calculation method without consideration of tensile residual stresses (acc. to ISO/TS 6336-4 (2019)) and the enhanced calculation method show the same results when only considering compressive residual stresses. This means the proposed calculation method is only an enhancement for the current calculation method, which allows the consideration of tensile residual stresses in the core if known.

In Figure 9, the recalculation of a gearing failed due to TFF in experimental investigations is shown. For the calculations without consideration of tensile residual stresses (RS profile acc. to Lang), a maximal material exposure of A_{max} = 0.9 is calculated. The material exposure depth profiles of ISO/TS 6336-4 and the higher order model are comparable. For the calculation with consideration of tensile residual stresses a residual stress depth profile was calculated with the herein proposed equation. Both enhanced models, that consider the tensile residual stresses with the residual stresses sensitivity $M_{RS}(HV)$ show comparable material exposure profiles with a maximum material exposure of $A_{max} = 1.1$. The enhanced method of ISO 6336-4 usually shows comparable or identical results as the enhanced higher order model. This also shows that a new material exposure limit in larger depth ($y \geq b_H$) has to be defined for the enhanced calculation methods.

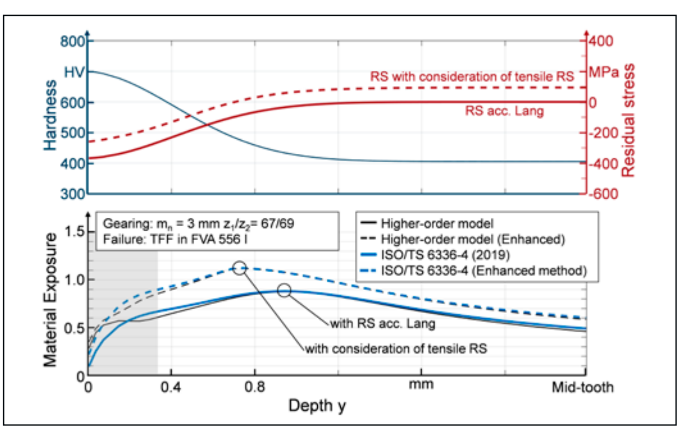

Figure 9—Comparison of calculated material exposure depth profiles: Higher-order model and ISO/TS 6336-4 and their enhanced methods including tensile residual stresses in the core area.

Validation of the Enhanced Calculation Methods with Recalculations of Gears

Chosen Gearings and Failure Modes

The proposed enhanced calculation method was extensively validated with various recalculations of TFF failures as well as non TFF failures. In the following, four different gearings are presented. The main geometry of the gearings as well as the data needed for the calculation methods is shown in Table 1. Gearing V01 is a reference gearing for pitting tests. This gearing was tested in various research projects and TFF failure has not been observed. The recalculation for this gearing is performed at the maximum tested torque where no TFF but pitting failure has occurred. The other gearings are known test gearings for TFF whereas the gearing V08 is relatively new. These gearings are recalculated at the fatigue limit regarding TFF. In addition, Hertzian pressure calculated according to the corresponding pinion torque is also given in Table 1.

Description	Symbol	Unit	Value for gearing:			
			V01	V04	V09	V08
center distance	a	mm	91.5	200	200	91.5
normal module	m_n	mm	4.5	3	5	3
number of teeth	z_1 / z_2	[–]	16 / 24	67 / 69	40 / 41	29 / 30
tooth width	b	mm	14	18	18	13
normal pressure angle	α	°	20	20	20	23.5
helix angle	β	°	0	0	0	0
CHD		mm	0.78	0.5	0.65	0.36
surface hardness		HV	740	700	695	735
core hardness		HV	400	405	410	450
material			16MnCr5	18CrNiMo7-6	18CrNiMo7-6	20MnCr5
material factor	K_{mat}		1.0	1.13	1.13	1.0
failure mode			Pitting	TFF	TFF	TFF
torque (at pinion)	T_1		max. applied	fatigue limit	fatigue limit	fatigue limit
Hertzian pressure	p_H	N/mm²	1897	1488	1575	1417

Table 1—Gearing data for the calculation.

Results of Recalculations of Load Carrying Capacity Investigations

In Figure 10, the maximal material exposure for recalculations of experimental investigations regarding the load carrying capacity is shown. The bars show the maximal material exposure in larger material depth ($y \geq b_H$) according to

ISO/TS 6336-4 (2019) and according to the herein proposed enhanced method with consideration of tensile residual stresses. The hardness depth profile was approximated with Lang's approach in all calculations. The residual stresses are calculated according to Lang from the hardness on the one hand and on the other hand according to Equation 9. The depth profiles for gearing V04 are exemplary shown in Figure 9. The circles in Figure 10 show the near surface maximal material exposure in a depth of $y < 1 \cdot b_H$, which can indicate a near surface failure.

The gearing V01 was investigated in FVA 125 III (Ref. 48) regarding pitting strength. Without consideration of tensile residual stresses a maximal material exposure in larger depth of $A_{max} = 0.6$ is shown. With consideration of tensile residual stresses the material exposure maximum in larger depth increases to $A_{max} = 0.86$. For the calculation of the risk of TFF of a gearing the maximal material exposure in a larger depth is decisive. However, the maximal exposure in depths $y < b_H$ can indicate a surface failure such as pitting. For this gearing a near surface material exposure maximum exists, that is even significantly higher than the maximum at larger depths. This is in good correlation to the observed pitting failures (no TFF) for this gearing in the test runs.

For the gearings that showed TFF in experimental investigations the recalculation was done with the load at the determined fatigue limit. The maximal material exposure in larger depth without consideration of tensile residual stresses is $A_{max} \geq 0.8$ in all cases. The maximal material exposure with consideration of tensile residual stresses is for the TFF endurance limit $A_{max} \geq 1.0$.

For all examples the near surface maximum material exposure is significantly smaller compared to the maximum value in larger material depth. This agrees with the observed failure mode TFF (no pitting) for all these gearings.

Based on the recalculation of experimental investigations it can be stated that with the herein proposed method for considering the tensile residual stresses in the core area, the maximal material exposure in larger material depth is increased by approximately 20 percent.

Based on these results a maximal material exposure limit for all documented test gears, which have been tested under constant load and a failure probability of 50 percent in larger depth $A_{max} = 1.0$ can be assumed (tensile RS included in the calculation). However, for the design of gears in industrial applications a material exposure limit of 1.0 should not be used. For the gears in practical applications, the greatest uncertainty results from the unknown and varying torque causing TFF. Furthermore, the associated failure probabilities are unknown and are certainly significantly lower than the 50 percent used as a basis for the load-carrying capacity investigations with test gears and consequently the definition of the material exposure limit. In addition, uncertainties arise from the unknown hardness depth profile, which can even be different for individual gears, as well as from various other influencing factors that cannot yet be considered with certainty in the TFF assessment. On the one hand, these can have an influence on the material side, such as non-metallic inclusions, when calculating the material strength profile. On the other hand, size-dependent factors (e. g., statistical or energetic size effect) are also to be expected but have not yet been determined.

For the application of the enhanced calculation method in industrial applications, it is therefore recommended that a material exposure limit at a larger depth of $A_{max} = 0.8$ should not be exceeded. In addition, a corresponding minimum safety factor should be considered depending on the available experience and the knowledge of the required input variables for the calculation.

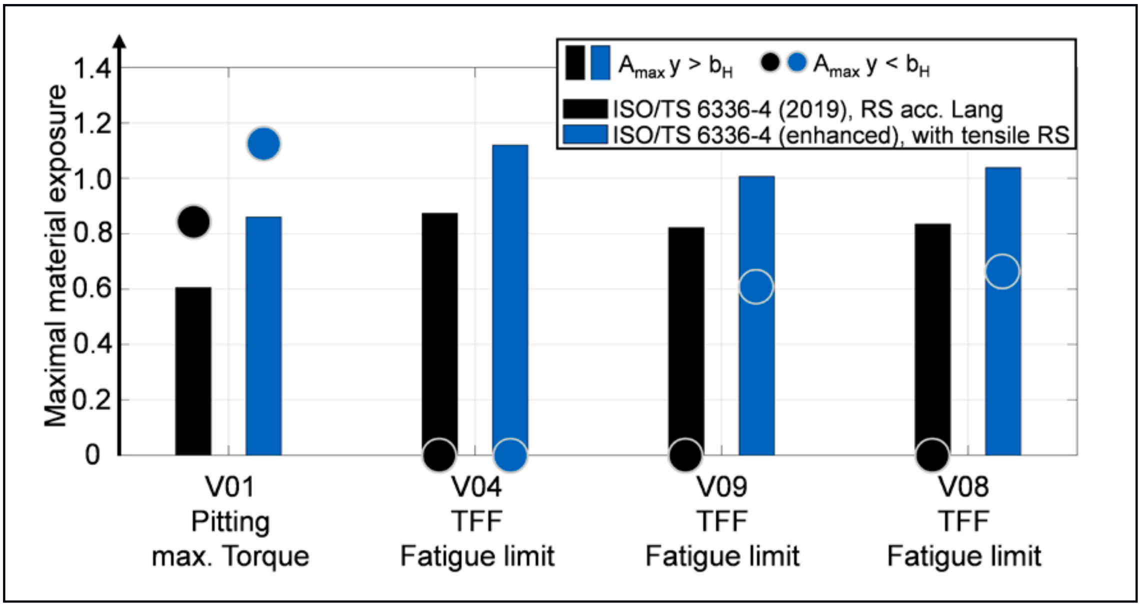

Figure 10—Comparison of calculated maximal material exposure values close to the surface and in larger depth acc. to ISO/TS 6336-4 and the proposed enhanced method.

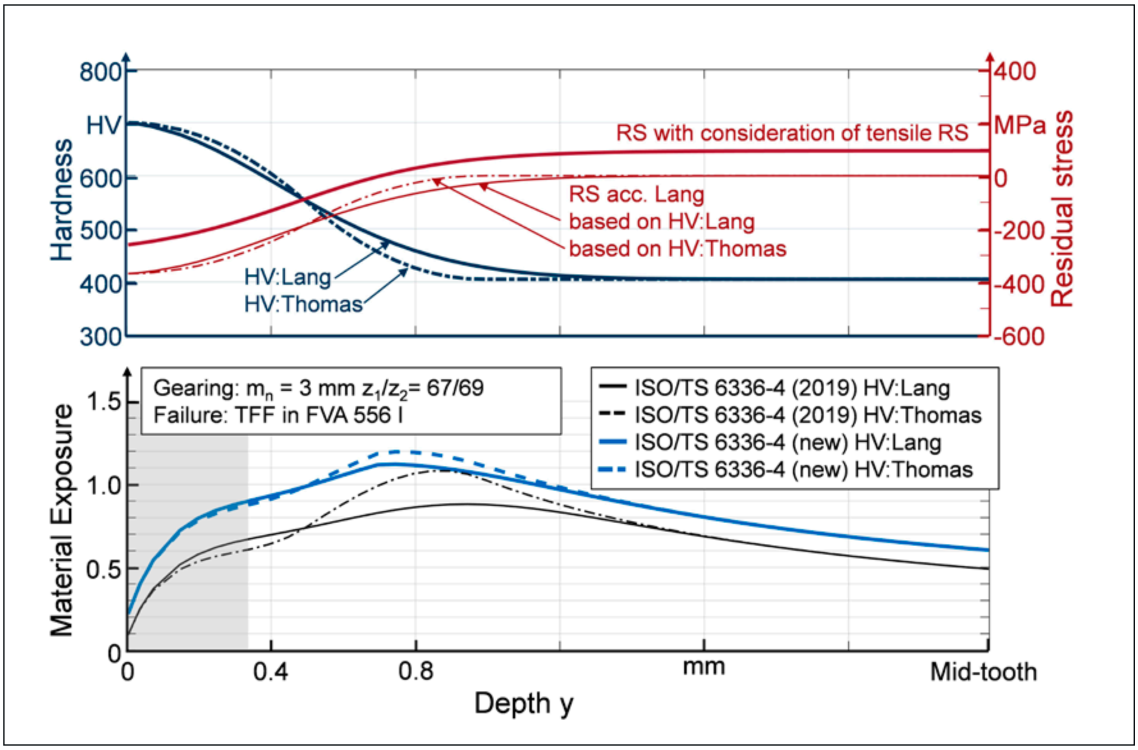

Figure 11—Influence of the hardness depth profile on the material exposure for the previous and presented enhanced calculation method. In grey the near surface area (depth up to 1 · b_H).

Further Theoretical Investigations Only Possible with the New Approach

Influence of the Hardness Depth Profile on the Tooth Flank Fracture Risk

The residual stress depth profile, especially in larger material depth is mostly uncertain. The hardness profile, on the other hand, is mostly known but subject to scattering. For the calculation of TFF risk according to ISO/TS 6336-4 it is recommended to approximate the measured hardness depth profile by Thomas' approach. With ISO/TS 6336-4 (2019) smaller deviations in the hardness depth profile (in larger material depth) already led to relatively strong differences in the calculated material exposure depth profile. The reason for this was the calculation of residual stresses from the hardness depth profile.

In Figure 11 the influence of the hardness depth profile on the material exposure depth profile is illustrated using the example of the hardness profiles calculated with Lang's and with Thomas' approach. Thomas' hardness depth profile shows a lower hardness at the transition to the core hardness than according to Lang. This small deviation is consequently also transferred to the residual stresses and leads to a major difference in the material exposure.

With the enhanced method, the residual stresses are calculated more independently from the hardness profile. This makes it possibly easier to get an estimation of the TFF risk without knowing an exact hardness profile. The material exposure depth profiles calculated with the enhanced method are approximately 20 percent higher but show only minor deviations in the material exposure profile for both hardness depth profiles.

The smaller shift of the maximum exposure in direction to the surface (when comparing the method of 2019 and enhanced method) is caused by the assumption of the residual stress depth profile. Here the residual stresses with consideration of tensile residual stresses according to Equation 9 have their transition from compressive to tensile or to zero nearer to the flank surface.

Results, Conclusions, and Outlook

This paper presents an enhancement of the calculation approach for tooth flank fracture risk by considering tensile residual stresses in larger material depth. The extension of the practical approach according to ISO/TS 6336-4 is still based on the higher-order calculation approach, which was previously able to take tensile residual stresses into account in principle but was not yet validated for this purpose. In addition, a simple non-iterative equation for estimating a residual stress depth profile is presented. With this equation measured or simulated residual stress depth profiles can be approximated including tensile residual stresses in the core area.

Since the calculation of the material strength was not adjusted, the extended approach results in a new maximum material exposure limit when tensile residual stresses are considered. For the determination of this limit, recalculations of TFF load carrying capacity investigations were carried out.

The enhanced method brings several decisive advantages, which are shown. First, the existing tensile residual stresses inside the tooth are taken into account as a function of gear size and CHD on the basis of extensive numerical and experimental investigations, thus increasing the reliability of the calculation method. Furthermore, uncertainties in the hardness depth profile have a significantly lower effect on the calculated material exposure since the residual stresses are not calculated in direct dependence on the hardness depth profile. In addition, it is now possible to theoretically investigate the optimal CHD, since the TFF risk of very high CHD's no longer leads to very low maximum material exposures regarding TFF, which cannot be expected in reality but was the case before the enhancement of the calculation method. With the enhanced method, taking tensile residual stresses into account, as the CHD increases, the TFF risk approaches a limit value at which the TFF risk no longer decreases. The theoretical investigation of an optimal CHD regarding TFF is possible now possible and is to be examined in detail next.

Acknowledgements

Supported by:

Federal Ministry for Economic Affairs and Climate Action

Forschungsnetzwerk Mittelstand

Forschungsvereinigung Antriebstechnik e.V.

on the basis of a decision by the German Bundestag

This research work was funded equally by the *Arbeitsgemeinschaft industrieller Forschungsvereinigungen e.V. (AiF)*, the German Federal Ministry for Economic Affairs and Climate Action (BMWi, IGF no. 20150N) and the *Forschungsvereinigung Antriebstechnik e.V. (FVA)*. The results shown in this work were taken from the research project FVA 835 (Ref. 10).

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Karsten Stahl is a full professor at the Institute of Machine Elements within the department of Mechanical Engineering at the Technical University of Munich and director of the Gear Research Center (FZG). His main research areas are power drive components, such as gears, synchronization systems, multi-disc clutches, and (electro-)mechanical drive systems.

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Frederic (Fred) Marlin Young

(1943—2023)

Fred Young, 80, former president and CEO, Forest City Gear passed away on July 17,2023. A graduate of Harlem High School, class of 1961, Young obtained his BA in English Literature from Rockford University, class of 1965, and went on to spend a year in the Navy Reserves. After spending nearly 40 years as an adventuring bachelor outdoorsman, he met the love of his life, Wendy Nutter, marrying her on the banks of the Wolf River on June 6, 1981. Fred's greatest joys were his three daughters, whom he taught to always seek adventure, bestow kindness and generosity, treasure friendship, and work hard and play hard. Fred took over the family business, Forest City Gear, in 1967. Founded by his parents in 1955, Fred took the small mom-and-pop shop to a global level, leading the company to manufacture some of the world's most difficult gearing for amazing end uses from NASA's Martian rovers and space station to robotic arms and racing yachts.

Young's full obituary can be found here:

geartechnology.com/articles/30395-frederic-fred-marlin-young-19432023

Gear Technology asked members of the gear community to discuss Young's remarkable influence through the years:

"I met Fred 30 years ago when he welcomed me as an Australian gear manufacturer into his plant in Roscoe. Fred was very open in sharing the reasons for his success. Back then Forest City Gear were already a market leader and I could see why. His generous sharing of information led me to somewhat benchmark our business to his. Key point–his continual investment in the latest technologies. Having followed that lead, our company is now the market leader here in Australia. Always welcoming, Fred and I became good friends that extended to our personal lives. His introductions to other AGMA members helped me integrate into the organization and thus enhanced my gear industry experiences globally. Fred had an eternal presence. He will be sadly missed by the industry and all of us who were fortunate to have known him personally."

Gordon New, Ronson Gear

"It's really hard to just share a few words about Fred and his impact on the gear industry. Fred was the first person I met in the gear industry when I joined 15 years ago. Sam Haines, our CEO at the time, took me to meet Fred and to tour Forest City. Fred and the team at Forest City greeted me like they would as a member of their family. Over the next years I had the pleasure of working with Fred and Wendy in business and as part of the AGMA. During one of my visits to Forest City, Fred was hunting, but took time to talk to me while he was on vacation. I do not think most people realize the impact that Fred and Wendy have had on the AGMA. The AGMA we enjoy today is a product of their efforts to make it a welcoming and inclusive association. Their generation of leadership molded the AGMA into one that makes new members feel like family and allows for competitors to collaborate and share to make the entire industry better."

Dean Burrows, Gear Motions

"Fred Young and Forest City Gear became well known for and synonymous with high quality gear production utilizing modern CNC gear manufacturing machinery and CNC inspection and automation in the 70s and 80s when this equipment was first being introduced. He always had his door open to everyone and showcased his technology in an effort to advance gear production globally. He will be missed for his friendliness, good humor, and innovation in the gear industry."

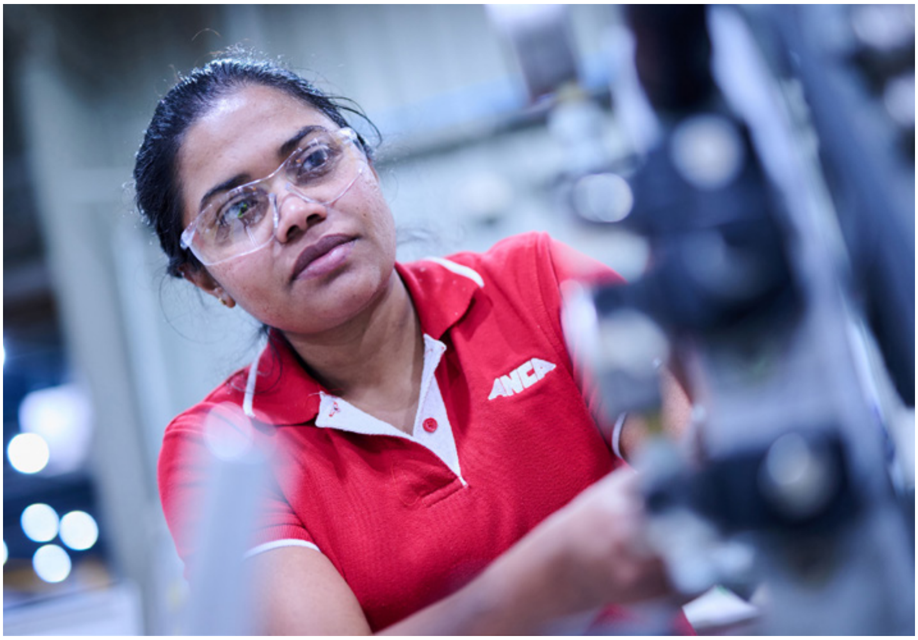
David Goodfellow, retired, Star SU LLC

"Fred's legacy is incredible. Between his innovation and technical expertise to grow his company from a small shop to a global name who manufactures some of the most precise gears available, to the personal impact he had on everyone that knew him through his kindness and generosity, Fred was a true leader who will be dearly missed."

Matthew E. Croson, AGMA, president

ANCA

LAUNCHES INAUGURAL FEMALE MACHINIST AWARD



ANCA proudly announces the launch of its first Female Machinist Award. This prestigious accolade aims to recognize and honor the outstanding achievements of female machinists in the tool and cutter grinding industry. By promoting gender diversity and equality, ANCA is dedicated to fostering an industry that excels in every aspect.

Johanna Boland, ANCA Group Strategy & Communications Manager and member of the judging panel, says: "Recognizing and celebrating the contributions of women in the tool and cutter grinding industry is a vital step towards unlocking the industry's true potential. By embracing and empowering women, we discover a wealth of diverse perspectives, fresh ideas, and extraordinary talent. ANCA is committed to shining a spotlight on these remarkable individuals, because we believe that their success fuels the success of our industry as a whole."

The Female Machinist Award is open to women of all skill levels who are actively working with ANCA technology in the tool and cutter grinding industry. We are searching for individuals who exhibit unwavering passion for their craft, demonstrate a commitment to excellence, and contribute to the advancement of the industry.

A panel of experienced professionals from the tool and cutter grinding industry will serve as judges for this award. Submissions will be evaluated based on the following criteria:

- Exceptional problem-solving skills to overcome challenges or obstacles during projects
- Innovative and effective tool design
- Demonstrated ability to think critically and find innovative solutions

The winner of the Female Machinist Award will be rewarded with a fully funded ticket to attend a prominent trade show where ANCA is exhibiting. This invaluable opportunity will enable the winner to connect with industry professionals, gain insights into the latest technological advancements, and build valuable relationships.

The winner will have exclusive access to the ANCA team, including top-tier leadership, skilled engineers, and renowned product experts. The prize also comes with opportunities to network with like-minded professionals and participate in educational seminars and workshops.

If you or someone you know embodies the qualities of a talented female machinist deserving of recognition, we strongly encourage you to apply for the Female Machinist Award today!

The application deadline is August 31, 2023. To learn more and apply, visit:

anca.com

Solar Atmospheres

COMMISSIONS NEW STATE-OF-THE-ART BRAZING FACILITY

Recently, Solar Atmospheres commissioned a new 25,000 square foot brazing facility aimed at high-volume, high-quality braze production. The facility boasts six vacuum furnaces dedicated to brazing, including a unique all-metal hot-zone furnace designed for brazing stainless steel to copper with silver and gold-based braze filler metal (BFM).

Solar specializes in the brazing of high-value components utilizing filler metals based on nickel, silver, gold, and copper. "Solar provides high-quality brazing services for numerous markets, as well as braze-manufacturing services of turn-key components utilizing a large base of suppliers that are also customers" states Mike Moyer, Solar's Vice President of Sales. "Over the last 40 years of brazing and heat treating, we have developed valuable relationships with some of the best and most capable manufacturers in the United States. This translates into unique resources that few others have in the marketplace."

The new state-of-the-art production facility boasts 4,000 square feet of climate-controlled workspace where technicians assemble and inspect parts, ranging from tiny capillary-tube manifolds to large land-based gas turbine blades. The operation incorporates increased capacity for helium leak testing and pre-braze tack welding of braze assemblies. "With Nadcap accreditation and AS9100 registration, our new facility operates as one expects from the Solar brand" states Chip Lahneman, Solar's General Manager of Brazing. "The investment in our new facility demonstrates Solar's commitment to meeting our customers brazing needs, now, and in the future."

www.solaratm.com

Mike Melzer

CELEBRATES 25 YEARS WITH GLOBAL SHOP SOLUTIONS

It's rare to find employees who work 25 years at the same company, especially in the volatile software industry. That's why Global Shop Solutions, a leading provider of ERP software for manufacturers, recently announced the 25th anniversary of Mike Melzer, vice president of operations and service.

"At Global Shop Solutions headquarters, Mike is often the first to arrive and the last to leave," says Dusty Alexander, president and CEO of Global Shop Solutions. "We deeply appreciate his energy, integrity, loyalty, and knack for addressing our customers' most challenging issues. As I've often said during our numerous customer visits together, standing alongside Mike makes me feel 10 feet tall – together, we can tackle anything!

"Others aptly refer to Mike as our Swiss Army knife,' highlighting his ability to create simple solutions to complex problems that others have struggled with," adds Alexander. "It's a rare and valuable gift that Mike possesses. We extend our heartfelt thanks to Mike and look forward to many more days at headquarters, Game Day trainings, and customer visits as we continue our mission to elevate manufacturers from good to great!"

Melzer earned his Engineering degree at Colorado School of Mines and joined Global Shop Solutions shortly thereafter. Starting out in service and consulting, he spent much of his time on the road converting customers to the latest version of Global Shop Solutions ERP software. The experience taught Melzer how to build good working relationships with customers and brainstorm better ways to get things done. It also paved the way for what was to come.

About two years into his tenure with the company, Melzer was chosen to run the company's service department. Since then, his creative thinking and leadership skills have helped Global Shop Solutions grow from a small family business operating in the U.S. to a globally respected ERP provider.

"Mike is highly regarded by customers and Global Shop Solutions employees," says Alexander. "He still travels frequently to help customers find unique solutions to ERP situations that require out-of-the-box thinking. When back at the office, he devotes significant time to making sure the company keeps employees engaged in their jobs by offering opportunities to learn, grow and advance in their careers."

Melzer is a skilled, experienced, and dedicated person who oversees the vital job of keeping Global Shop Solutions customers happy. What has kept Melzer on board for 25 years?

"This company is exceptional to work for," says Melzer. "I love traveling, helping people solve problems, teaching customers and coaching employees. Most of all, Global Shop Solutions is a great group of people. We have a world-class ERP product that I am proud of, but what separates us from the competition is our people."

globalshopsolutions.com

Star SU

EXPANDS SALES NETWORK FOR STAR CUTTER PRODUCTS ACROSS NORTH AMERICA

Star SU, the marketing, sales, and service affiliate of Star Cutter Company, has announced the hiring of three new area sales managers (ASMs). Each ASM will be responsible for growing sales in his territory across multiple product lines, illustrating the company's ability to better serve customers through its vertically integrated structure.

Prior to joining Star SU, Noah Cantara served as a carbide rods product specialist at Sandvik Hyperion and Hyperion Materials and Technology, as well as having experience as a machine operator responsible for grinding and manufacturing carbide inserts.

Cantara served in the United States Army Reserve (Fort Custer, MI.) and holds a Bachelor of Science in Operations Management from Oakland University in Rochester, MI.

David Johnson comes to the Star SU family after working as a sales application engineer for Mapal, Inc., as well as having been a test technician for Mahle Engine. His primary product focus will be on the company's round tools and gear tools offerings.

He has a Bachelor of Science in Heavy Equipment Service and Engineering Technology from Ferris State University in Big Rapids, MI.

Daniel Larsen joins Star SU with a strong background in machine tools after being employed as a software support engineer at Hurco, responsible for testing and validation of new software, as well as working as an applications engineer at Index Corporation and Meredith Machinery. Additionally, he has sales experience, having recently served as a territory manager for JMC Sales and Engineering, a cutting tools and MRO distributor.

starcutter.com

Anthony Riportella

PROMOTED TO INSIDE SALES MANAGER AT BOURN & KOCH

Bourn & Koch announces the promotion of Anthony Riportella to the position of inside sales manager. In his new role, Riportella will oversee the inside sales team and support the company's numerous American-made machine tool brands, including Bullard, Blanchard, DeVlieg, and Fellows machine tools.

Riportella brings a wealth of experience to his new position, having previously excelled in both inside and outside sales roles at Bourn & Koch. His understanding of the company's product lines and dedication to customer satisfaction make him an ideal choice to spearhead customer care and inside sales efforts.

Bourn & Koch has a long-standing reputation for manufacturing high-quality, American-made machine tools that exceed industry standards. With his comprehensive knowledge of the company's products and its customer base, Riportella is poised to deliver exceptional service and support to Bourn & Koch's customers for both their new machine tools and legacy brands such as Bullard, DeVlieg, Barber-Colman, and Mattison.

Having worked closely with customers in various capacities at Bourn & Koch, Riportella deeply understands their unique challenges and requirements for keeping their machine tools productive, both new and old. This insight will allow him to effectively lead the inside sales team to exceed customer expectations by providing prompt support for their machine tools.

As the Inside Sales Manager, Riportella will play an important role in nurturing customer relationships, streamlining sales processes, and ensuring that Bourn & Koch continues to provide support for machine tools to customers across the globe.

bourn-koch.com

Nidec Machine Tool

LAUNCHES NEW CUTTING TOOL FACTORY IN INDIA

Nidec Machine Tool Corporation announced that it will construct a new factory for Nidec India Precision Tools Ltd. ("NMTI"), the company's cutting tool manufacturer and seller in Ranipet of India's Tamil Nadu State. With its production capacity 1.5 times the company's current manufacturing capability, the new factory will produce hob cutters, pinion cutters, and other cutting tools. After its launch, the factory will be able to quickly supply the Company's customers in India with its products and meet their needs in response to the growing demand for autos, construction, and farming machinery.

To be constructed on NMTI's 13.6-acre property in Ranipet, the southern city of Chennai, the new factory will have a floor space of 22,000 sq. ft., and be home to production lines of cutting tools (hobbing, shaping, shaving, and broaching machines) to cut external and internal gear teeth, with a production capacity 1.5 times of its existing facility.

In addition, with a shorter lead time and an expanded product lineup, the new factory will meet a wide range of its customers' needs speedily, while improving recoating and other after-sales services.

Relatively close to NMTI are Chennai and Bengaluru, where the country's auto industry is concentrated. With many two- and four-wheel vehicle manufacturers and suppliers related to machine tool manufacturers in those cities, NMTI aims to quickly supply its products to meet the industries' diverse needs. Furthermore, with a machine tool show room to be added by autumn this year for customers to see actual products, the new factory will also serve as a sales base of machine tools.

India expects to see its vehicles' unit sales increase at a steady pace of 10–15 percent annually. Additionally, based on the global movement towards a decarbonized society, the country's demand for transmissions, which require multiple gears, is expected to increase as, among other trends, the vehicle electrification intensifies and compressed natural gas (CNG) vehicles further gain market share.

Since its foundation in 1963, NMTI has been locally designing, manufacturing, and selling cutting tools for gear machining for the past 60 years. With its efficient and durable cutting tools gaining popularity from many customers, the company expanded its businesses as the market grew larger. This latest investment for production increase is NMTI's first large-scale investment after joining the Nidec Group in 2021, and the company is poised to secure a supply base to respond to the market's rapid expansion promptly, and seek synergies based on its high-cost competitiveness, to meet customers' expectations.

nidec.com/en/machinetool

Emco

ANNOUNCES MARKUS NOLTE AS CEO

Dr. Markus Nolte has accepted the position as CEO at EMCO GmbH. A total of 800 employees, five production sites and a global sales and services network stand for high-quality machine tools "Made in the Heart of Europe", for innovations and for customer proximity.

Nolte will drive Emco's ambitious growth strategy. "I am looking forward to this exciting challenge in a highly dynamic market environment. Our team's expertise and EMCO's innovative product portfolio are the ideal prerequisites for expanding our market position as a provider of cutting-edge technology and top-class services," Nolte said.

Over the past 25 years, Nolte has acquired extensive experience in different management functions and industries, including as the CEO of a publicly listed supplier to the aerospace industry and as the head of sales and development at an international automotive supplier.

A full-service provider in turning and milling and a manufacturer of high-tech turnkey solutions, Emco is perfectly prepared for the next growth steps. A strengthened management team accompanies Nolte on this ambitious strategic path: Jörg Weinkogl has been responsible for the sales, service, and marketing departments since June 1, 2023. With his many years of experience at Emco, Mag. Horst Rettenbacher strengthens the management team in his capacity as CFO.

emco-world.com

September 13—Digital Factory 2023

Join dynamic keynotes and discussions from industry and policy leaders on Digital Design, Digital Manufacturing, Workforce Development, Sustainability and Supply Networks. Current speakers include the CEOs of Rockwell Automation, GE Digital, Formlabs, Autodesk, Re:Build Manufacturing and leaders from Hasbro, MIT, AWS, Steelcase, Atlas Copco, and the State of Massachusetts. Connect with like-minded organizations pushing the limits on digital transformation. Previous attendees include GE, Amazon, Ford J&J, PWC, MIT, Lockheed Martin, FedEx, John Deere and more. Experience a large space for technology discovery, including the full Formlabs product portfolio, fun networking meals and a hands-on pop-up factory where attendees can join the assembly line to make their own product. Digital Factory 2023 (Boston, MA) is powered by Formlabs and Autodesk.

geartechnology.com/events/5078-digital-factory-2023

September 13–15—International Conference on Gear Production 2023

As an accompanying event to the International Conference on Gears 2023, the 5th International Conference on Gear Production (Garching, Germany) is one of the most important biannual meeting points for the gear manufacturing industry both for technical experts and for decision-makers. Current challenges and solutions are presented and discussed, strongly emphasizing new potentials in productivity and/or the flexibility of gear manufacturing processes. High-level expertise will be ensured by our conference presidents: Prof. Dr.-Ing. Christian Brecher and Prof. Dr.-Ing. Thomas Bergs MBA, WZL, RWTH Aachen as well as Prof. Dr.-Ing. Karsten Stahl, FZG, Technical University of Munich (TUM) in Garching. They will take you through the conference program and moderate the sessions in 2023. Do not miss an event outlining new trends for the gear producing industry of tomorrow.

geartechnology.com/events/5077-international-conference-on-gear-production-2023

September 18–10—EMO Hannover 2023

EMO Hannover is the breeding ground for innovations, key debates, and new business partnerships. Technologies include automation, robotics, additive manufacturing, sustainability, connectivity and more. 1,750+ exhibitors from 42 countries are currently expected at EMO Hannover 2023. They will present the entire spectrum of production technology. Major points of interest include machining centers and lathes, cutting tools and clamping devices, measuring equipment and control systems. "The breadth of the technical offerings is unparalleled at the international trade fair for production technology," emphasized Markus Heering, executive director, VDW. The event highlights the challenges that exist in production: greater efficiency, more flexibility, better quality, increased accuracy, the integration of AI, comprehensive factory-wide networking, and more.

geartechnology.com/events/5071-emo-hannover-2023

October 17–19—Motion + Power Technology Expo 2023

Produced by AGMA, Motion + Power Technology Expo (Detroit) is a three-day show that connects professionals looking for motion power solutions with manufacturers, suppliers, and buyers. Attendees will find new power transmission parts, materials, and manufacturing processes. Buy, sell, and get business done with organizations in aerospace, automotive, agricultural, energy, construction and more. Hundreds of exhibitors and attendees means MPT Expo is a unique opportunity to find partners that can help fulfill your specific production needs. The show is colocated with Heat Treat 2023 and IMAT 2023.

geartechnology.com/events/5076-motion-power-technology-expo-2023

November 12–15—2023 STLE TFC and E-Mobility Conferences

The 2023 STLE Tribology Frontiers Conference (TFC) will be held November 12–14 in Cleveland. The event will allow attendees to engage with world-renowned industry, academic and government researchers to learn more about the technical, environmental, and social issues impacting tribology research in the 21st Century. The 2023 STLE Tribology & Lubrication for E-Mobility Conference will be held in conjunction with the TFC from November 14–15. The event will feature educational sessions and networking discussions with leading industry experts covering technical content, analysis, and best practices for addressing the challenges and opportunities associated with electric vehicle technologies and how they will impact the tribology and lubrication field.

geartechnology.com/events/5062-2023-stle-tribology-frontiers-conference-and-tribology-and-lubrication-for-e-mobility-conference

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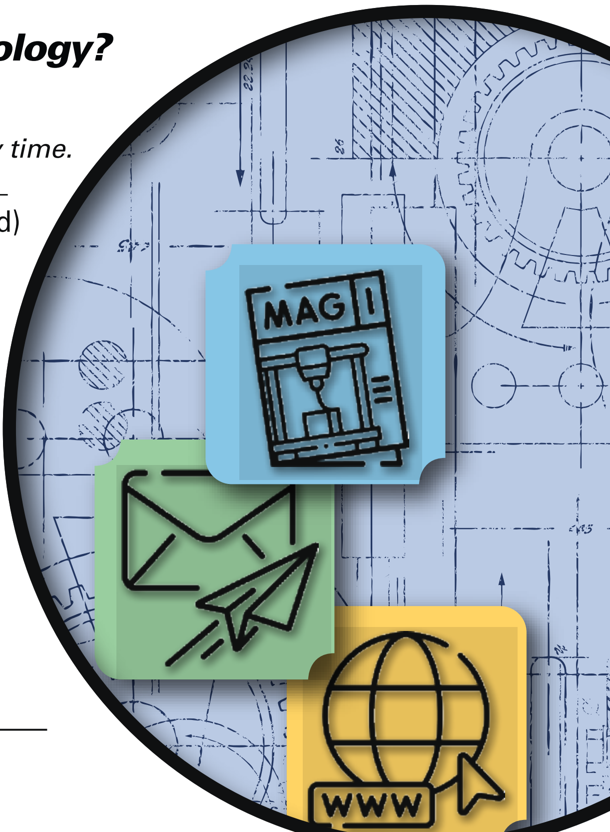

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Adding to the Digital Job Shop

Tools are expanding to stay ahead of today's unique manufacturing challenges.

Matthew Jaster, Senior Editor

We came across an interesting statistic recently in our normal product coverage for Gear Technology magazine. United Grinding had more than 2,500 remote deployments during the pandemic. Digital assistance systems—big and small—helped machine operators navigate production output in real time during this chaotic work period.

These flexible working models provide a way to stay connected with customers under any circumstance. Laptops, smartphones, tablets and even wearables can assist with condition monitoring and predictive maintenance while sensors and barcodes dispatch key product information in real-time.

United Grinding continues to expand its digital solutions and products regularly to meet the changing demands of the manufacturing sector (*grinding.com/en/digitalization/digital-solutions/*). Is it time for your shop to consider expanding your digital footprint as well?

Neugart recently provided digital information for analog components. The link between the physical gearbox and the digital world in this example occurs via a data matrix code (DMC), a 2D code on the gearbox nameplate—scanned via smartphone or tablet.

This identification leads immediately and around the clock to the relevant product information and other functions. The user then receives, for example, a clear list of all the versions of the gearbox in question or can download the appropriate operating and mounting instructions (*neugart.com*).

GE Digital's *Asset Performance Management (APM)* software allows owners to optimize asset performance and O&M efficiency across equipment types, a plant, or an entire fleet with modules in Strategy, Reliability, Health, and Integrity, and more—all under one software suite.

Power generation organizations must adapt and modernize to maintain sustainable and profitable operations within certain constraints, such as limited expertise and resources, changing energy demands and resource types, and aging equipment. APM software helps organizations identify and minimize risk and embed process efficiencies and data analytics in their workflows (*ge.com*).

Senseye Predictive Maintenance offers a cloud-based platform designed to support large-scale asset monitoring. By utilizing custom AI algorithms, the platform effectively identifies both existing and potential issues, empowering maintainers to prevent malfunctions and unplanned downtime.

Accessible through any web browser on any device, the platform allows inspections to be conducted at any time and from anywhere, resulting in time savings and promoting a proactive maintenance approach. Its seamless integration into real-world workflows enables users to make informed decisions and optimize their operations.

Senseye Predictive Maintenance takes an asset-agnostic approach by automatically constructing models. This streamlines the work of maintenance teams, reduces the likelihood of unexpected outages, eliminates manual inspections, minimizes the need for excess spare parts, and prevents unnecessary over-maintenance (*sw.siemens.com*).

These are just a few examples of how the digital job shop is changing manufacturing operations through app-based and mobile tools accessible 365 days a year—day or night.

While these upgrades require the right infrastructure, most job shops have the basics in place to make the transition work. Workforce talent, technology, data, and a fair amount of ambition can transform any MRO department with a little patience and creativity.

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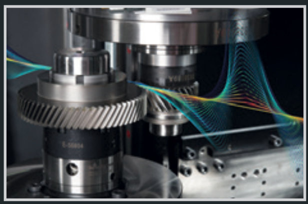

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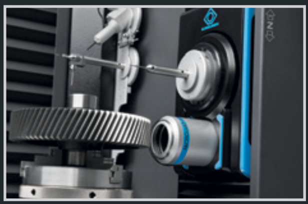

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