gear TECHNOLOGY®

NOVEMBER/ DECEMBER 2024

AGMA Member Visits

Workforce Culture

Chamfering

Precision Gear Inspection

Arvin's Angle

TECHNICAL

Experimental and Analytical Study of the Effect of Shot Peening on Gear Micropitting and Contact Fatigue Failure

An Experimental Study on the NVH Performance of Plastic Gears

Gear Technology is POWERED by The American Gear Manufacturers Association

geartechnology.com

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Gear cutting tools and services

Star SU offers a wide variety of gear cutting tools and services, including:

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- Chamfer hobs
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- Shaper cutters
- Scudding® and Power Skiving cutters
- Shaving cutters
- Chamfer and deburring tools
- Rack and saw cutters
- Master gears
- Ring and plug gauges
- Advanced coatings including ALTENSA, ALCONA PRO and **NEW** ALCRONA EVO
- Tool re-sharpening

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The Star NXT linear CNC tool and cutter grinding machine sharpens both straight and spiral gash hob designs up to 8” OD x 10” OAL. With a small footprint and maximized grind zone, the NXT also sharpens disk, shank and helical type shaper cutters, Scudding® and skiving cutters, and a wide range of round tools, making it a versatile tool room machine.

MODUL Profilator

Gear Cutting Tools
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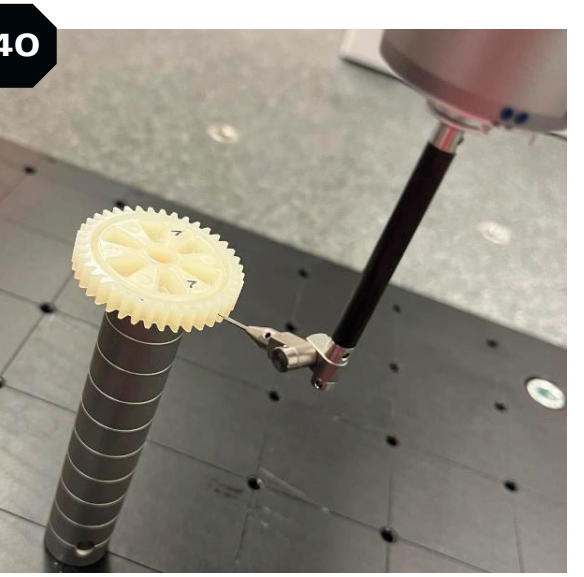

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GEAR HONING

DVS TECHNOLOGY AMERICA

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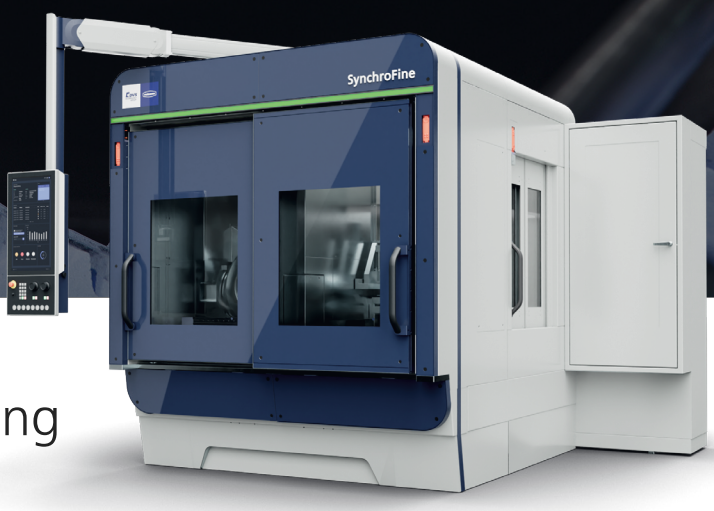

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gear TECHNOLOGY®

Vol. 41. No. 8

Wishing You and Yours
the Brightest of Holidays.

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www.forestcitygear.com

gear TECHNOLOGY

GT VIDEOS

Gleason Modernization Programs

This video looks at a complete machine remanufacture on a Gleason P300 with all machine functions. The machine is returned to Gleason, where it is completely disassembled and rebuilt. A machine remanufacture is like buying a new machine but without the need to purchase new peripherals or to rethink existing process chains.

geartechnology.com/media/videos/play/283

EVENT SPOTLIGHT

The Bearing Show North America/Lubricant Expo North America

The Bearing Show connects the evolving needs of bearings end users with the latest technologies serving OEM development, maintenance professionals and R&D engineers. It is colocated with the Lubricant Expo, North America's newest exhibition and conference, connecting lubricant solution providers with the full range of end-user buyers, as well as the entire chemical and equipment supply chain with thousands of engineers and executives in attendance.

geartechnology.com/events/5109-the-bearing-show-north-america-lubricant-expo-north-america

AS SEEN IN *PTE*

Lubrication Excellence

The increasing cost of food and beverage machinery makes running equipment to failure not just impractical, but potentially devastating to your bottom line. However, there are solutions that can lead to significant savings, and an often overlooked one is implementing an effective lubrication program.

powertransmission.com/articles/10049-lubrication-excellence

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Michael Goldstein founded *Gear Technology* in 1984 and served as Publisher and Editor-in-Chief from 1984 through 2019. Thanks to his efforts, *the Michael Goldstein Gear Technology Library,* the largest collection of gear knowledge available anywhere, will remain a free and open resource for the gear industry. More than 40 years' worth of technical articles can be found online at *geartechnology.com.* Michael continues working with the magazine in a consulting role and can be reached via e-mail at *mwg42@hotmail.com.*

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I certify that all information furnished on this form is true and complete. I understand that anyone who furnishes false or misleading information on this form or who omits material or information requested on the form may be subject to criminal sanctions (including fines and imprisonment) and/or civil sanctions (including civil penalties).

Happy Holidays

As the year draws to a close, I'd like to take a moment to express my heartfelt gratitude for the continued support of *Gear Technology*'s readers, advertisers and authors. Thank you for being an integral part of the gear community. This holiday season, as I reflect on the challenges, triumphs, and growth of the past year, I am reminded of the shared passion we all have for advancing the field of gear manufacturing.

Your dedication to pushing the boundaries of innovation, excellence and precision in your work is what inspires the *Gear Technology* and AGMA team every day. Whether you're engineering the future of gears, refining manufacturing processes, or contributing to the development of cutting-edge solutions, your commitment fuels the progress of our industry—and we're proud to be a part of that journey with you.

This year, we have strived to bring you the most relevant, insightful, and forward-thinking content to keep you informed and inspired. From the latest technological advancements to expert advice and industry trends, our mission remains clear: to support your ongoing learning and growth.

This holiday season, we hope you find time to unwind, recharge, and enjoy precious moments with loved ones. We look forward to continuing our work together in the coming year, bringing you more valuable resources, stories, and insights that support your work and the continued evolution of the gear industry.

We have a ton in store for you next year, including completely redesigned websites and a refreshed focus on digital content. We have a full slate of content scheduled, including our annual State-of-the-Gear-Industry survey in January, and we're already looking forward to MPT Expo in Detroit next fall.

Hopefully you are also excited about the prospects of 2025. I know that many of you have big plans for your businesses, your careers and the new technologies you're looking to implement. May the New Year bring you success, joy, and fulfillment both personally and professionally.

Thank you once again for your trust and for being a vital part of our community.

Randy Stott

Publisher & Editor-in-Chief
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Nidec

LAUNCHES LATEST ZFA GEAR GRINDERS

The two ZFA series gear grinders are designed to perform high-speed and high-precision finish machining on gears. The two models are each designed for a different gear size range, with ZFA160 capable of handling gears with an external diameter of up to 160 mm, and ZFA260 accommodating gears with an external diameter of up to 260 mm. Capable of meeting the increasingly sophisticated users' needs, both ZFA160 and ZFA260 can mass-produce gears with a gear accuracy level equivalent to ISO 3 (JIS level N3).

In regard to high-speed machining performance, the two models, with a newly developed twin-table structure and high-speed rotary performance, boast a nonmachining time of 4 seconds, a 33 percent improvement from ZE16C, the current model, and a 50 percent improvement from ZE26C. In addition, to secure a stable high-precision machining, ZFA160 and ZFA260 employ stiffer work-table structures, grinding stone heads, and dress units among others. Furthermore, the models' main axis structures were made to endure high-speed machining, while, for their machines' heads (boards to comprise the machines' main units), a thermostable material (mineral cast), which suppresses vibration from high-speed machining and heat-caused dimension change, was adopted to stabilize accuracy during high-volume production (O.B.D. variation range during consecutive machining: app. 10 µm).

ZFA160 and ZFA260 boast features for machining EV gears as well, such as "simultaneous double-tooth flank bias adjustment," a function to suppress distortion on flanks, and "low-noise machining," which reduces periodical asperity on tooth flanks, among many other high-precision machining technologies.

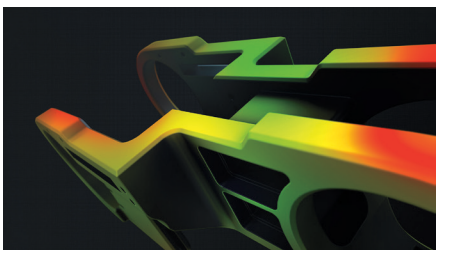
Furthermore, as part of actions to curb environmental load, the users of the two latest models can select a circular, filter fabric coolant tank to process sludge- and coolant-containing waste from a machining process. This feature enables ZFA160 and ZFA260 to discharge zero amount of sludge-containing paper filter, helping them generate less industrial waste than other models.

As automobiles become electrified, quieter, more fuel-efficient, and produced at low cost, there is a globally growing need for high-precision finish of gears and the mass production of precision gears. In addition, as the demand for a variety of reducers for high-performance robots increases, the public are increasingly interested in gear grinders capable of high-speed and high-precision machining.

nidec.com

Zeiss

OFFERS INSPECTION AND DATA MANAGEMENT INNOVATIONS



With the recent software release Zeiss Industrial Quality Solutions (Zeiss IQS) enhances its extensive software portfolio, introducing cutting-edge innovations in multiple software products to optimize inspection processes and streamline data handling capabilities.

Together with the prevailing CMM gold standard software *Zeiss Calypso*, *Zeiss Inspect* is the foundation for further development of the Zeiss Industrial Quality Solutions software landscape. *Zeiss Inspect* facilitates intuitive inspection of optical 3D and X-ray data and includes functions that support efficient automated processes. Flexible customization is possible thanks to numerous apps available in the Zeiss Quality Software Store and the built-in Python interface. AI-based applications enhance the overall capabilities of the software and are one of the current focus topics for software development at Zeiss IQS.

"The vision is one software that solves all metrology tasks," says Dr. Marc Wawerla, CEO of Zeiss IQS. Prospectively, *Zeiss Inspect* software will offer solutions for the complete technology portfolio offered by Zeiss and unmet by any other competitor.

"Using our all-in-one software, customers benefit from streamlined workflows and a consistent user experience. This facilitates learning and reduces training effort. Our expert software *Zeiss Calypso* stays the well-established standard for tactile measurements. The latest version was released in June this year and we are already working on the next release," explains Christoph Grieser, head of global software sales at ZEISS IQS.

Zeiss Inspect 2025 introduces new features, further increasing throughput, performance, and efficiency for 3D scanning and CT inspection.

Zeiss Inspect Optical 3D is the standard for the inspection and evaluation of 3D measuring data. It now provides a more intuitive, task-focused workflow for surface defect detection, supports scanning with multiple types of sensors in one project, and includes an optimized inspection workflow assistant for clear guidance, making it more user-friendly.

With the new release of *Zeiss Caligo* customers can export data automatically into *Zeiss Inspect Optical 3D*. Enabling faster data transfer and polygonization of the point cloud and extending evaluation capabilities.

Zeiss Inspect X-Ray enhances highly automated CT data inspection and enables efficient workflows. A novel concept for the simple handling of complex multi-component parts simplifies the inspection. Using new Multiview interface options customers can display different views in several combinations and conveniently inspect parts from multiple perspectives.

AI-based inspection is transforming production and quality assurance.

Automated inspection processes increase efficiency and quality while reducing costs. Routine tasks can be automated using AI models trained by machine learning. These models can easily be generated and used without being an AI expert. One application example is AI-based defect detection for CT data. Turning data into meaningful insights and thus improving efficiency and data quality.

Zeiss PiWeb 2025 introduces the *PiWeb Monitor* as a new browser-based application, allowing users to view and share reports effortlessly without installation. It retains key features like interactive CAD models and statistical analyses. The update also includes flexible data import with plug-ins, centralized license management, enhanced statistical tools, streamlining measurement processes and improving data analysis.

With the newly launched product family *Zeiss Connected Quality*, Zeiss IQS enhances its software portfolio with an innovative solution that seamlessly connects measuring systems, operators and quality data worldwide. The central collaboration platform for global quality operations introduces a whole new level of efficiency and data exchange. With its comprehensive software portfolio Zeiss IQS enables efficient quality inspection and data management, providing industries with reliable tools to ensure product excellence.

zeiss.com

LMT Tools

OFFERS HIGH-PRECISION, AUTOMATICALLY ADJUSTABLE TOOLS WITH FOUR CUTTING EDGES

The customized design of complex tool solutions is one of LMT Tools' greatest strengths. The engineers in the "Advanced Tools" division support their customers as a strategic technology partner and use their decades of experience and high level of technological and application expertise to create high-performance tool systems that are 100 per cent tailored to the respective customer requirements. The latest development stage: four-edged automatically adjustable tools with maximum performance, precision, flexibility and process reliability.

Automatically adjustable tools are tool systems with movable cutting edges that can be controlled via a drawbar in the tool and slides. They enable the machining of complex component geometries in a single clamping operation and are primarily used in the automotive industry. With four-edged automatically adjustable tools, LMT Tools offers customized high-performance tools for a productive machining process with short cycle and nonproductive times, high component quality and maximum process reliability.

The tool system has four cutting edges, a stable, centrifugal force-resistant design and high-precision, complex tool/insert components, allowing high cutting speeds with impressive precision and first-class surface quality. This leads to a significant reduction in cycle times resulting in cost savings. The four cutting edges can be adjusted continuously, highly accurately and evenly in the micrometer range (transmission ratio 1:4) and ensure µm-precise machining of a wide range of contours and diameters in one component with just one tool. The controllable cutting edges also allow any tool wear to be compensated for quickly and easily via the machining center control system. Manual adjustment is no longer necessary, which reduces downtime and increases productivity.

Depending on the application conditions and the material to be machined, indexable inserts with different cutting materials and geometries are used. For example, inserts with wiper geometry ensure the best surfaces and PCD-tipped inserts guarantee maximum performance when machining engine components and aluminum housings. Three levels can be set on the clamping holder—diameter, length and angle. This contributes to an excellent surface finish. The four-edged automatically adjustable tools are equipped with a central coolant supply that directs the coolant specifically to each cutting edge. The effective cooling and optimized chip removal increase productivity and maximize process reliability.

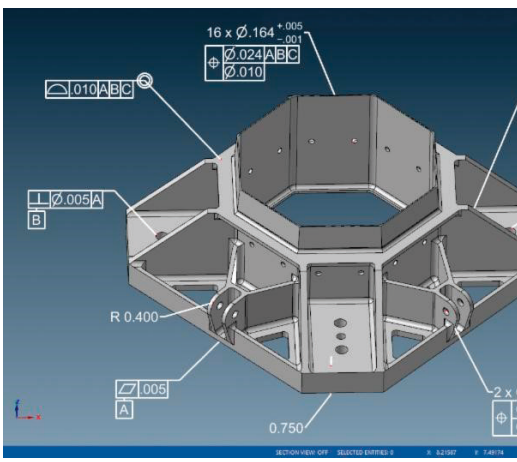
"Automatically adjustable tools offer a high degree of flexibility and cost-effectiveness and are an ideal choice for complex machining processes with tight manufacturing tolerances, for example in the automotive industry," says Rene Seger, project engineer, advanced engineering at LMT Tools, adding "Our actuating tools with four cutting edges fulfill the highest demands in terms of precision and surface quality and guarantee short cycle times with the greatest possible process reliability. Together with the customer, we develop the optimum tool solution for their application-specific requirements. In doing so, we keep an eye on the entire production process."

lmt-tools.com

Verisurf

DEMONSTRATES MACHINE TOOL PROBING SUITE

Verisurf Software, Inc. demonstrated its new *Machine Tool Probing (MTP)* suite at IMTS 2024. The solution is designed to support in-process inspection directly on CNC machine tools. As the only CAD/CAM-based metrology software on the



market. Verisurf continues to build on its heritage of intelligent Model-Based Definition (MBD) with new features, enhancements, and optimized workflows for inspection, reporting, reverse engineering, tool building, and guided assembly.

MTP extends Verisurf's commitment to universal compatibility and offers manufacturers inspection and reporting options beyond typical CMMs. Autonomous on-machine milling and inspection are accomplished with a single setup. CMM hardware costs are eliminated, parts (especially large parts) do not need to be moved to and from the metrology lab, environmental stability is maintained, no additional fixtures or realignment of parts is necessary for measurement, and the closed-loop process improves overall process control.

Verisurf Software is configured in application modules delivered through powerful solution suites designed to optimize the user experience and execution of workflows. The Verisurf user interface presents applications in a Windows ribbon bar style. This provides a familiar user experience and enables new and existing customers to quickly identify and utilize each solution suite's workflows and underlying features, tools, and capabilities, helping to maximize their metrology investment.

"The Verisurf *MTP Suite* provides extended flexibility for quality inspection. Our no-code programming and open platform compatibility allow customers to create automated inspection plans with unmatched efficiency that can be executed on stationary or portable CMMs, and now, on all equipped CNC machine tools as well," said Ernie Husted, Verisurf's president and CEO.

Verisurf is built on the Mastercam platform, which allows the CAM and CAI (Computer Aided Inspection) programming to be generated using the same software. This provides numerous benefits over other on-machine inspection applications. The programming process and file management complexity are reduced, measurement results can be directly applied to improve machining, and overall process control is increased by closing the loop between the physical machined part and the intelligent CAD model.

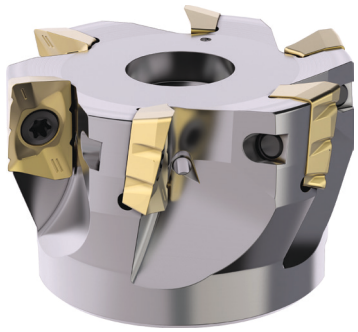
verisurf.com

Seco Tools

INTRODUCES LATEST CHIP SPLITTER MILLING INSERTS

Seco has introduced two new chip splitter milling inserts that lower the stress on both the machine and cutting tool for improved milling process stability. The Turbo 12 and 18 chip splitter inserts for the company's Turbo cutters—available in five grades for both square shoulder and helical milling cutters—significantly reduce chatter, vibration and stress on manufacturing equipment.

The Turbo 12 and 18 chip splitter inserts incorporate grooves on both of their cutting edges to minimize chip size and reduce cutting forces without reducing cutting data and depth of cut. By keeping chips as small as possible, shops lessen the risk of chip jamming, which improves process security and allows for more effective machining of deep pockets.



Product managers, Magnus Engdahl and Michael Davies work in tandem and spearhead the team who develop the inserts. "The Turbo 12 and 18 chip splitter milling inserts apply to various machining applications and materials," said Engdahl.

"The versatility of the inserts makes them suitable for a wide range of industry segments and materials, providing customers with a flexibility," adds Davies.

Hard-to-reach part features can pose challenges, and even the most robust combinations of machine and tool can struggle with long overhangs. Seco chip splitter inserts overcome these challenges by effectively evacuating chips from deep pockets for improved chip flow. Plus, Turbo 12 and 18 chip splitter inserts reduce chatter commonly associated with long-reach applications, resulting in longer tool life and better surface finishes.

Because of their stability and ability to reduce cutting forces, Turbo 12 and 18 chip splitter inserts give shops the much-needed process security and reliability required for effective unattended machining operations. As a result, shops increase output while also minimizing stress on the machine and tool.

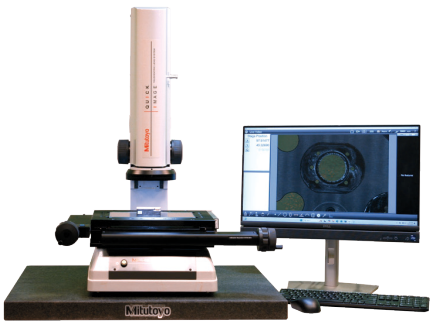
secotools.com

Mitutoyo America Corporation

RELEASES NEW *METLOGIX M3* WITH THE MITUTOYO QUICK IMAGE VISION SYSTEM

Mitutoyo America Corporation, a leader in precision measuring instruments, is

excited to announce the integration of the powerful *Metlogix M3* software into the Mitutoyo Quick Image (QI) 2D Vision Measuring System. This latest enhancement promises to elevate the precision and efficiency of noncontact measurements, further solidifying Mitutoyo's commitment to providing innovative technology solutions to meet modern quality control needs.



Unmatched Efficiency and Ease of Use

The integration of *Metlogix M3* software transforms the Quick Image system, known for its superior accuracy and ease of use, into an even more robust tool for noncontact measurements. The *M3* software introduces a highly intuitive, icon-driven interface designed for simplicity and speed.

Key Features of the *Metlogix M3* Software with Quick Image:

- Pattern-Based Measurements: The *M3* software provides innovative pattern-based tools that simplify the measurement process, making it easy to measure multiple points in a single action. This dramatically reduces setup time and increases productivity.
- Advanced Video Probes: The software's advanced video edge detection tools, such as EyeMeasure and MeasureLogic, enable fast, accurate edge and feature capture. The VTouch probe brings unprecedented functionality by allowing video-based touch probing for quick acquisition of individual points.
- Field of View Measurement: Metlogix's powerful Field of View (FOV) functionality automates part measurements by simply placing multiple parts in the camera's view. The system detects, measures, and displays results without the need for operator intervention, streamlining the inspection process.
- SuperImage Stitching: For larger workpieces up to 400 mm, the Quick Image system utilizes an ultra-long 90 mm working distance to capture and stitch multiple frames into a single image with Metlogix's SuperImage feature. This function enhances accuracy and clarity over larger areas while allowing flexible, soft fixture setups for repeated measurements.

Versatility and Scalability

With the enhanced capabilities of the *M3* software, the Quick Image system can support a wide range of workpiece sizes, measuring up to 400 mm with its stage stitching function. This ensures that manufacturers can measure larger components with precision and efficiency.

mitutoyo.com

Vector company photo at Mine Expo 2024 in Las Vegas.

108 Years Old Is the New 30

Why AGMA's tenure doesn't affect its relevancy to a modern manufacturer

Rebecca Brinkley, Senior Director, Member Engagement, AGMA

It was a busy year for the gear industry. Large and small companies had to navigate the interest rates, tariffs, supply chain disruptions, labor shortages, and the unknown economic outlook with an election year in the U.S. Leaders that normally would be brainstorming their five-year strategic plans had to get comfortable with a day-to-day strategy. As each quarter ended, however, AGMA witnessed resiliency, innovation, collaboration, and even quite a bit of growth for some sectors—it was an exciting year to visit members in person.

AGMA Member Federal Gear showcases various-sized projects they handle at their manufacturing plant in Cleveland.

AGMA staff, including myself, logged thousands of miles traveling worldwide to see first-hand the incredible work that manufacturers and suppliers do to keep the industry healthy and up to date with emerging technologies, smart factories, apprenticeship programs and so much more. The right association does not just support its members from behind a desk but goes to events, tradeshows, manufacturing plants, and conferences to connect those it serves—AGMA goes where its members are, and that is how we can offer the best value even after 100 years.

One of the most consistent things between all the places I traveled was the focus on modernizing the plant floor, creating sustainable solutions to improve processes and life cycle, communicating with end users, and, as usual, growing and training the future workforce. Let's take a deeper dive into what much of this means for those here in the U.S. and what we saw at the international level.

Modernization of the Manufacturing Process

Four years ago, AGMA dedicated a full-time person to developing an Emerging Technology department to: "Identify, investigate, and inform AGMA members of emerging technologies that may disrupt or significantly impact the gear manufacturing industry." The AGMA Board of Directors and staff built the department based on members' needs to further understand what could affect their business on a technological level and to be the conduit for subject matter experts to share real-time data and solutions through webinars, guest speakers, or industry events. Many of the members who

AGMA Member Forest City Gear CEO Kika Young shows AGMA's Senior Director, Events & Education, Leah Lewis, some of the products they manufacture at their facility in Rockford, IL.

Head of Customer Service Cutting and Grinding Oils at Blaser Swisslube, Patrick Toenz, teaches Senior Director, Member Engagement, AGMA, Rebecca Brinkley how to measure and detect impurities in lubrications to avoid any downtime in manufacturing.

visited this year expressed the unparalleled value that this department has brought to their plant managers, operators, and even the leadership at the strategic planning level.

Across the globe, smaller factories brought in automation for the first time. They invested in having the capability to remove the third shift, if necessary because they had a cell that could work overnight to complete work. Many did not know if bringing in robotic arms or more sophisticated machines would be financially viable. Still, they beamed with pride when demonstrating the efficiency and productivity the technology made possible. Although some employees are still skeptical about how their future fits with the "machines," they do acknowledge that there is more flexibility. As automation becomes more mainstream and affordable, one question remains: Now, you are not just bringing in a robot; how do you train your current operators to run it?

Sustainability of the Manufacturing Process

You will hear the word sustainability if you have visited a tradeshow, conference or manufacturing company in Europe recently (along with many other places). This is where many of the visits differed among members – the focus of what that word means. For some, it is a marketing term that meets the demands of what the end user's consciousness tells them to buy, but for others, it is an authentic way of life. From government regulations to company footprint policies, many suppliers and manufacturers prioritize clean energy, operational efficiencies, protecting natural resources and environments, and just taking a long-term approach to how they offer solutions. I could see charts on plant floors, listen to staff meetings at foundries, and learn how companies want to maximize the importance of "thinking before doing" in all parts of their jobs.

AGMA Board Member, Star SU President, Andreas Blind and Director of Marketing, Mark Parillo, stand in front of their gear-cutting tools table at the 2024 IMTS in Chicago.

A new AGMA Member Affolter Group apprentice demonstrates learned machining skills at the manufacturing facility in Bien, Switzerland.

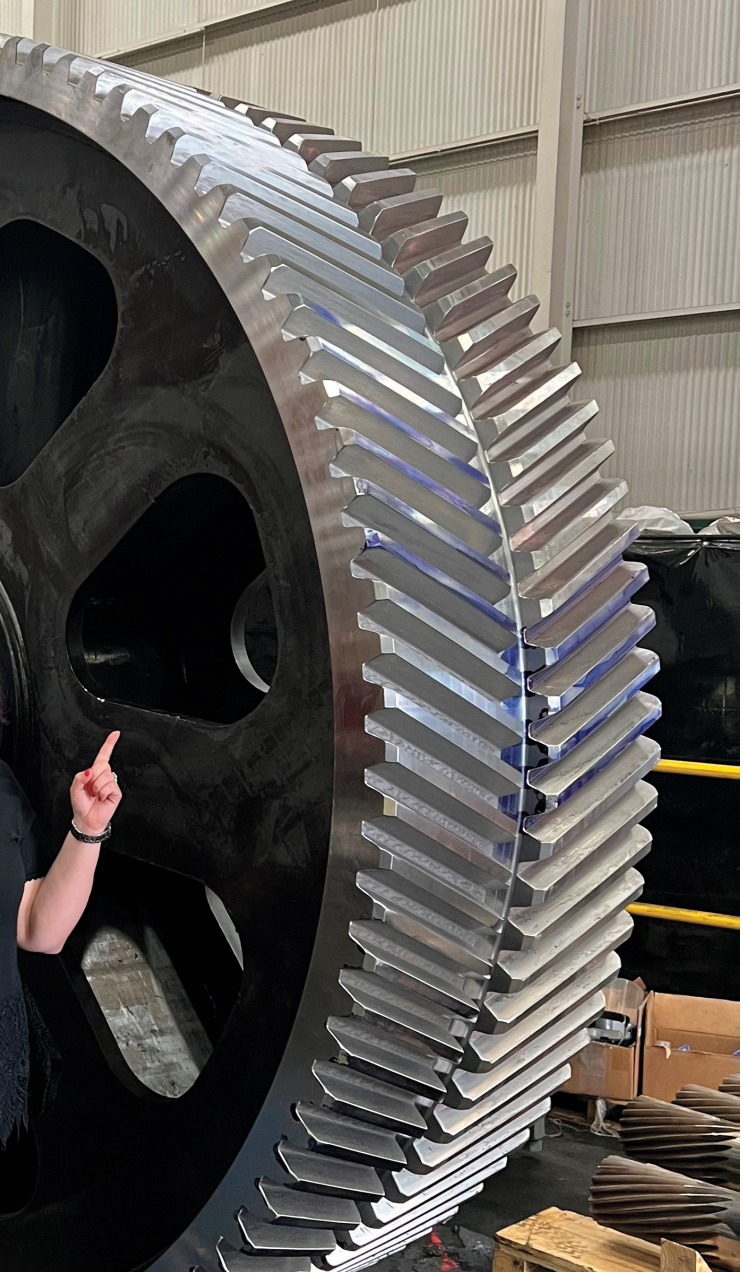
AGMA's Senior Director, Member Engagement, Rebecca Brinkley, stands shocked after seeing a giant double helical gear at her recent Horsburgh & Scott visit.

It is important to note that even with the best intentions, sometimes the job needs to get out the door as quickly as possible. Many manufacturers stated that for most of the year, they were not even out to bid—they either did not have enough capacity or lead times, pushing them back with some supply chain issues. Either way, it is all hands on deck, and although they will meet the regulatory requirements, the sustainability effort might take a back burner to meet customers' demands. If you are in the defense, aerospace, space or medical industries—you might be able to relate to this. Either way, we see an increase in the number of members talking about the subject; AGMA is committed to ensuring that all the regulations, government contract requirements and other important resources are discussed during our Trade Webinars—another way we offer value to the modern manufacturer.

Workforce of the Manufacturing Process

Having a well-trained staff has been a challenge for the trades for decades. Whether it is the reputation of doing dirty jobs, the lack of decent pay, or just difficult hours to balance a family and work, people have not given manufacturing jobs a fair shake, and our members feel it. It does not matter what country you work in; the workforce issue is everywhere. When touring many factories, it was evident that machines were left unused and entire cells were dark from months of not having enough staff. Although that is not a great news story, it is a truth that many people face and, therefore, find ways around it. Many staff saw fewer people at tradeshow booths to avoid disruption back at the plant, some events did not attract two or three people from the same company to avoid downtime, and unless the programming was imperative, our Gear Geeks had to weigh out the ROI of each thing they signed up for.

AGMA has pivoted to meet this issue by offering many resources online. The Workforce Training Series, the three online courses that are free to members, has been fully revamped and updated to help businesses provide an immediate training tool right from the comfort of their computers. Other classes have been put online and now, more than ever, our instructors have been contracted to go onsite to teach operators on their machines. The business saves money on travel and hotel expenses, and its employees get to apply the skills they have learned in their direct work environment. This value goes far beyond the dollar and can ensure employees feel invested, making them stay longer.



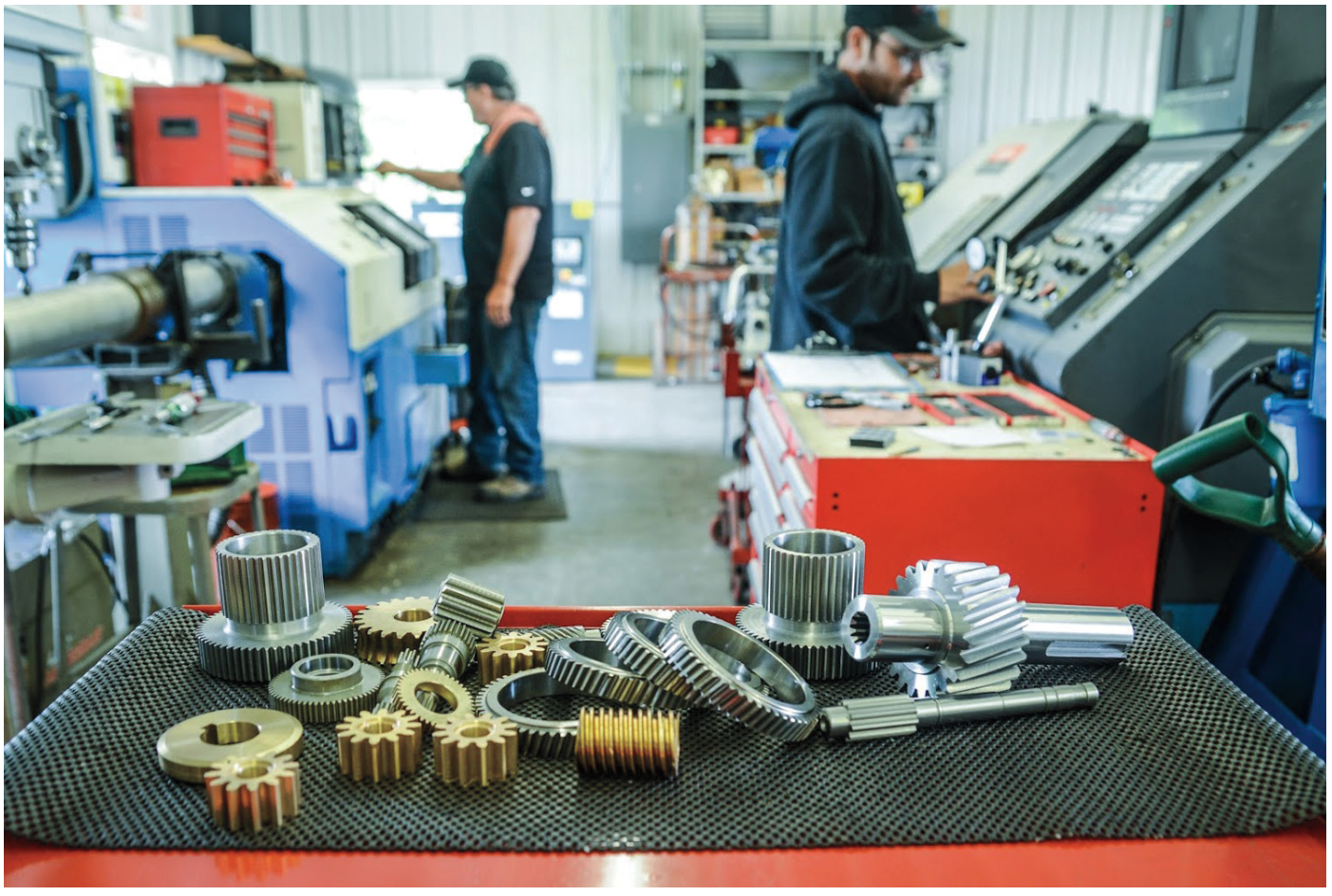
Our association's job is to make our members' jobs easier. Whether that is through being the periscope for emerging technologies and gathering subject matter experts to share realistic solutions or through offering education to help teach and grow their workforce, AGMA and its Board of Directors work diligently with members to drive the value of what is included with membership. Traveling around the world to visit with hundreds of members in 2024 gave us great insight into the needs and wants of those on the plant floor and in the C-Suite. We are grateful to be the resource many in the gearing community consider their go-to. We love gathering our industry professionals and talking about the important things happening to them and because of them. A great deal of planes, trains and automobiles later, I still think that I have the best members on the planet, and I know my fellow AGMA staff members are working to ensure that we reach another 108 years of providing value (but still only looking 30)!

agma.org

Gearing Up for Success

Transforming workplace culture in gear manufacturing

Lisa Ryan, Certified Speaking Professional



As you navigate the ever-evolving landscape of gear manufacturing, it's become increasingly clear that success isn't solely determined by the precision of your machines or the latest technological advancements. While these factors remain crucial, the true differentiator in today's competitive market lies in cultivating and nurturing your most valuable asset: your people.

Picture this: You're standing on your gear manufacturing floor, surrounded by the rhythmic hum of cutting-edge machinery and the gleam of freshly milled gears. You've invested in the latest technology and top-notch equipment. Your team possesses the technical expertise to produce components that power clean energy solutions, drive vehicles safely across continents, and push the boundaries of what's possible in countless industries. Yet, something feels off. Despite all the precision in your gears, your workplace culture could use some fine-tuning.

In my years of working with manufacturers, I've seen this scenario play out time and time again. The solution isn't always about buying the newest machine or implementing the latest software. Often, it's about something much more fundamental: how you treat each other and approach your work each day. It's about creating a culture that values both your machines' precision and your people's potential.

In this article, we're going to explore a framework that can transform your workplace culture and keep your team engaged, motivated, and loyal. We'll dive into six key areas that, when addressed, can make a significant difference in your day-to-day operations and long-term success.

The Six Gears of Grategy

1. Attitude: Your Foundation for Progress

In gear manufacturing, where microns make the difference between a smooth-running transmission and a noisy failure, attitude is the bedrock that supports everything else. It's not just about being positive; it's about being open to change and willing to see the real picture of what's happening in your plant.

Remember the introduction of advanced grinding technologies? Some saw it as a threat, while others viewed it as an opportunity to enhance their capabilities. The companies that thrived were those with leaders and teams who had the right attitude—open to new technologies and willing to adapt their processes.

To cultivate a productive attitude in your organization:

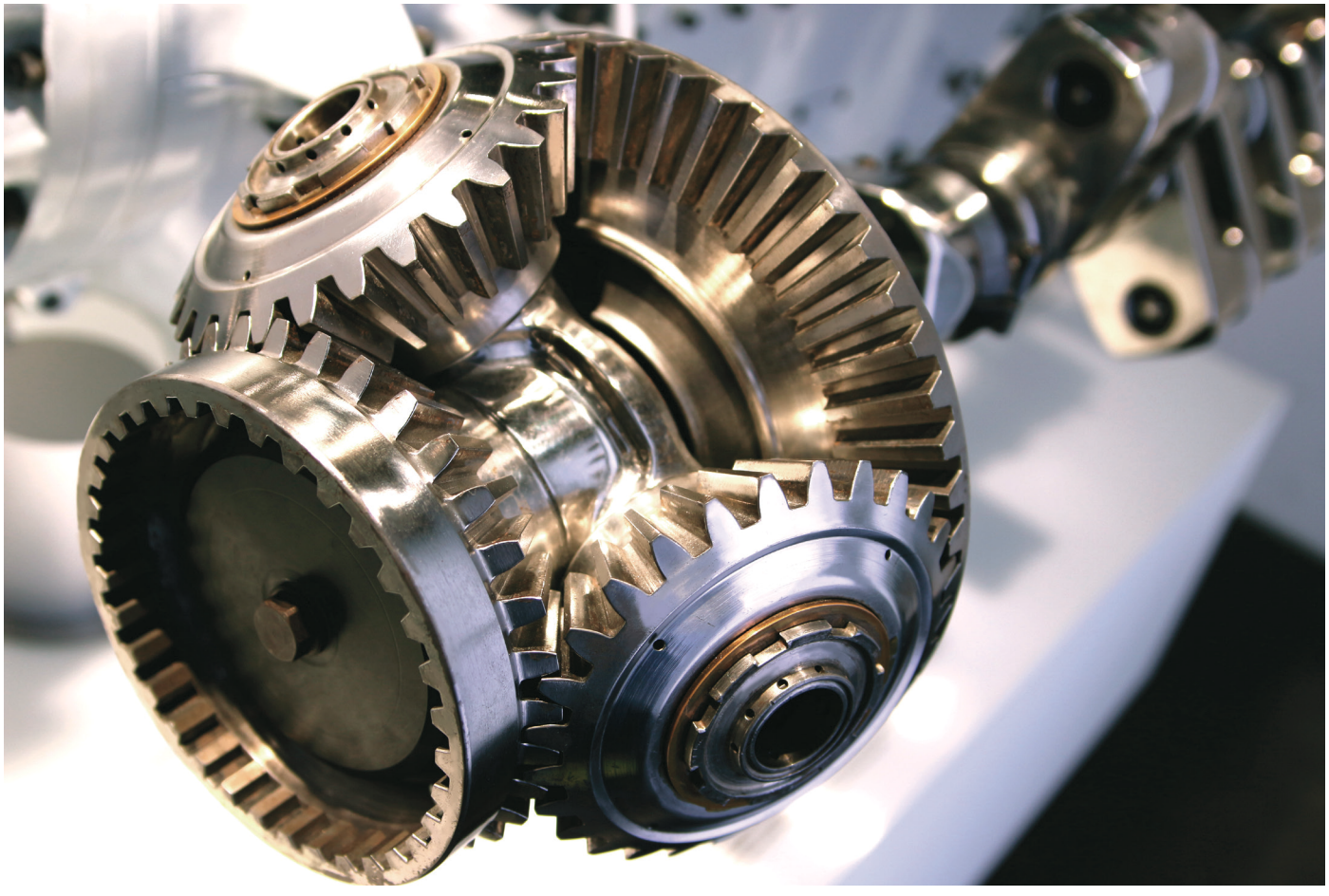
- **Embrace reality-based thinking.** Don't shy away from hard truths about your operations. If your OEE (Overall Equipment Effectiveness) isn't where it should be, acknowledge it openly. This honesty creates a foundation for real improvement.
- **View challenges as opportunities for growth.** When faced with a difficult customer requirement, instead of thinking "We can't do that," ask "How can we make this work?" This shift in attitude often leads to innovative solutions and can even open up new market opportunities.
- **Lead by example.** As a leader, your attitude sets the tone for the entire organization. If you're resistant to change or unwilling to acknowledge problems, your team will follow suit. On the flip side, if you approach challenges with enthusiasm and a problem-solving mindset, you'll inspire your team to do the same.

2. Appreciation: An Unexpected Tool for Operational Excellence

Appreciation, in this context, is about training your mind to find the good, no matter what's happening around you. It's a powerful tool that can help you maintain a positive outlook even when facing the toughest challenges in your operations.

Try these three strategies to cultivate appreciation:

- **Start a daily gratitude journal.** At the end of each shift, write down three things that went well or that you're grateful for. It could be as simple as a machine that ran without a hitch, a problem you solved in a complex design, or a moment of clarity in a challenging project. This practice trains your brain to look for the positive, even on the toughest days.
- **Practice mindful observation.** Once a day, take a moment to truly observe your operation. Notice the precision of your machines, the skill of your operators, or the quality of your finished products. Appreciating these details can reignite your passion for the work and help you see your daily tasks in a new light.



- **Find gratitude in setbacks.** When things go wrong—and in manufacturing, they sometimes do—challenge yourself to find something to be grateful for. Perhaps a failure in a heat treatment process led to an important discovery, or a delay allowed time for an even better solution to emerge.

3. Access: Unlocking the Genius on Your Shop Floor

Here's a wild idea: The next big innovation in your gear shop might come from the person you least expect. That's what access is all about—creating an environment where ideas can flow freely, regardless of job title or years of experience.

Consider these approaches:

- **Implement an open-door policy.** Or better yet, a no-door policy. Make it easy for anyone to share ideas. This could mean regular walk-throughs where you engage with operators and ask for their input on process improvements.
- **Set up a suggestion box (physical or digital) where people can submit ideas anonymously.** Review these suggestions regularly and implement the best ones. Then, make sure to publicize the improvements and credit the innovators.
- **Hold regular brainstorming sessions.** Make them engaging—maybe over a pizza lunch. You'd be amazed at what people come up with when they're relaxed and feel heard. Topics could range from ways to reduce setup time to ideas for improving shop floor organization.

Remember, the person operating a gear grinding machine day in and day out often has insights that even the most experienced gear engineer might miss. By creating an environment of open access, you're tapping into a wealth of knowledge and creativity that could revolutionize your operations.

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4. Applause: Celebrating Success, One Component at a Time

In your world, you're often so focused on what went wrong (that tolerance that was off by a hair, that delivery that was 10 minutes late) that you forget to celebrate what went right. And that's a missed opportunity.

Here's how to start:

- **Did your team just complete a big order ahead of schedule?** Celebrate it! This could be as simple as a company-wide email acknowledging the achievement, or as elaborate as a catered lunch for the team.
- **Did someone figure out a way to reduce setup time on a tricky helical gear?** Shout it from the rooftops (or at least the shop floor)! Consider creating a "Wall of Fame" where innovative solutions are showcased.
- **Implement a peer recognition program.** Sometimes the best applause comes from colleagues. Set up a system where team members can nominate each other for outstanding work. This not only boosts morale but also encourages a culture of excellence and mutual respect.

Remember, in manufacturing, you're often dealing with tolerances that are invisible to the naked eye. But that doesn't mean your celebrations should be equally microscopic. By applauding successes, both big and small, you're reinforcing the behaviors and attitudes that drive your company forward.

5. Acts of Service: Manufacturing a Better Community

Community engagement isn't just about feeling good or boosting your PR. It's about crafting a future where your business can thrive. Think of it as precision community calibration.

Consider these approaches:

- **Partner with local schools for STEM programs.** You're not just helping kids; you're potentially manufacturing your future workforce. This could involve hosting field trips to your facility, sponsoring robotics teams, or offering internships to promising students.
- **Open your doors for facility tours.** You're not just showing off shiny machines; you're buffing away those old, rusty perceptions of manufacturing. Invite local business leaders, educators, and community members to see modern manufacturing in action.
- **Participate in local events.** It's about calibrating your business to the needs and values of your community. This could mean sponsoring a local sports team, participating in charity runs, or setting up a booth at community fairs to showcase the high-tech nature of modern gear manufacturing.

By engaging with your community, you're not just being a good corporate citizen. You're also addressing one of the biggest challenges facing your industry: the skills gap. By showing young people the exciting, high-tech nature of modern manufacturing, you're helping to ensure a pipeline of skilled workers for the future.

6. Accountability: The Secret Sauce of Excellence

In your world, accountability isn't about pointing fingers. It's about empowerment.

Here's how to build a culture of accountability:

- **Set clear expectations.** Make sure everyone knows not just what they're supposed to do, but why it matters. This goes beyond job descriptions. It's about helping each team member understand how their work contributes to the bigger picture.
- Implement KPIs that truly reflect what's important—not just production numbers, but quality metrics, innovation goals, and customer satisfaction. For example, track not only gears produced per hour, but also first-pass yield rates, customer returns, and on-time delivery percentages.
- Make it safe to fail. I know, in your business, failure can be costly. But if your team is afraid to try new things or speak up when they see a problem, you're missing out on potentially game-changing innovations. Create a culture where "fail fast, learn fast" is the norm.

Accountability also means recognizing and rewarding those who consistently meet or exceed expectations. This could involve performance-based bonuses, opportunities for advancement, or simply public recognition of a job well done.

Manufacturing Your Stronger Future

As you implement these six gears, it's crucial to recognize the unique characteristics that will shape the 2025 workplace and beyond. Today's workforce is more digitally connected, culturally diverse, and values-driven than ever. Employees are not just looking for a paycheck; they seek purpose, growth, and a sense of belonging. This shift calls for a fresh approach to leadership—empathetic, flexible, and forward-thinking.

In this new landscape:

- **Connect work to a greater purpose:** Clearly communicate your company's mission and how each role contributes to it. Encourage employee input to foster a sense of ownership and pride in their work.
- **Invest in professional development:** Offer training programs and mentorship opportunities that help employees level up their skills. Regularly discuss career aspirations and provide support to achieve these goals.
- **Prioritize effective communication:** Ensure transparent and open communication at all levels. Set clear expectations and create an environment where feedback is not just welcomed but acted upon.
- **Create a positive work environment:** Ensure your team has the resources they need to succeed and promote a healthy work-life balance to keep stress at bay.
- **Show gratitude and appreciation:** Never underestimate the power of a 'thank you'. Use both verbal recognition and nonverbal gestures to make a big impact.
- **Understand the ripple effect of appreciation:** Recognize that a happy team leads to happy customers and lower turnover rates.
- **Embrace the manager's role in engagement:** Practice active listening to understand your team's needs and be adaptable to new strategies when necessary.

So there you have it—the Six Gears of Grategy. I know what you're

thinking. "Lisa, this all sounds great, but I've got gears to make and deadlines to meet." I hear you. But here's the thing: in today's world, making great gears isn't enough. To really succeed, to attract and keep the best talent, to stay ahead of the competition, you need more than just precision machines. You need a precision culture.

Remember, you're not just making components. You're making parts that power clean energy solutions, drive vehicles safely across continents, and push the boundaries of what's possible in countless industries. That level of importance demands more than just technical skill. It demands a culture of excellence, innovation, and yes, gratitude.

Implementing these strategies isn't always easy. It requires commitment, consistency, and sometimes, a willingness to step out of your comfort zone. But the payoff can be enormous. Imagine a workplace where problems are seen as opportunities, where innovation flows freely from all levels of the organization, and where every team member feels valued and understands their role in the bigger picture of gear manufacturing.

That's the kind of workplace that not only produces precision parts but also precision people—skilled, engaged, and committed to excellence. It's the kind of workplace that can weather economic ups and downs, adapt to technological changes, and consistently deliver value to customers.

So, if you're ready to start gearing up for a stronger future, with these Gears of Grategy in place, you'll be cutting through challenges and polishing your success in no time. The future of manufacturing isn't just about better machines—it's about better cultures. And that future starts with you.

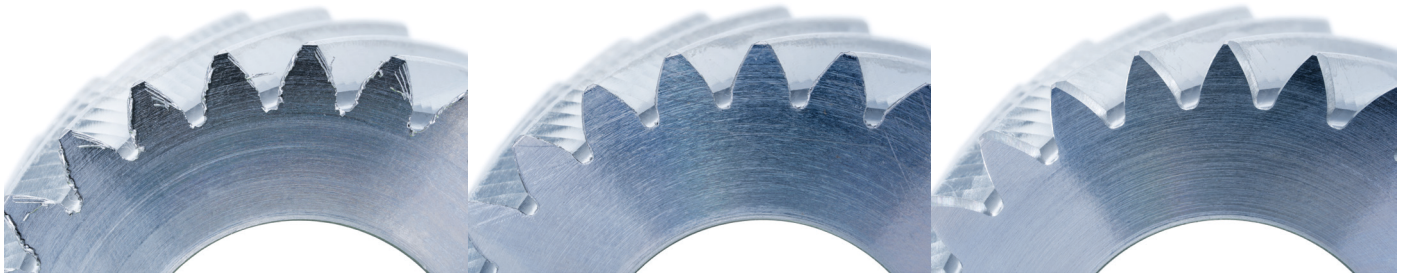
lisaryanspeaks.com

Lisa Ryan is the Chief Appreciation Strategist and Founder of Grategy, where she specializes in workplace culture transformation through the strategic application of gratitude.

Chamfering Can Make the Difference—The Choice Is Yours

Match the ideal solution to the workpiece

Gottfried Klein, Director of Product Management, Soft Machining Solutions, Gleason Corporation



Gear hobbed with remaining hob burr (left). Gear hobbed and rough deburred during hobbing (middle). Gear after hobbing, rough deburring and then chamfer hobbing in parallel with hobbing (right).

They say necessity is the mother of invention. The arrival of a new generation of cylindrical gear chamfering solutions in recent years isn't by accident. Gear manufacturers who might have turned a deaf ear to a new chamfering technology just a few years ago now welcome it with open arms. After all, the benefits of quality chamfering are now well-known, and their application is near-mandatory. Inadequate and uneven chamfers cause extraordinary costs when applying expensive hard-finishing tools down the value stream. Gears that aren't properly chamfered and deburred can lead to overloaded edges and unanticipated and undesirable noise. This is particularly true in EV applications where torque transmission, unlike combustion engine vehicles, goes from zero to a much higher maximum almost instantly. As a result, EV gears require hard finishing (honing and threaded wheel grinding), and chamfering/deburring becomes critical. In the case of honing, a burr as small as just a few microns left on the hardened flank of a gear can cause excessive and costly wear on the honing ring, increasing tool cost and reducing productivity.

Nonetheless, gear manufacturers are wary of introducing anything to their processes that will appreciably increase cost-per-piece. Chamfering solutions must be both effective and extremely economical. Ideally, they should be ingeniously paired with preceding soft-cutting machines so that the long-term total cost of ownership becomes virtually unnoticeable—at most just a penny or two per piece. No single chamfering solution fits all. Each offers advantages and disadvantages that can rule them out, given the needs of a particular application, or make them the perfect fit.

For comparison purposes, let's look at several common and most recent chamfering technologies and their likely range of applications from small workpieces produced in high volumes to larger workpieces produced in lots as small as one.

Chamfer Rolling for High-Volume Production

Chamfer rolling with secondary deburring discs. A very fast process that can, however, form a secondary burr that must be removed downstream.

Sometimes referred to as press chamfering or rotary chamfering/deburring, this very fast forming process has been around for years, and it is used effectively for high-volume production of planetary gears or shafts with interfering contours. Using gear-

shaped tools that mesh with the workpiece creates chamfers along the tooth edges. Excess material flows mainly to the face side of the gear, where it's cut away with single blades, deburring discs, or file discs, depending on gear shape and/or machine configuration. However, the forming process can result in a minute deformation of the workpiece and material flowing into the gear tooth flank itself, thus forming a secondary burr that must be removed in yet another operation before hard finishing downstream. Additionally, with dry machining now predominant, the forming process isn't as efficient as when performed wet, reducing tool life. For EV applications in particular, these factors can combine to raise costs to prohibitive levels.

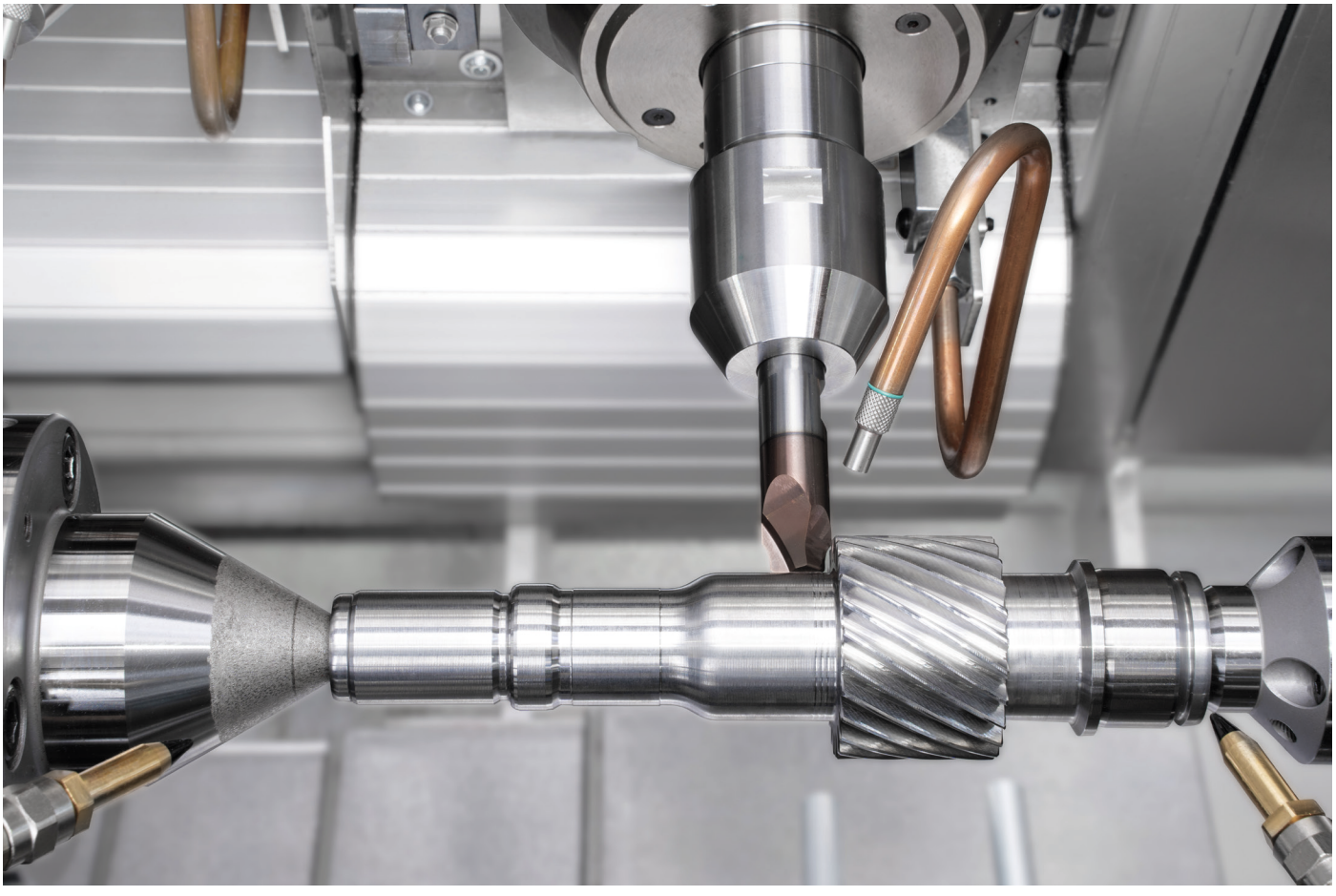
Radial Chamfering for Small to High Volume Production

Chamfer rolling is a poor choice for EV transmission gears, pinions, and shafts; new chamfering processes are needed. One of these is radial chamfering. It can now be applied in parallel with gear hobbing for the first time. Rather than forming the chamfer through rolling, it is produced with a cutting process using either one or two resharpenable milling cutters, thus eliminating a subsequent operation to remove the excess material that can result from chamfer rolling. With cycle times and tool cost per piece of paramount importance, replacing chamfer rolling with radial chamfering makes perfect sense—particularly for shaft-type parts. These shafts, often with the root diameter of the chamfered gear and the shaft diameter in close proximity, are inherently more difficult to chamfer and deburr due to the clearance requirement. Radial chamfering is the right chamfer process for gears with adjacent contours that need to be shaped or power skived as well. Even with just a few millimeters gap common to cluster gears, double pinions or rotor shafts, radial chamfering with the proper tool design offers the ideal solution.

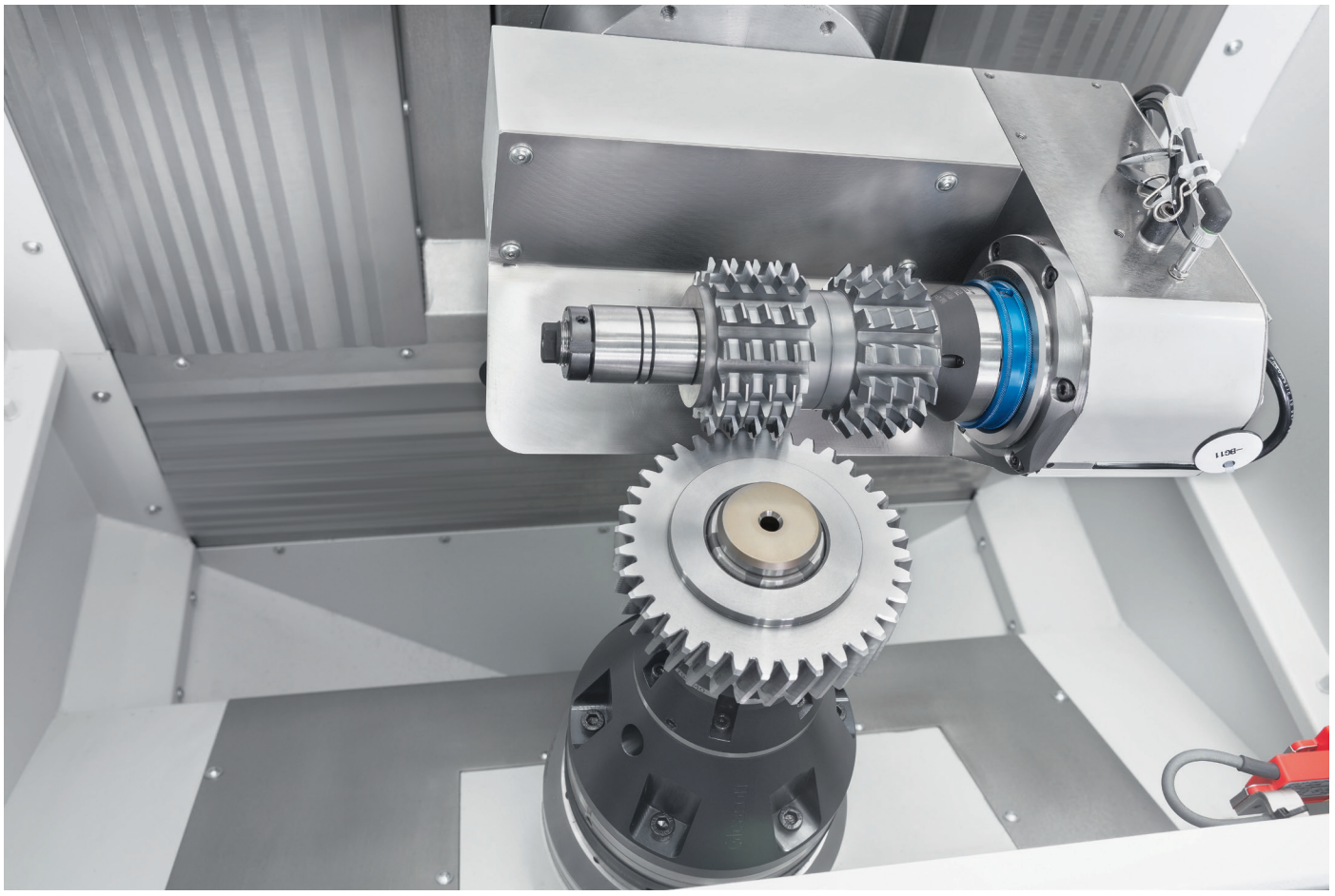
A single radial chamfering tool can be designed for chamfering the gear flanks, with or without root chamfering. A two-tool option adds more flexibility to adjust the chamfer angle with tools specifically designed for the obtuse and acute edges to meet a customer's specific design requirements before the subsequent hard-finishing operations. This is particularly advantageous in the case of gears with high helix angles where obtuse and acute angles can be quite different. Using Gleason simulation software, chamfer form, angle, width and even the expected inspection graph will be defined in advance.

Chamfer Hobbing for Medium to High Volume Production

While chamfering with hobs has been known for decades, chamfer hobbing takes the process to a new level. Chamfering is performed using a Gleason chamfer hob. The cutting tool has characteristics very similar to a gear hob. It is made with high-speed steel and features AlCroNite Pro coating for exceptional tool life in dry-cutting conditions. With Gleason chamfer hobbing, one chamfer hob is



Radial chamfering for shafts and gears with collision issues and shortest cycle time requirements.



Chamfer hobbing with low tool cost.

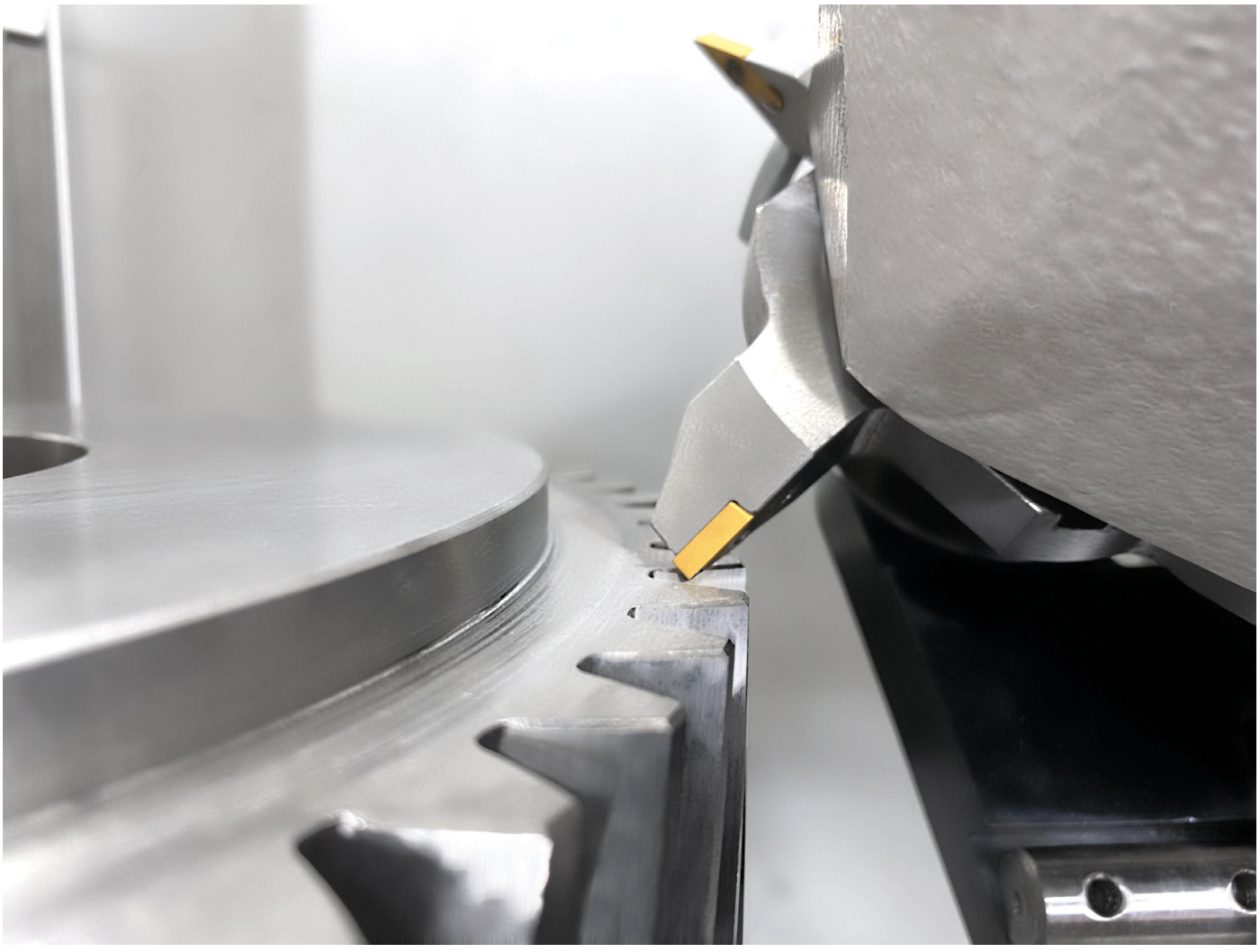
used for each tooth flank, with a tooth profile specifically designed for the chamfer form that's required. The chamfer hob looks like a standard gear hob but with asymmetric teeth. One flank is designed for cutting the chamfer, the other flank is designed not to touch the counter flank. This process delivers great flexibility regarding required chamfer angles. Typically, parallel-chamfer forms are cut along the tooth edge only or including the root area. Chamfer angles like those commonly produced in the chamfer rolling process are targeted (15–30 degrees on the obtuse edge, 25–35 degrees on the acute edge). In the chamfer hob design process, Gleason technology software is used to simulate the required chamfer and identify and avoid all potential collisions of the tools with the counter flank and interfering contours above and below the actual gearing. By cutting into the gap, burrs are avoided on the face side of the gears. With typical chamfer angles, there are no measurable burrs on the flank that require removal downstream. These factors, plus tool shifting to more evenly distribute wear and extend tool life, result in the absolute lowest tool-cost-per-piece: just one cent or less on average for a typical EV intermediate gear.

Fly Cutter Chamfering

While fly cutter chamfering has long been used in bevel gear cutting applications, it has just recently been made available for larger (truck-size) cylindrical gear production and those applications where maximum flexibility and frequent part changeover make the use of dedicated tools (e.g., chamfer rolling and chamfer hobbing) prohibitively costly. Instead, this process mills the chamfer with its desired characteristics along the gear edge contour by synchronizing a fly cutter—generally a star-shaped body with four standard, replaceable inserts—with workpiece rotation. Since each edge of the tooth is done separately and the chamfer size and angle depend on machine movements, not tool design, the process is quite universal. With just a relatively few different standard inserted blade sets and base bodies, a single tool can be used for different modules, pressure angles and number of teeth. Size and chamfer angle can easily be programmed.

Chamfering Integration Made Easy

Naturally, all the aforementioned chamfering processes must be made available to gear manufacturers such that their impact on cycle times, tool cost per piece and the price of total ownership is so small as to be virtually inconsequential. Chamfering can be fully integrated with hobbing and power skiving machines and performed in parallel with these primary cutting processes. In cases where hobbing machines already exist and replacement is not desirable, chamfer design requirements can, of course, be met with standalone chamfering machines such as the Gleason 280CD, which currently offers both chamfer hobbing and fly cutter chamfering. In every case, the approach has always been to make chamfering technologies as readily available and as easy to integrate as the cutting processes themselves. For example, for the latest requirements of EV transmission gears, pinions, and shafts, where cycle times and tool cost per piece are critically important, Gleason offers the new horizontal 100HCD



Fly cutter chamfering for the highest flexibility—one tool for many different workpieces.

hobbing machine. It performs radial chamfering in parallel with gear hobbing, thus not impacting chip-to-chip times. The new vertical Genesis 180HCD and 280HCD hobbing machines also feature chamfering in parallel with gear hobbing: chamfer hobbing on the 180HCD and the option for both chamfer hobbing and fly cutter chamfering on the 280HCD for workpieces with diameters up to 280 mm and module 5 mm. Note that these machines feature either an additional gantry loader or a 4-station ring loader to link gear hobbing with chamfer cutting and external automation/storage.

Gleason Genesis 280HCD hobbing machine with integrated chamfer station for chamfer hobbing or fly cutter chamfering.

Finally, when any of these technologies cuts a chamfer, the quality engineer must ensure it's in tolerance according to the part print. Measuring is mandatory. This process can be slow and laborious with conventional mechanical contour measurement machines. Today's gear inspection technologies, like the Gleason GMS series of analytical gear measuring systems, can be equipped with integrated chamfer inspection software to speed and simplify the chamfer inspection process by providing a complete analysis of different chamfer sizes and angles, thus simplifying comparison with the workpiece drawing.

Summary

These latest solutions are available today to apply the right chamfer process to widely disparate applications such as automotive-type gears and shafts, truck-size gears, or job shop applications. Most importantly, the total ownership cost for chamfering has never been lower, nor has the case for chamfering been more compelling.

gleason.com

Quality Controlled

German Gear Company installs first Klingelnberg P 152 measuring center

Matthew Jaster, Senior Editor

A large internal gear in production at Zahnradfertigung OTT GmbH & Co. KG.

Zahnradfertigung OTT GmbH & Co. KG was the first company to install the new fully automatic CNC-controlled P 152 precision measuring center from Klingelnberg in its ultra-modern machine park.

"With our broad spectrum, we must be extremely flexible. Especially in contract gear manufacturing, we simply must be able to measure everything on our machines—from internal gears and cylindrical gears to worm wheels and worm shafts, as well as pinion-type cutters and special gears. Since we already have a Klingelnberg P 350 W Precision Measuring Center for wind power applications, compatibility was also important to us," said Jens Haag, managing director Zahnradfertigung OTT.

"The P 152 is also very compact and therefore an accurate measuring instrument for its size. That also appealed to us. The positive experience we had with our P 350 W meant that there was no question of looking for another manufacturer. It is important to us that components come from a single source—in this case Klingelnberg—to ensure seamless processes," Haag added.

Entrepreneurial Spirit

Zahnradfertigung OTT, located in Bodelshausen, Germany, has evolved over the course of its company history from a contract gear manufacturer to a complete supplier of drive elements. Its international customers come from machine tools, large gearbox manufacturers, wind power plants, special machine construction, mining, and wherever drive elements are required.

Zahnradfertigung OTT manufactures drive elements and gear parts for a host of applications. The portfolio range is very broad: In the worm gear pair sector, it extends from standard and duplex geometry to OTT's own patented high precision worm gears. Cylindrical gears from 100 mm to 3,700 mm in diameter are manufactured in the contract manufacturing area—everything from running gears and splines to special profiles. This is done using various manufacturing processes, depending on the quality requirements. The company is also a supplier of complete gear components for transmissions. This includes turning and boring work in the diameter range from 500 mm to 3,500 mm.

"We are an owner-managed family business that is now run by the third generation. Our customers value our modern production facilities, our reliability, and our flexibility, which is geared very closely to the customer. Our defining factor, however, is the quality of our manufactured products," Haag said.

Modern Challenges

After coronavirus, the energy crisis, inflation, and now the threat of recession, Haag stated that the company is primarily hoping for calmer waters again.

"We are simply living in very turbulent times. As a supplier to gearbox manufacturers, we have also been facing competitors from Asia and India for a few years now, most of whom have completely

Figure 1—Inherently rigid design, energy-efficient, and highly flexible: The new P 152 precision measuring center now also applies proven principles for high-volume and mass production of smaller components to large components.

Figure 2—Jens Haag, Managing Director Zahnradfertigung OTT GmbH & Co. KG (left), and Patrick Henes, Head of Quality Assurance, in front of the loaded P 152 precision measuring center.

Figure 3—Kai Bartel, Head of Product Line Precision Measuring Centers Klingelnberg (left), and Stefan Finkbeiner, Sales Director Klingelnberg, were delighted to present the P 152, the latest member of the Klingelnberg Precision Measuring Centers family (P-Series), at EMO.

different production options than we do in terms of price. This makes it all the more important for us to manufacture high-quality products, achieve fast and reliable delivery times and also offer projects and components that not everyone can produce. Standing out from the crowd in certain areas is important—by delivering on traditional German virtues such as inventiveness and innovation," Haag said.

"With the successor model to the P 150, we wanted to apply the principle of smaller measuring instruments to medium and large precision measuring centers: an inherently rigid construction that no longer requires a foundation. The challenge was to achieve the same accuracy. We did this by developing new correction procedures. The P 152 is a 100 percent in-house development that incorporates all our Klingelnberg know-how. And we are proud of the fact that we have succeeded in achieving all the technical goals we set for ourselves," said

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Kai Bartel, head of product line precision measuring centers at Klingelnberg."

Bartel further discussed the performance features that characterize the P 152.

"Full software compatibility and high accuracy, and the various z-axes of 1,200 mm/1,500 mm and chucking lengths of up to 2 m. We have also improved operability and ergonomics. Thanks to its high efficiency, the precision measuring center is characterized by low power consumption during operation and a small footprint. With the P 152, we were able to create a modern measuring center with an efficient layout and a very harmonious appearance."

Application Benefits

Internally, the new P 152 is thought to close the gap in the Klingelnberg measuring center portfolio.

"The fact the P 152 no longer requires a foundation significantly reduces the workload for our customers. In addition to lower costs, this also offers very flexible installation options," said Stefan Finkbeiner, sales director at Klingelnberg.

The measuring center will be of particular interest to all gear manufacturers who need to cover a wide range of components—from small to 1,520 mm component diameters and weighing up to 8 tons—as well as a wide variety of measuring tasks.

"The P 152 enables measurements to be performed regarding dimensions, geometry, position, tools, roughness, worms, worm wheels, and much more. The P 152 is the ideal addition, especially for customers who have a machine park in the range of, for example, the Höfler Rapid 800/1250/1600 cylindrical gear grinding machine. This is because the maximum workpiece weight of eight tons is suitable for the parts that are manufactured on these machines," said Finkbeiner.

High Demand

Finkbeiner believes Klingelnberg has launched exactly the right product at the right time. The launch went extremely well and demand is currently very high.

"The P 152 precisely meets the requirements of our customers, such as Zahnradfertigung OTT, with whom we have a long-standing, trusting, and open working relationship. Zahnradfertigung OTT has a very wide range of components to deliver."

"Our initial experiences with our new precision measuring center have been very positive. We have been able to significantly reduce measuring times compared to our Höfler EMZ 2602 gear measuring machine, which has now been decommissioned. Various measurements can now be carried out in a single clamping operation, including of course the gear geometry, shape, and position as well as the surface roughness of the tooth flanks," said Patrick Henes, head of quality assurance at Zahnradfertigung OTT.

Since Zahnradfertigung OTT received the first delivered P 152, there were small suggestions for improvement here and there, which were quickly implemented by Klingelnberg.

"Our wide range of parts in particular means that we have many individual requirements in terms of how gears must be tested and evaluated. Klingelnberg always provided us with reliable and highly professional support to make various adjustments to the software," Henes said.

"It was an important pilot project for us too," added Bartel. "So, we were very pleased with the positive feedback from Zahnradfertigung OTT—both during the acceptance process and afterward."

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Figure 4—Klingelnberg Precision Measuring Centers (P-Series) handle most measuring tasks in a wide range of industries. For example, the P 350 W is designed for workpieces up to 3,800 mm in diameter and 20,000 kg in weight, making it ideal for components for wind power plants.

Keeping Up with the Latest Technology

Observations on robotics, machine tools and heat treating

Joe Arvin

In terms of technology, we certainly live in amazing times. Think about it: We live in a world where you can interact with artificial intelligence via your smartphone, which essentially possesses the collective knowledge base of humanity.

The advancement of technology reaches into every corner of our civilization, and this certainly applies to the manufacturing sector. Many new developments are taking place, and as I've said for decades, the key to remaining competitive in manufacturing is to embrace the latest technology and implement it to the best of your abilities.

You might be thinking, "That sounds great, Joe, but come on. I've got my hands full getting quality parts out the door for our customers. How am I supposed to keep up with everything that's going on with technology? And what about the cost?"

This is certainly a challenge. Regarding the cost of investing in technology and its critical importance for future success, I suggest reviewing my Arvin's Angle article in *Gear Technology* from February 2023, titled "Remaining Competitive—Don't Let Technology Pass You By." This presents a few insights about navigating the cost issues associated with updating your technology.

Then there is the issue of keeping pace with technology. Since I have had the privilege of visiting numerous gear plants and research centers in the U.S., as well as 170 in 33 countries, and I closely watch the progression of technology, I wanted to share my observations about some technological advancements.

For the purpose of this article, I will focus on three key areas: Robotics, Machine Tools, and Heat Treating.

Robotics

Regarding robotics, we've all seen online videos of how robots are now taking human form, coupled with artificial intelligence, and even equipped with facial expressions. While this is happening, what about applications for manufacturing?

Robotics in the factory is nothing new, as this technology has been in place since the 1970s. Today, most people think robots are used in manufacturing for lifting heavy loads, performing repetitive non-precision tasks, loading and unloading machine tools, and welding. However, the field of robotics has also been greatly impacted by technological advancements. Today, the application of robotics has expanded into areas such as hazardous environment tasks, police work, military, space exploration, caregiving, and even microsurgeries. With the rapid development of artificial intelligence, we will certainly see more advanced robots becoming available with better accuracy, agility and flexibility, making their integration into manufacturing a logical fit.

Not long ago, I met with Bryan d'Ouville, director of FANUC America's Midwest Robotics Group in Hoffman Estates, IL. There, I had the opportunity to see some of these advanced capabilities firsthand. I strongly recommend finding time to visit.

Additionally, I have had several project-related discussions with Matrix Design, an integration company located in Bartlett, IL.

To get the latest information on robots and their integration, I also spoke with individuals from both FANUC and Matrix to get their perspectives.

David Bruce, Manager of Engineering for FANUC America's Vision Group

Q: What are some of the latest developments in robotics technology?

Bruce: A key advancement is 3D vision guidance. With the assistance of 3D vision, robots are now used for assembly and part picking in warehouses. This allows for sorting and packaging. In the case of [FANUC's] iRVision Robots with 3D vision guidance, they can locate and retrieve parts that are not uniformly placed.

Furthermore, there are 3D Vision Systems that continually monitor a robot's position, motion, and direction. If a person enters the robot's work envelope, this safety vision system will stop or slow down the robot depending on the relative motion of the robot and the person. Robot vision also prevents collisions with the workpiece or the machine tool itself.

3D vision is certainly an amazing enhancement, as people could not work around previous robotic systems due to obvious safety reasons. Bruce had additional comments.

Bruce: Often, in vision-guided applications, a task will be split between two robots. One robot will pick a part using a rough-pick method and place it so that a second robot, also using vision, will pick the part more accurately for the next step in the process. Bin picking is a good example of this, where retrieving a part from a bin of piled-up parts cannot be done very accurately. The second step is required to achieve the necessary accuracy for the next step. Sometimes, the same robot will do both steps, with the second snap done while the robot is still moving, which is referred to as "snap on the fly."

Virgil Wilson, Staff Engineer at FANUC Robotics (Retired)

Q: What are some other capabilities of today's robotic technology?

Wilson: FANUC's line of CRX collaborative robot models (cobots) is equipped with a built-in force control feature. There is no need for an external force sensor, mounting hardware or cabling. The integrated force control offers a wide range of ICON-based force control options suitable for material removal and assembly tasks. The force control capabilities are advantageous for various applications, including assembly and material removal processes such as gear deburring.

From my time at the FANUC demonstration facility in Hoffman Estates, I saw that precise robotic inspection is also possible. The workpiece can be removed from the machine and placed on an inspection table. An advanced vision robot can precisely grasp the part and perform the inspection with preset gauging—and this is not just the simple use of go/no go gauges. The gauging results can be forwarded to the CNC machine for auto adjustments for control of size and length.

With the advancements of robotic capabilities comes the natural expansion of applications as robots become more capable and flexible. I also spoke with Patrick Bertsche of Matrix.

Patrick Bertsche, CEO of Matrix Design

Q: What are you seeing in terms of the applications of robots based on their advancing capabilities?

Bertsche: The types of applications in which robots can be used have changed considerably over the years. Many companies are now thinking holistically about their processes and not just automating an isolated operation.

There have been several advancements in distributed control systems (DCS)—flexible zone controls, and being able to control robot speeds and receive reliable feedback via the robot controllers.

There are still a great number of industrial robots being used, with their reliability, robustness, and speed. These are very different from collaborative robots, but there is a place for both, and companies now have more choices when integrating robotics.

To see excerpts of my interviews with David Bruce and Patrick Bertsche on robotics, please visit our website at *AGSLearningCenter.com*.

I saw another interesting robotic application in an automated cell in Europe.

I observed auto inspection operations integrated into a completely automated machining cell utilizing five machine tools. Using vision, a robot removed forgings from a bin with parts positioned randomly. The part was loaded into the machining cell and came out the other end as a finished part. It was then auto-loaded into a shipping container for heat treatment or for shipping to the customer. These capabilities mean dramatic potential for increased productivity.

Machine Tools

Machine tools have continuously evolved, incorporating the latest technologies to enhance their capabilities. While avoiding references to specific manufacturers, here are some notable advancements in the field.

One notable development is the introduction of an internal grinder designed to generate internal spur and helical gears with AGMA Class 14 quality. Unlike traditional methods that rely on form grinding and single indexing for internal gears, this machine utilizes a more advanced approach.

It employs a vitrified, dressable, multi-start threaded grinding wheel to generate gear teeth through continuous motion. The cross-axis angle facilitates high tool speed at the tooth surface, improving efficiency and precision.

With tool spindle speeds reaching up to 15,000 rpm, this method achieves high metal removal rates, making generative internal gear grinding both productive and cost-effective, particularly for high-volume production.

Additionally, these machines feature the capability to make profile angle adjustments during production. Full multi-axis control allows for precise adjustments to symmetrical and asymmetrical pressure angles (fHα), as well as involute crowning and tip relief.

For instance, a gear with a 1.22 normal module, 24-degree normal pressure angle (NPA), 92 teeth, 20-degree helix, 120 mm reference diameter, and 25 mm face width would have a cycle time of just 183 seconds, including proportional dressing time. This impressive efficiency highlights the machine's ability to meet demanding production requirements.

Several gear companies are now grinding the gear teeth on spur, spiral and hypoid gears from solid. This eliminates the need for standalone gear cutters, heads, blades and sharpening machines. While this is not a new method, it is becoming more common.

With the latest grinding wheel technology, cycle times for grinding from solid can be faster or equal to the cutting operation, depending on the gear's diametral pitch.

A significant advantage of grinding teeth from solid is the elimination of stress induced during various cutting operations. This stress can be unpredictable and cause problems during heat treatment in the form of distortion as it is released.

Several companies are using large CNC machining centers to cut the gear teeth on large bevel gears. With this method, quality is equivalent, but there is no need for single-purpose gear cutting machines.

Integrated Machining Operations

Several gear companies are performing turning, drilling, milling and hobbing gears or external splines in one machine tool. Typically, these operations are performed in a multi-axis CNC machine with dual chucks, live tooling, and in some cases, two turrets (upper

and lower). Depending on the part configuration, they could be ready for heat treatment with no other machining required.

One gear company was able to turn, drill, mill, hob, cut internal splines, and straight tooth bevel gears in one machine. They were also working on the ability to cut spiral bevel gear teeth in the same machine.

The takeaway is that the future of gear manufacturing will involve machine tools that can perform multiple operations in one machine. My advice is to keep an eye out for this capability because of competition and profitability concerns.

Heat Treat

So we've talked about robotics and machine tools. What about heat treating?

A major concern with heat treating is related distortion. There are multiple causes of stress-related distortion from heat treating operations. These include the condition of the forging or bar stock, stress induced by stock removal operations, cutting tool pressures, part racking during carburization, and differences in cooling rates between thick and thin sections during quenching. (Don't get me started on the condition of the heat treating equipment.)

The Vacuum Process

It appears that vacuum processes for carburizing, hardening, and quenching are becoming more standard in the industry. As with grinding from solid, vacuum technology is not new, but it is becoming more common. One of the key benefits of vacuum carburizing is improved gas flow, which yields a more uniform depth of case.

Additionally, using vacuum for quenching eliminates the need for washing parts to remove quench oil. This also addresses EPA concerns and costs related to disposing of contaminated oil and parts washing fluids. Furthermore, vacuum use eliminates safety concerns and costs from quench oil fires and can potentially reduce insurance costs.

There is also new advanced gas quenching technology that can be paired with vacuum heat treatment that eliminates the need for most die press quenching operations. This technique achieves a more uniform cooling rate as it quenches one piece at a time. The quenching nozzles have varying gas flow volumes directed at the desired thick and thin sections while the part is rotated, yielding a uniform cooling rate across all geometric features. As a result, in many cases, it is unnecessary to leave excess material on sections of the part to manage distortion. This technology is flexible such that it can quench parts in-line after single-piece flow furnaces, either vacuum or atmospheric.

Conclusion

In conclusion, I am amazed to compare the advances in manufacturing technology over my career in the gear business. With the emergence of additive manufacturing and artificial intelligence, we need to hold onto our hats for the next wave.

Finally, I would like to thank those at FANUC and Matrix for their contributions to this article. Be sure to watch my interviews with them on *AGSLearningCenter.com* for additional information.

A Final Word

If you have any questions or comments, I would look forward to hearing from you. Also, if you missed any of my previous articles, below is a list of them by issue number and page. They are also available on the *Gear Technology* website. If you'd like for me to send you a copy, please send me an email or just give me a call.

Update: AGMA Emerging Technology Committees

Mary Ellen Doran, AGMA Vice President, Emerging Technology

Before diving into the latest committee developments, I want to remind everyone about the 2023 Emerging Technology Webinar Series, available on-demand until December 31. (Don't miss this valuable resource before it's removed to make room for our 2025 webinar series.) These twelve one-hour sessions span topics like AI and robotics implementation, ultrafine surface finishing for gear teeth, and digitalization for productivity gains. A big thank you to our expert presenters from How to Robot, Notoros, Klingelnberg, 3DEO, Visionify, Skuld, Fortify, Lumafield, Kapp, Liebherr, Mantle3D, and KnowBe4—we truly appreciate your contributions.

2024 Committee Highlights

3D Printing Committee

Dr. Aaron Isaacson, managing director of the Gear Research Institute at Penn State University, recently presented at a committee meeting. He shared insights into their groundbreaking work on 3D-printed gears and repairs using laser-directed energy deposition technology. Topics included testing with Ferrium C-64, bending fatigue characterization, contact fatigue, and scuffing. Collaborative efforts with Talens Systems/Ikergune were also discussed, focusing on refining bending fatigue methodologies for additively manufactured gears. Ikergune has been invited to share their findings during our February 2025 webinar.

Looking ahead, the committee will plan visits during the RAPID curated tour on April 9, 2025, in Detroit, co-located with SME's AERODEF Aerospace and Defense Show. Discussions include expanding this experience for AGMA members.

Electric Vehicle Technology (EVT) Committee

The EVT Committee recently hosted a Q&A with United Protective Technologies (UPT) about their nanocomposite coatings, which UPT later presented at the AGMA Fall Technical Meeting (FTM) in October. These developments, along with November's emerging tech webinar (available on-demand), reflect significant progress in EV standards. The Technical Division Executive Committee (TDEC) encourages participation in drafting an electric vehicle information sheet, an important step for members in the EV sector.

AGMA's Inaugural Emerging Technology Event at LIFT in Detroit this past June.

Robotics Committee

Progress continues on the Robotics Committee's white paper, led by Jacques Lemire. Jacques attended the Robo Business Conference in California and the IEEE Humanoid Conference in France, gathering key insights on humanoid robots and their gear/gearbox applications. A panel discussion about the white paper is planned for March 2025.

Looking Ahead to 2025

Exciting initiatives are on the horizon:

- The AGMA Fall Technical Meeting (FTM) has expanded its Call for Papers (CFP) to include emerging technologies—abstracts are **due by January 17**.
- AGMA is preparing 3D printing case studies for the Strategic Networking and Leadership (SNL) Event in June, showcasing member innovations in jigs, fixtures, and prototyping.
- Plans are underway for potential partnerships with AMT and NTMA for a joint technology conference early in 2025.
- Emerging tech education opportunities may debut at the Motion + Power Technology Expo on October 21–23 in Detroit.

Upcoming Webinars

Mark your calendars for these 2025 webinars, held at 1:00 p.m. Eastern on the first Wednesday of each month:

- **January 8:** LIFT discusses efforts to advance materials, manufacturing processes, and workforce development.
- **February 5:** The latest research on 3D-printed metal gears.
- **March 5:** A Robotics Committee-led panel discussion on humanoid robotics.

Let's start 2025 strong! For questions or more information, reach out to me at *doran@agma.org*.

ABMA Update

Todd Praneis, AGMA Vice President, Technical Division

You may or may not know that AGMA manages the American Bearing Manufacturers Association, ABMA, similarly to AGMA. Because gears and bearings go together like "peas and carrots!" to borrow a phrase from one of my favorite movies. I thought that the GT audience would like an update on what is going on in the technical division of ABMA.

ABMA has one technical committee, the Accredited Standards Committee (ASC) B3, to handle all the standards development. They maintain 27 ABMA standards, 16 adopted ISO standards, and help form the US position through ISO Technical Advisory Group (TAG) work on 84 ISO standards related to bearings under ISO Technical Committee 4.

The current projects that the committee is working on are:

- Revision project: ANSI/ABMA 4-1994, *Tolerance Definitions and Gauging Practices for Ball and Roller Bearings*. This is a front-to-back revision, clarifying and improving the specifications and information presented as well as updating symbols and definitions to better align with ISO standards The document had been in stabilized maintenance since 2013.
- Revision project: ANSI/ABMA 20-2011, *Radial Bearings of Ball, Cylindrical Roller and Spherical Roller Types—Metric Design*. This is a front-to-back revision, updating the style of the document, clarifying and expanding the included size range, and updating symbols and definitions to better align with match ISO standards. This document was last revised in 2011 and reaffirmed in 2020.
- New project: ABMA Wind Turbine Bearing Failure Atlas. This new project committee was formed to update and add to a 2006 National Renewable Energy Laboratory document regarding bearing failures, specifically focusing on bearings in the various parts of a land-based wind turbine. The committee is reviewing and updating the information, separating the failures by their location in the wind turbine, and considering adding new failure cases. Failure modes are identified, and potential causes are discussed along with possible mitigation strategies. This document is intended to be used by maintenance or service personnel, repair technicians, and wind turbine owners to help communicate with bearing manufacturers and wind turbine component manufacturers.

If you have any questions about any of these projects, please contact *info@americanbearings.org* to learn more. To have a balance of opinions on the committee, we are especially looking for companies that purchase bearings but do not manufacture bearings and individuals or organizations that neither purchase nor manufacture bearings but have knowledge and interest in bearings, such as consultants and academics, to join.

Experimental and Analytical Study of the Effect of Shot Peening on Gear Micropitting and Contact Fatigue Failure

Dr.-Ing. Dalia Jbily, Dr.-Ing. Luc Amar and Dr.-Ing. André Simonneau

Micropitting damage is one of the failure modes commonly observed on case-hardened gears and is caused by cyclic stresses and plastic flow on the asperity scale (Ref. 1). The micropitting degrades progressively the geometries of the contact surfaces which can result in the fatigue failure in the form of macropitting (Ref. 2).

Shot peening is a cold working process in which the surface of a part is bombarded with small spherical media called *shot*. Each shot striking the material acts as a tiny peening hammer, imparting to the surface a small indentation or dimple which results in a thin layer of high-magnitude residual compressive stress at the surface (Ref. 3).

The shot peening is not a substitute for heat treatment, but an additional and useful process to increase fatigue life. Various investigations were performed in several research projects about the influence of shot peening on the load-carrying capacity of gears. It was found that shot peening increases the bending fatigue strength as well as the pitting load-carrying capacity (Refs. 4–8). The literature provides information on the micropitting phenomenon: description, morphology, appearance, etc., but it gives very little information on the relationship between shot peening and the appearance of micropitting. Nevertheless, what is clear is the important role played by surface roughness.

The shot peening process often leads to increased surface roughness values, so combining shot peening and superfinishing increases the load-carrying capacity of gears against micropitting and macropitting (Refs. 9, 10). Superfinishing involves an additional cost and sometimes it is not an economical solution for the industries.

A previous study (Ref. 11) aims to use shot peening to increase the resistance to micropitting by optimizing the surface topography without operation post shot peening. This study allowed the identification of a particular type of shot peening (conventional shot peening) leading to surface topography and roughness parameters optimization resulting in a delay of the micropitting apparition. However, this solution has been validated on rollers and through fatigue tests on a twin disc bench.

This study aims to investigate the effect of this identified type of shot peening on the micropitting resistance of the gear tooth flanks and the macropitting resistance and to compare the experimental results with the calculation results based on standard methods (ISO/TS 6336-22:2018 [Ref. 12] for micropitting and ISO 6336: 2019 [Ref. 13] and AGMA 2101-D04 [Ref. 14] for pitting).

Experimental Study

To study the sensitivity of gear surfaces to micropitting, contact fatigue tests were carried out on the back-to-back test rig (Figure 1) developed by Design Unit. This is a gear test rig in an initially closed mechanical loop. This test rig allows two identical gears to be tested simultaneously under the same loading conditions.

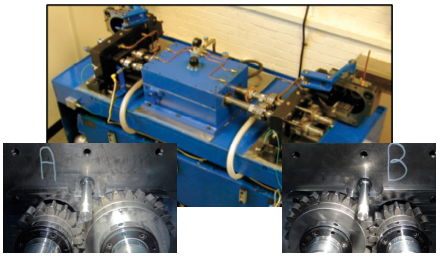


Figure 1—Back-to-back test rig (91.5 mm center distance).

Gear Specimens

Table 1 below summarizes the macrogeometric characteristics of the test gear teeth. It should be noted that this is the most studied gear geometry in the literature on gear contact fatigue using this type of test rig.

Nominal gear geometry	Pinion	Gear wheel
Normal module (mm)	4.5	
Normal pressure angle (degrees)	20	
Number of teeth	16	24
Profile shift coefficient	+0.1817	+0.1715
Reference profile	ISO 53:1998 Profile A	ISO 53:1998 Profile A
Tip diameter (mm)	82.4	118.3
Accuracy grade (ISO 1328)	5	5
Facewidth (mm)	18	14
Centre distance (mm)	91.5	
Gear ratio	1.5	

Table 1—Characteristics of the test gear.

Microgeometric modifications (profile and flank line modifications) are introduced at the teeth of the studied gear to get as close as possible to the definition conditions of industrial gears. Table 2 below summarizes the microgeometric characteristics of the gear teeth used in the tests.

Microgeometric corrections			Pinion	Gear wheel
Flank line crowning	C_β	µm	35	0
Tip relief value	C_a	µm	50	50
Type of Tip relief	-	-	arc-like	arc-like
Tip relief application diameter	d_{Ca}	mm	79.268	115.448

Table 2—Microgeometric tooth modifications.

It should be noted that the geometric and loading data are based on the two reference documents which describe tests to be conducted on an FZG type test rig (Refs. 16, 17).

The table below includes the main operation data of the gear.

Operation	
Lubrication type	Oil injection lubrication
Designation	Mobilgear 600 XP 150
Viscosity at 40°C	150 cSt
Viscosity at 100°C	14.7 cSt
Lubricant temperature	80°C
Load stage micropitting test	10

Table 3—Operation data.

Materials and Surface Finishing

A summary of the specimens used in this study, their manufacturing process and surface treatments are described below:

- Reference gear (REF): Case-hardened + quenched; the specimens are cut and then heat treated. After heat treatment, the gears are ground to remove any irregularities that may have occurred during heat treatment.
- Shot peened gear (SP): Case-hardened + quenched + shot peened; the specimens were first cut and ground. The tooth surfaces were then shot peened to create compressive residual stresses across the surface.

The mechanical characteristics of materials are as follows.

Materials	Symbol	Unit	Steel
Material type	-	-	Case hardening steel
Surface hardening heat treatment	-	-	Case hardened, quenched, shot peened
Material	-	-	18CrNiMo7-6
Surface hardness	-	HV	750
Core hardness	-	HB	325
Tensile strength	R_m	MPa	1,200
Yield strength	R_e	MPa	850
Young's modulus of elasticity	E	MPa	206,000
Poisson's ratio	ν	-	0.3
Quality grade ISO 6336-5	-	-	MQ
Allowable bending stress number (durability)	σ_{Flim}	MPa	430
Allowable contact stress number (durability)	σ_{Hlim}	MPa	1,500
Quality grade AGMA 2001	-	-	2
Allowable bending stress number (durability)	s_{at}	Lbf/in²	65,000
		MPa	448
Allowable contact stress number (durability)	s_{ac}	Lbf/in²	225,000
		MPa	1,551
Hardening depth	CHD_{max}	mm	1
	CHD_{min}	mm	0.8

Table 4—Mechanical characteristics of material.

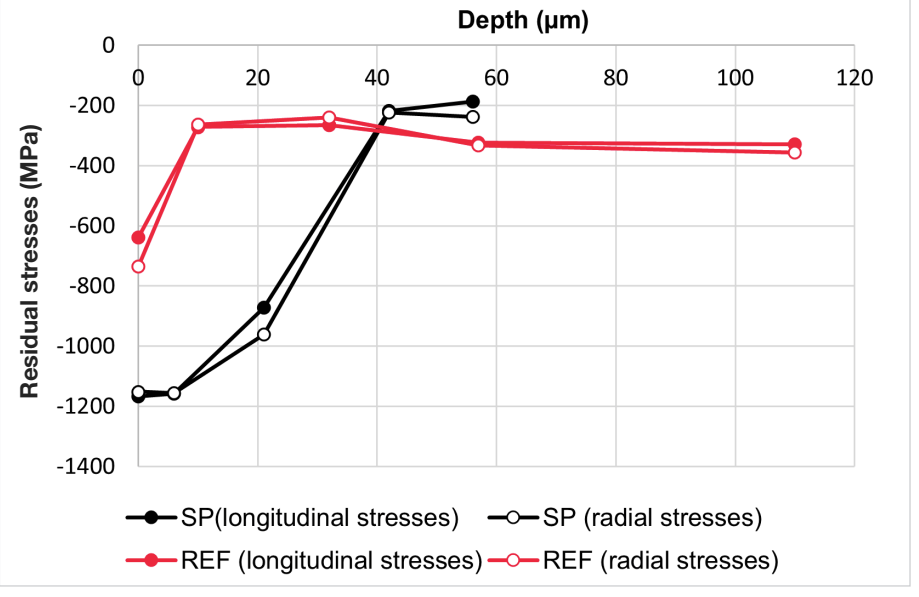


Figure 2—Comparison of the residual stresses in the unpeened (REF), and shot-peened (SP) condition.

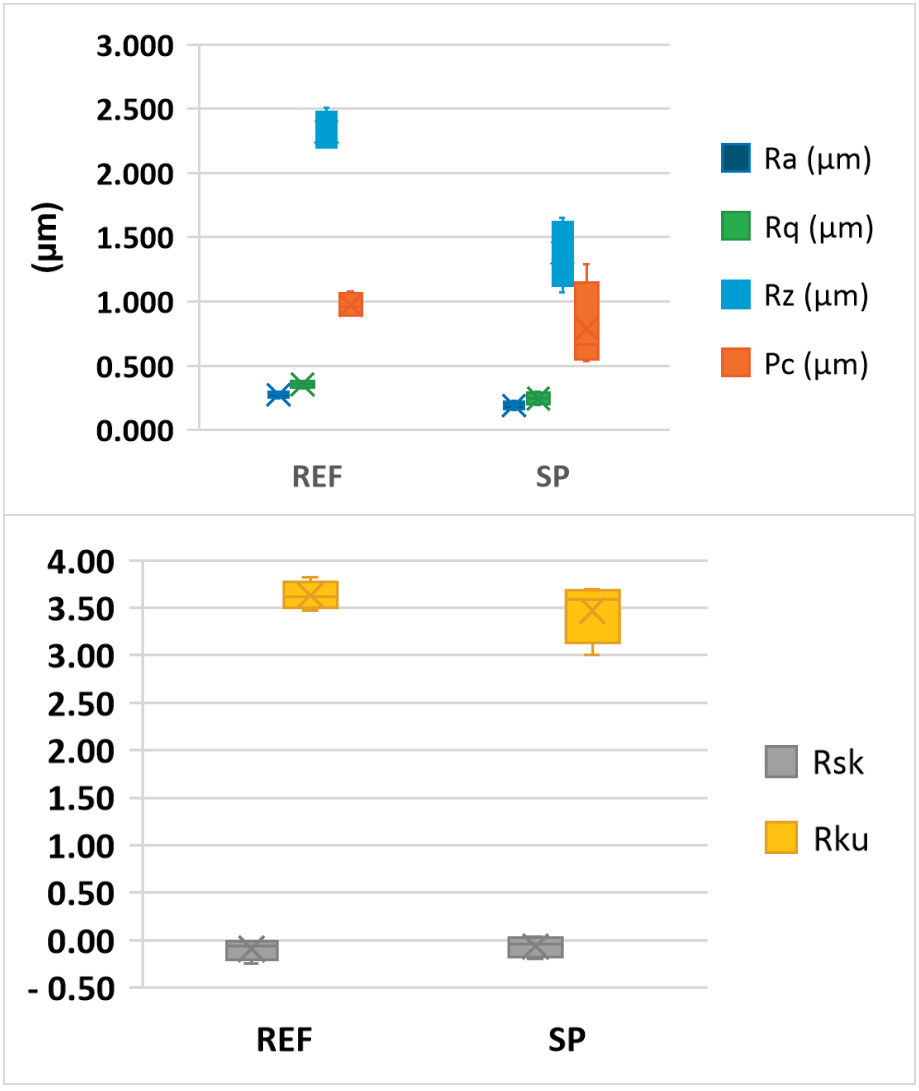


Figure 3—Roughness comparison.

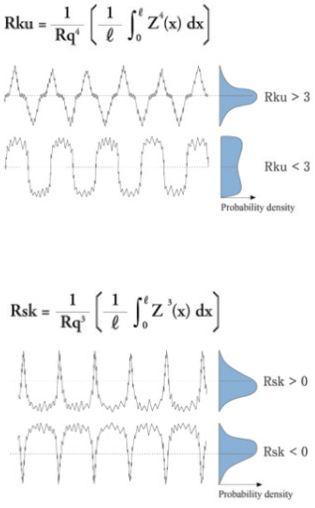


Figure 4—Definition of roughness profile parameters: Kurtosis (Rku) and Skewness (Rsk).

Shot Peening

The gears were shot peened using a nozzle device. The shot peening conditions are as follows: G2: UFS100, Pressure 6 bars, 200 percent, angle 30 degrees (single shot—200 percent coverage).

The measurement of residual stresses in test specimens was carried out using an X-ray diffractometer.

Figure 2 shows that shot peening increases the residual stresses in the surface layer to a depth of about 40µm. The residual stress profile of the nonpeened teeth shows a very high stress gradient on the surface (-600MPa to -250MPa over a depth of 10µm) characteristic of the grinding operation.

The surface roughness of the flanks of the test gear teeth was measured before testing. The measurements were made on 3 teeth of each gear and on the two flanks of each tooth. The roughness was characterized by white light interferometry using a Bruker noncontact 3D surface roughness machine. The measurement results show that *Rsk* and *Rku* have the same orders of magnitude while *Ra, Rq, Pc* and *Rz* have lower values on the shot-peened gears (see Figure 3).

We have to remember that *Rku* describes the peaks shape, and *Rsk* the presence of peaks or valleys. Based on the diagram in Figure 4, the configuration $Rku < 3$ and $Rsk < 0$ gives logically a surface topography that is unfavorable to the appearance of micropitting. *Pc* is the mean height of the primary profile element.

Test Results

All pinion and wheel teeth are numbered to allow clear identification of damage locations. The test cycle includes stop phases to follow the evolution of the degradation of the active flanks. At each stop, photos of the flanks are taken. The criteria to finish the test is generalized macropitting damage of the active flanks. Photographs of the gear tooth flanks are taken, showing the initial state and after the different loading cycles, enabling observation of the evolution of the damage on the flanks. An example of the results is shown in Figure 5.

For all the tests carried out on the shot-peened gears (SP) and the nonpeened (REF), the micropitting damage on the flanks is initiated in the dedendum zone where the sliding conditions are the most severe.

The observation of the images of the surfaces thus obtained makes it possible to highlight the following points:

- The micropitting started in the dedendum zone below the pitch diameter of the reference flanks (unpeened) and shot peened (SP) flanks after the same test time or earlier. The micropitting covers a large part of the tooth dedendum on shot-peened flanks.
- The presence of micropitting around the pitch line of the pinion is also noted, which may have been caused by stress concentration in this area. The occurrence of micropitting is not usual in this area, it is often observed in the tooth dedendum. Similar results have already been obtained in other research from the literature (Ref. 17).

- For comparable test durations, the micropitting area on the shot-peened flanks (SP) is greater than that on the nonpeened flanks (REF).
- A difference in the evolution of the micropitting on teeth between REF and SP flanks. Micropitting on REF flanks is progressive.

The tests carried out on gears were conducted until the appearance of Macropitting/spalling on the teeth flanks.

The appearance of spalling on the REF gears was observed after about 8.85×10^6 cycles of loading (66 hours on average) whereas on the SP gears, macropitting was observed on the pinion after about 28.2×10^6 (209 hours), the test was conducted up to 32.26×10^6 (239 hours) but no widespread macropitting / spalling on the flanks was observed.

Analytical Study

Several international standards have been developed to guide the design of gears to ensure sufficient load capacity to prevent their failure. These methods are developed by many international and national committees such as ISO, AGMA, and DIN, to guide the different aspects of gear design. In this section, we present a brief review of standard methods for calculating the load capacity of gears concerning macropitting and micropitting, then the calculation results based on these methods are presented and compared with the experimental results presented previously. This calculation is performed using the *KISSsoft* 2022 software package.

Review of Gear Load-Capacity Calculations

Calculation of Micropitting Load Capacity

The ISO/TS 6336-22:2018 calculation method of the micropitting load capacity is based on the principle that micropitting occurs when the minimum specific lubricant film thickness of a gear is below a permissible value for the specific film thickness. So, the safety factor against micropitting is defined as the ratio between the minimum specific film thickness of the lubricant and the permissible specific film thickness of the lubricant.

$$S_\lambda = \frac{\lambda_{GF,\min}}{\lambda_{GFP}} \geq S_{\lambda,\min} \quad (1)$$

$\lambda_{GF,\min} = \min(\lambda_{GF,Y})$ the minimum specific lubricant film thickness in the contact area

$\lambda_{GF,Y}$ the local specific lubricant film thickness

λ_{GFP} the permissible specific lubricant film thickness

$S_{\lambda,\min}$ minimum required safety factor

ISO/TS 6336-22 does not give advice on a minimum safety factor that should be applied to avoid the risk of micropitting. Instead, it provides guidance for the selection of its value depending on the qualitative reliability of the assumptions on which the calculations are based and according to the reliability requirements. A recommendation for a reasonable minimum safety factor against micropitting, S_λ, is proposed in (Ref. 18) as shown in Figure 7.

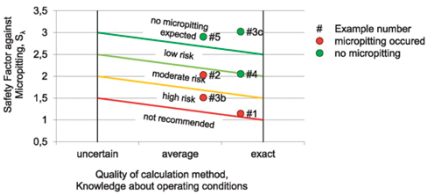


Figure 7—Micropitting safety factor according to Ref. 18.

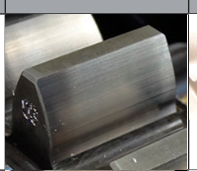
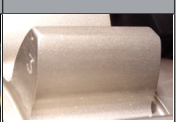
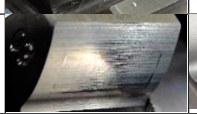
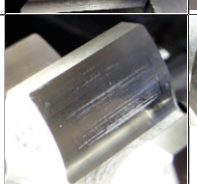
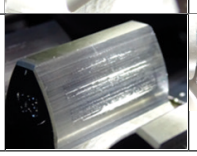
Number of cycles	Pinion REF	Pinion SP
0		
67,500 (0.5 hour)		
135,000 (1 hour)		
270,000 (2 hours)		

Figure 5—Evolution of the surface condition of the REF flanks and SP flanks.

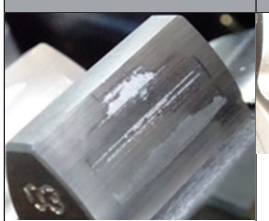
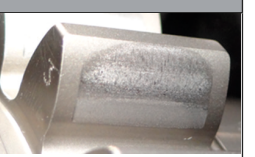
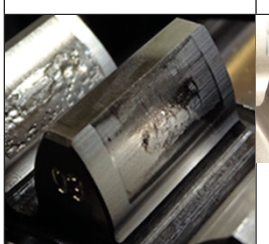
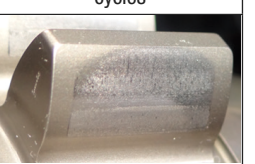
Pinion REF	Pinion SP
 (32 hours) 4.32×10^6 cycles	 (32 hours) 4.32×10^6 cycles
 (65.5 hours) 8.85×10^6 cycles	 (59 hours) 7.97×10^6 cycles
	 239 hours (31.55×10^6 cycles)

Figure 6—Evolution of micropitting to macropitting/spalling.

The technical specification defines two methods Method A and Method B to determine the local specific lubricant film thickness. In method A, the local specific lubricant film thickness can be determined in the complete contact area by any appropriate gear computing program. Method B is a simplified method based on the assumption that the determinant local specific lubricant film thickness occurs on the tooth flank in the area of negative sliding. The calculation of the local specific lubricant film thickness is limited to certain points on the path of contact.

The local specific thickness of the lubricant film is defined by ISO 6336-22: 2018 as the ratio between the thickness (h_Y) of the lubricant film and the average roughness of the surfaces in contact.

$$\lambda = \frac{h_Y}{R_a}, R_a = 0.5 * (R_{a1} + R_{a2}) \quad (2)$$

Where:
h_Y is the local thickness of the lubricant film
R_a is the arithmetic mean effective roughness value
R_{a1} is the arithmetic mean roughness of the pinion
R_{a2} is the arithmetic mean roughness of the wheel

The local lubricant film thickness, h_Y, is calculated according to Dowson/Higginson

$$h_Y = 1600 \cdot \rho_{n,Y} \cdot G_M^{0.6} \cdot U_Y^{0.7} \cdot W_Y^{-0.13} \cdot S_{GF,Y}^{0.22} \quad (3)$$

Where:
$\rho_{n,Y}$ is the normal radius of relative curvature at point Y
G_M is the material parameter
U_Y is the local velocity parameter
W_Y is the local load parameter
$S_{GF,Y}$ is the local sliding parameter

The standard defines two methods to determine the permissible specific lubricant film thickness, λ_{GFP}.

- Method A is the more accurate, which is based on experimental investigations or service experience relating to micropitting on real gears are used. For this method, the test gears need to have the same design as the actual gear pair, and by extension, the gear manufacturing, gear accuracy, operating conditions, lubricant and operating temperature must be appropriate for the actual gearbox. As a result, this method causes high costs. So, the cost required for this method is in general only justifiable for the development of new products as well as for gear pairs where failure would have serious consequences
- Method B, the permissible specific lubricant film thickness, λ_{GFP}, is calculated from the critical specific lubricant film thickness, λ_{GFT}, which is the result of any standardized test method applicable to evaluate the micropitting load capacity of lubricants or materials utilizing defined test gears operated under specified test conditions.

Calculation of Macropitting Load Capacity

Currently, the most popular standards are ISO 6336:2019 and AGMA 2101-D04, these international methods allow the load capacity of metal gears to be verified by considering the two commonly used sizing criteria:

Field	Dimensioning criterion	Associated risk
Durability	Fatigue tooth bending	Tooth fracture under cyclic stress gradual cracking (fracture at tooth root)
	Fatigue surface contact pressure	Cyclic stress gradual damage of tooth flank (pitting)

Table 5—Dimensioning criterion.

Generally, these international methods are based on the comparison of applied stresses with allowable stresses.

This calculation is performed using the *KISSsoft* 2022 software package.

AGMA and ISO design procedures are similar, with minor variations, and contain correction factors obtained from experiments and experience, which consider various uncertainties. These methods consider geometric design, material and heat treatment, manufacturing, and operating conditions.

The gear contact stress calculation is based on the Hertz theory, the formulas of maximum contact stress and the permissible contact stress for the two standards are presented below:

ISO 6336-2 2019	AGMA 2101-D04
Nominal contact stress (theoretical value)	
$\sigma_{H0} = Z_H Z_E Z_\varepsilon Z_\beta \sqrt{\frac{F_t}{d_1 b}\frac{u+1}{u}}$ (4)	$\sigma_{H0} = C_P \sqrt{\frac{F_t}{d_{w1} b}\frac{Z_R}{Z_I}}$ (5)
Contact stress (nominal contact stress modified)	
$\sigma_H = Z_{B,D}\sigma_{H0}\sqrt{K_A K_\gamma K_v K_{H\beta} K_{H\alpha}}$ (6) *B for pinion, D for wheel*	$\sigma_H = \sigma_{H0}\sqrt{K_O K_v K_s K_M}$ (7)
Permissible contact stress	
$\sigma_{HP} = \frac{\sigma_{Hlim} Z_{NT}}{S_{H\min}} Z_L Z_V Z_R Z_W Z_X$ (8)	$\sigma_H \le \frac{S_{ac}}{S_H}\frac{Z_N}{K_T}\frac{Z_W}{K_R}$ (9)

Table 6—Contact stress formulas.

Where:

σ_{H0} is the nominal contact stress
σ_H is the calculated contact stress
F_t is the nominal tangential load
u is transmission ratio
Z_H is zone factor
Z_E is elasticity factor
Z_ε is contact ratio factor
Z_β is helix angle factor
C_p is elastic coefficient
d_{w1} is operating pitch diameter of pinion
Z_I is geometry factor for pitting resistance, Z_I plays somewhat the same role as the combination of the terms: $(u+1)/u$, Z_ε, Z_β of ISO
d_1 is pitch diameter of pinion
b is the facewidth
Z_R is surface condition factor is supposed to take into account the surface condition, the residual stress state and the plasticity effects. At the moment there is no development and Z_R =1.

To consider loading fluctuations due to the set-up, the driving and driven elements, the behaviour of the gear pair, the standards add K factors, to transform nominal contact stress in contact stress applied on the tooth flank:

K_A (ISO) is the application factor
K_V (ISO & AGMA) is the gear internal dynamic factor
$K_{H\beta}$ (ISO) is the face load factor for contact stress
$K_{H\alpha}$ (ISO) is the transverse load factor for contact stress
K_o (AGMA) is overload factor
K_s (AGMA) is size factor
K_m (AGMA) is load distribution factor
σ_{HP} is the permissible contact stress
σ_{Hlim} (ISO), S_{ac} (AGMA is the allowable contact stress number which determines the stress level that can be accepted by the material and its associated heat treatment. It is based on a Wöhler fatigue curve determined experimentally.

In this study, according to ISO, the allowable stress number σ_{Hlim} was obtained from ISO 6336-5. It is derived from the contact pressure that may be sustained for 50×10^6 load cycles (for case-hardened steel) without the occurrence of pitting for a one percent probability of damage (99 percent reliability). The AGMA method defines the allowable contact stress value S_{ac} for 10^7 load cycles with also 99 percent reliability.

S_{Hmin} is the minimum safety factor which is to be agreed on between the designer and customer. To consider the condition of the material in relation to the experimentally established data in a different environment the ISO & AGMA methods also introduce corrective factors.

Z_{NT} is the life factor
Z_L is the lubricant factor
Z_R is the roughness factor
Z_V is the velocity factor
Z_W is the work hardening factor
Z_X is the size factor for contact stress
Z_N is stress cycle factor
K_T is temperature factor
K_R is reliability factor which allows the calculation of the gears for reliability levels other than one failure in 100 at 10^7 cycles
S_H is safety factor for pitting

The contact stress σ_H should be less than the permissible contact stress for preventing failure. The safety factor against pitting is defined as the ratio between the permissible contact stress and the contact stress.

The AGMA standard includes the effect of surface condition, but it does not provide instructions or guidance for defining its value.

Analytical Results

The contact pressure stresses of the gear pair teeth and the specific lubricant film thickness are determined, using *KISSsoft*, at nominal torque (372.6 Nm) on the pinion and a speed of 2,250 rpm.

Micropitting

The specific sliding (Figure 8) at the root of the pinion teeth is high (3.75) and exceeds the value generally recommended according to the rules of art (3 in absolute value).

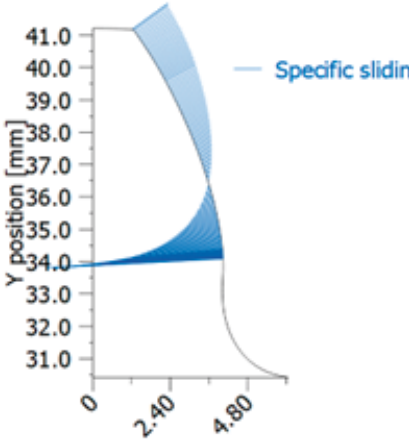


Figure 8—Specific sliding along tooth profile.

As shown in Figure 9, the maximum contact stresses occur in the pinion flank dedendum between the single contact point B and the pitch point C, when it meshes with the wheel addendum. The contact stress results reveal that micropitting can start in the pinion flank dedendum between point B and point C as this area is subject to a high level of contact pressure stresses.

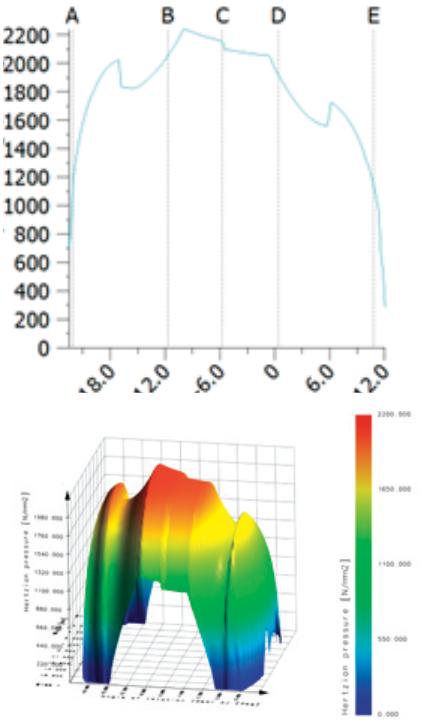


Figure 9—Distribution of 2D and 3D contact pressures.

Figure 10 shows the variation of the lubricant film thickness along the tooth flank in a meshing cycle; this local thickness is derived from the Dowson and Higginson equation adopted by ISO/TS 6336-22.

As shown in Figure 11, the specific thickness of the lubricant film varies along the tooth flank during meshing, and the maximum film thickness occurs at the pitch point C due to pure rolling. The area between the start of the meshing A at the root of the pinion and the single contact point B presents the greatest risk of micropitting due to the lower lubricant film thicknesses accompanied by high-pressure contact stresses (Figure 9) compared to the other contact points along the line of action.

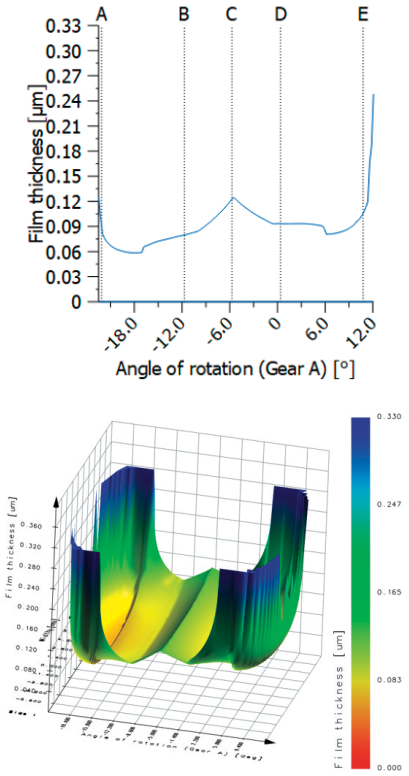


Figure 10—2D and 3D lubricant film thickness according to ISO 6336-22.

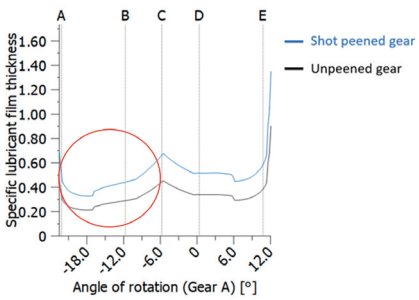


Figure 11—Comparison of specific lubricant film thickness.

The results obtained in terms of the specific lubricating film thickness λ highlight the following points:

- The unpeened (REF) and shot peened (SP) gears operated in a boundary lubrication regime ($\lambda < 1$). In this regime, the lubricating film is present in the valleys and the surface roughness peaks are in direct contact, which causes the plastic deformation due to the very thin film over the whole contact area, thus micropitting (and wear) is likely to occur in the tooth addendum and dedendum areas.
- It can also be seen that the shot-peened gears have a higher λ (Figure 11), as they have lower *Ra* values than the unpeened gears.

Figure 12 and Figure 15 show the safety of the gears against the micropitting according to ISO/TS 6336-22. The safety of the REF gear is lower than that of the SP gear because it has a lower local specific lubricant film thickness.

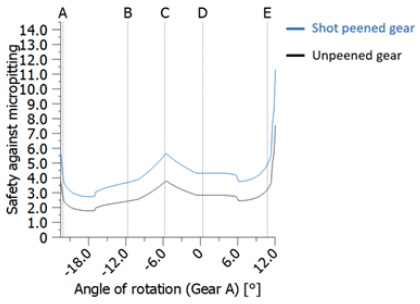
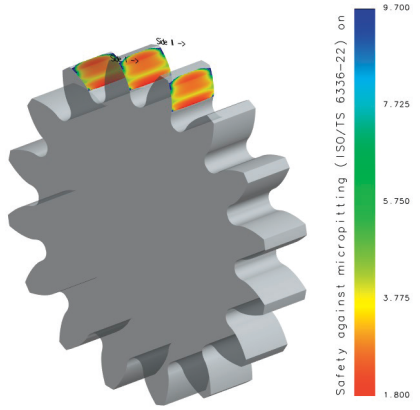


Figure 12—Micropitting safety on the path of contact of gears according to ISO 6336-22:2018.

Pinion without shot peening (REF)



Pinion with shot peening (SP)

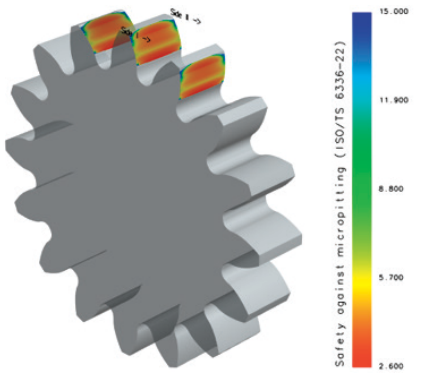
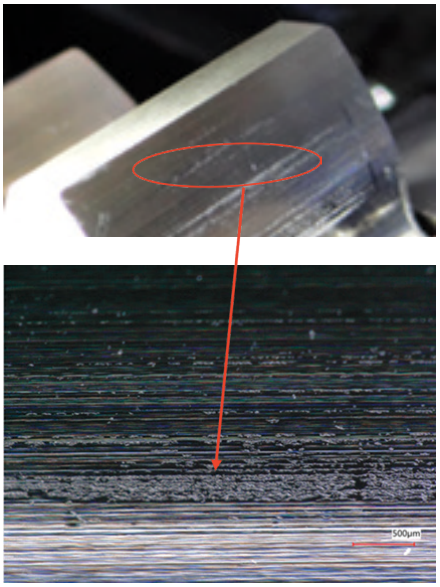


Figure 13—Safety against micropitting on the tooth.

Therefore, from the experimental tests conducted in this study, the ISO results of the specific lubricant film thickness provide a good correlation with the occurrence of micropitting on the tooth flanks, an example of the occurrence of micropitting on test gears is shown in Figure 14.

Pinion without shot peening (REF)



Pinion with shot peening (SP)

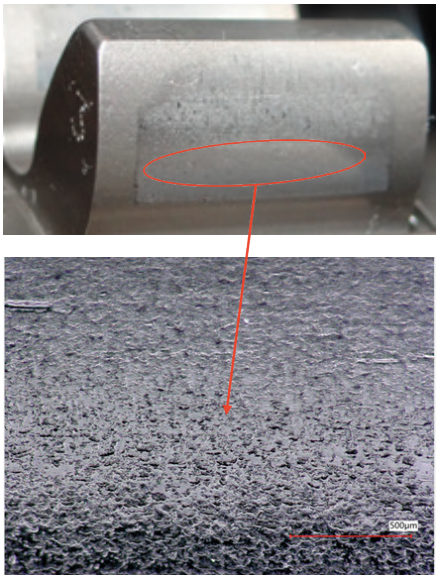


Figure 14—Appearance of micropitting on test gears after 67,500 cycles.

Macropitting

The theoretical lifetime of the gear is calculated according to both methods ISO 6336-2 and AGMA by calculating the number of cycles which leads to safety factor of 1.

The gear lifetimes obtained are presented below. The S_{Hmin} and S_H are considered equal to one.

It should be noted that for all the tests carried out on the REF gears (unpeened) and shot peened (SP), no bending fracture at the tooth root was observed.

According to the ISO standard, the number of load cycles for the one percent probability of appearance of the first pitting on the pinion is 1.58×10^6 cycles (11.7 hours) and that for a generalized pitting is 10.12×10^6 cycles (75 hours). This correlates with the experimental results observed on case-hardened gears after 8.8×10^6 load cycles. The number of pitting cycles for the different tests is plotted on the Wöhler curves at the corresponding contact pressure corresponding to the nominal operating torque as shown in Figure 15.

However, when comparing the lifetime calculated according to the standards with that obtained experimentally on the shot-peened gears, macropitting occurred after 27.56×10^6 cycles. The service life has increased by approximately 60 percent. This improvement can be explained by the increase of residual compressive stresses into the surface layer after the shot peening treatment.

The ISO standard considers the effect of shot peening on the improvement of the bending strength at the tooth root of carburized case-hardened gears. The benefit values attributed to shot peening are:

ML — 0 %

MQ — 10 %

ME — 5 %

But this standard does not consider this positive effect of the increase of the residual compressive surface stresses via the application of shot peening on the resistance to macropitting, which makes the gears load capacity calculations conservative.

Conclusion

The shot peening of ground flanks gears led to higher residual surface stresses compared to un peened ground gears flanks. The testing results show that micropitting occurs on the shot peened (SP) and unpeened gears (REF) after approximately the same running time, although the roughness parameters have lower values on shot peened gears. The micropitting area on the shot peened flanks is greater than that on the unpeened flanks for the same test durations.

The analytical results show that the gears have a specific lubricant film thickness λ lower than 1, which is consistent with the fact that all surface conditions (shot peened and unpeened) led to the occurrence of micropitting. A good correlation is obtained between the experimental and analytical results in terms of the occurrence of micropitting in the dedendum area of gear teeth.

High safety factors according to ISO 6336-22 (>2) do not indicate

Tooth flank service life (hours)	ISO 6336		AGMA 2101	
	Pinion	Wheel	Pinion	Wheel
with unallowed pitting	11.7	42.8	0.28	0.42
with allowed pitting	75	370	-	-

Table 7—Tooth flank lifetimes calculation.

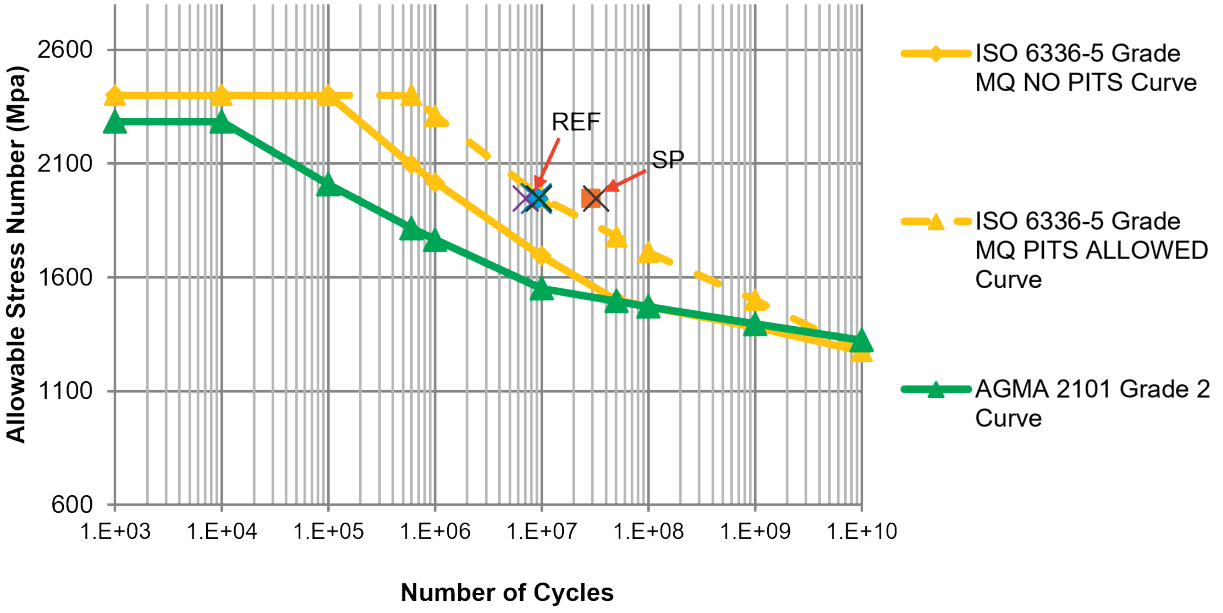
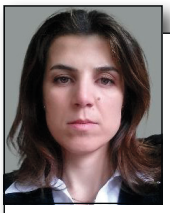


Figure 15—Wöhler curves comparison of pitting cycles.

the absence of micropitting as demonstrated by the test results. These observations agree with those made by Olson et al. (Ref. 19).

Shot peening did not delay the appearance of micropitting on gears but its evolution to macropitting/spalling. The shot peening has increased the life of the gear against pitting by more than 50 percent. This improvement introduced by residual surface stresses due to shot peening is not considered in the current standard calculation methods.

Further studies will be conducted to better understand the results obtained by analysis of the damage mechanisms and friction tests to measure the friction coefficient. These tests will allow us to find correlations between the friction coefficient and the surface condition after shot peening and they could enable us to optimize the shot peening parameters to improve the surface condition.



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An Experimental Study on the NVH Performance of Plastic Gears

Damijan Zorko, Rok Kalister, Borut Černe

High-performance plastic gears are increasingly replacing metal gears in a multitude of applications due to their many advantages. The most important of these are lower weight, substantially reduced lubrication requirements, more cost-effective mass production, significantly better NVH (noise, vibration and harshness) behavior, and chemical resistance. Most plastic gears are produced by injection molding, which enables great design flexibility, e.g., joining several machine elements into one molded part, while gear geometry modifications like enlarged root rounding or altered profile shapes are possible (Ref. 1).

Plastic gears naturally exhibit also some disadvantages compared to metal gears. The most notable ones are lower load-bearing capacity, poorer thermal conductivity, mechanical susceptibility to temperature changes, and lower acheivable manufacturing precision. The load-bearing capacity is the most important property; several studies have explored ways to improve it, either with a special gear design (Ref. 2) or enhanced materials (Ref. 3).

Along with ever-increasing customer requirements, the NVH behavior of polymer gears is also gaining importance. One of the early studies of the acoustic performance of polymer gears was carried out by Hoskins et al. (Ref. 4), in which the researchers examined the influence of diverse materials used in polymer gears and different operational circumstances on the spectrum of sound frequencies. Parameters such as the texture of the surface, wear, and temperature, stemming from the interaction between tooth surfaces, were recognized as the factors affecting the intensity of sound energy.

Trobentar et al. (Ref. 5) compared the acoustic behavior of polymer gears with different tooth profiles, i.e., involute and S-gears. The tooth profile of the S-gears had a convex addendum and concave dedendum, which resulted in a progressively curved (in the shape of the letter S) path of contact. The authors found that S-gears exhibit lower noise than involute gears due to the more favorable contact conditions—Polanec et al. (Ref. 6) studied the noise of coated POM polymer gears. Three physical vapor deposition (PVD) coatings were investigated, i.e., aluminum, chromium, and chromium nitrite. The study revealed that uncoated polymer gears exhibited the lowest sound pressure level; hence, no positive impact of the coating on the reduced noise could be confirmed. Furthermore, the coating started to peel off during operation causing increased friction and meshing disturbances, which resulted in an increased sound-pressure level.

NVH performance of Polyamide (PA) 46 gear was dealt with in the study by van Wissen et al. (Ref. 7). Authors studied the noise behavior of a gear pair where both gears were made of PA46 and compared results to a case where a PA46 gear was meshing with a steel one. Tests were done at three different rotational speeds, ranging from 200 rpm up to 800 rpm, and three different torques, ranging from 0.2 Nm to 1 Nm. A steep increase in noise was reported when increasing the rotational speed. Similar behavior was also observed when increasing the transmitted torque. Cathelin presented a systematic study on the NVH of plastic gears (Ref. 8). The study reveals the complex behavior of plastic gear NVH, which strongly depends on operating conditions. Different unreinforced material grades were tested in the study; however, both gears were always made of the same material. A comparison to a steel gear pair, tested at the same conditions, is provided, highlighting the superior NVH behavior of plastic gears when compared against steel ones.

The following study presents an experimental methodology, employed to characterize the NVH behavior of plastic gears NVH in application-like operating conditions, presenting guidelines for material selection in terms of optimal gear NVH. Five different combinations of plastic materials were utilized, both unreinforced and fiber-reinforced; however, it was always a dissimilar combination of the materials applied for the testing. The evaluated noise and vibrations are compared to a benchmark steel gear pair.

Methodology

Gear Sample Preparation

The test gear geometry was defined as per VDI 2736; Part 4, Table 1 (Ref. 1). Plastic gears were produced and used according to VDI 2736 "size 1-gear geometry" for the tests. The gear's geometric parameters are presented in Table 1. The gears were made by injection molding in a single cavity injection molding tool. An Engel Victory 50 (Engel Austria GmbH, Austria) machine was used for molding. A mold with a hot runner system and a central pin-point gate of diameter 1.3 mm was used. The gear body is designed with a wavy structure that follows a uniform thickness of 2.5 mm (Figure 1). The transition from the gear body to the teeth is designed with a symmetric groove, which enables symmetric filling of the teeth. Gears were produced utilizing 7 commercially available plastic compounds, commonly employed for gear applications. The tool was designed with the possibility of exchanging cavities; hence, several different cavities were employed for molding to compensate for the different shrinkage of the tested materials. The goal was to produce all gears in the same quality range to exclude the gear quality affecting the NVH performance. The basic composition of the used grades was as follows:

1. Polyoxymethylene (homopolymer)—POM
2. Polyamide 66—PA66
3. Polyamide 6 + 15% glass fibers—PA6+15%GF
4. Polyphthalamide + 30% glass fibers—PPA+30%GF
5. Polyamide 66 + 30% glass fibers—PA66+30%GF
6. Polyoxymethylene + 10% aramid fibers—POM+10%AF

As a benchmark for comparison, three sets of steel gears (heat-treated 42CrMo4) were also produced.

Parameter	Nomenclature	Unit	Value
Centre distance	a	mm	38.45
Normal module	m_n	mm	1
Face width	b	mm	6
Number of teeth	z_1/z_2	/	39
Tip diameter	d_{a1max}/d_{a1min}	mm	40.40/40.30
	d_{a2max}/d_{a2min}	mm	40.40/40.30
Root diameter	d_{f1max}/d_{f1min}	mm	35.866/35.691
	d_{f2max}/d_{f2min}	mm	35.866/35.691
Tip rounding	r_{K1}/r_{K2}	mm	0.08
Profile shift coefficient	x_1	/	-0.259
	x_2	/	-0.259
Pressure angle	α_n	°	20
Helix angle	β	°	0
Profile	h^*_{aP}	/	0.96/0.96
	h^*_{fP}	/	1.25/1.25
	ρ^*_{fP}	/	0.25/0.25

Table 1—Geometric parameters of the tested gear pairs.

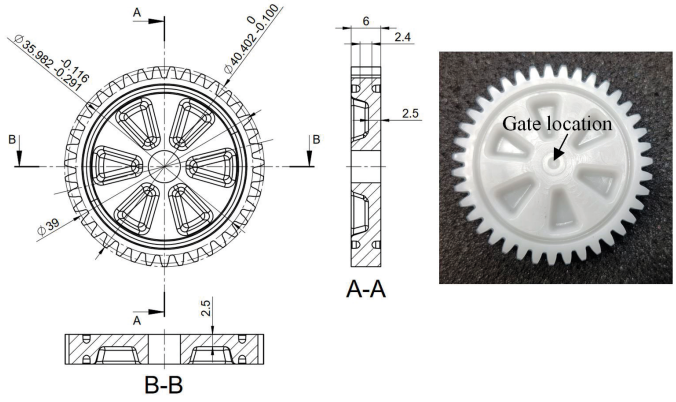


Figure 1—Tested gear samples.

Gear Quality Inspection

Three gears of each material were subject to geometric quality measurements on a Zeiss CMM machine, employing a Zeiss VAST XXT scanning sensor (Figure 2). The measured gear parameters were profile, lead, pitch, and runout, which were characterized according to ISO 1328 (Ref. 9) gear quality inspection standard. The evaluated parameters and the associated quality grades are summarized in Table 2. Based on the evaluated quality grades, which were at a comparable level for all seven grades, it can be concluded that the gear's quality grade did not have a notable effect on the gear pair's NVH response during testing.

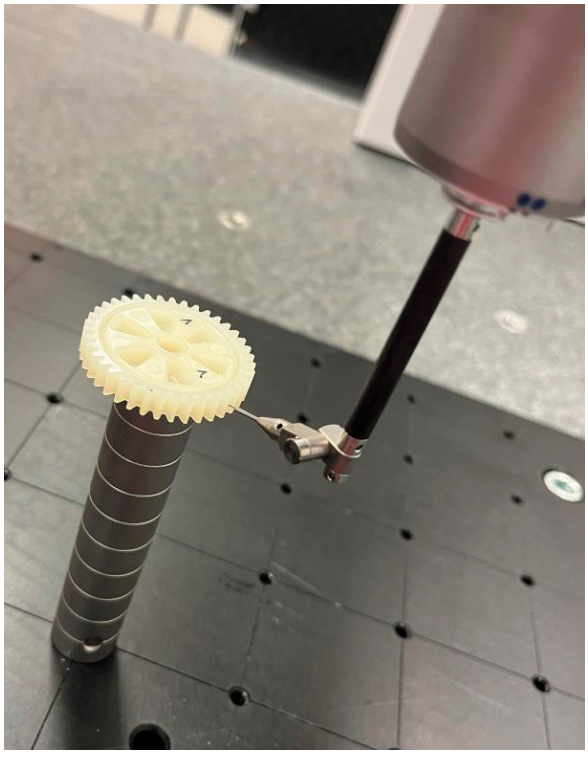


Figure 2—Sample gear during the geometric quality inspection.

	POM	PA66	PA6+15%GF	PPA+30%GF	PA66+30%GF	POM+10%AF	Steel
Total profile deviation (F_α)	9	10	10	10	10	10	8
Profile form deviation ($f_{f\alpha}$)	4	5	6	5	5	6	6
Profile slope deviation ($f_{H\alpha}$)	10	10	10	10	10	10	8
Total lead deviation (F_β)	10	10	10	10	10	10	8
Lead form deviation ($f_{f\beta}$)	4	6	5	4	4	5	6
Lead slope deviation ($f_{H\beta}$)	10	10	11	11	11	11	7
Single pitch deviation (f_p)	8	9	9	8	8	8	6
Total pitch deviation (F_p)	9	10	10	9	9	9	7
Runout (F_r)	10	9	10	9	10	10	7

Table 2—Determined quality grades for produced sample gears.

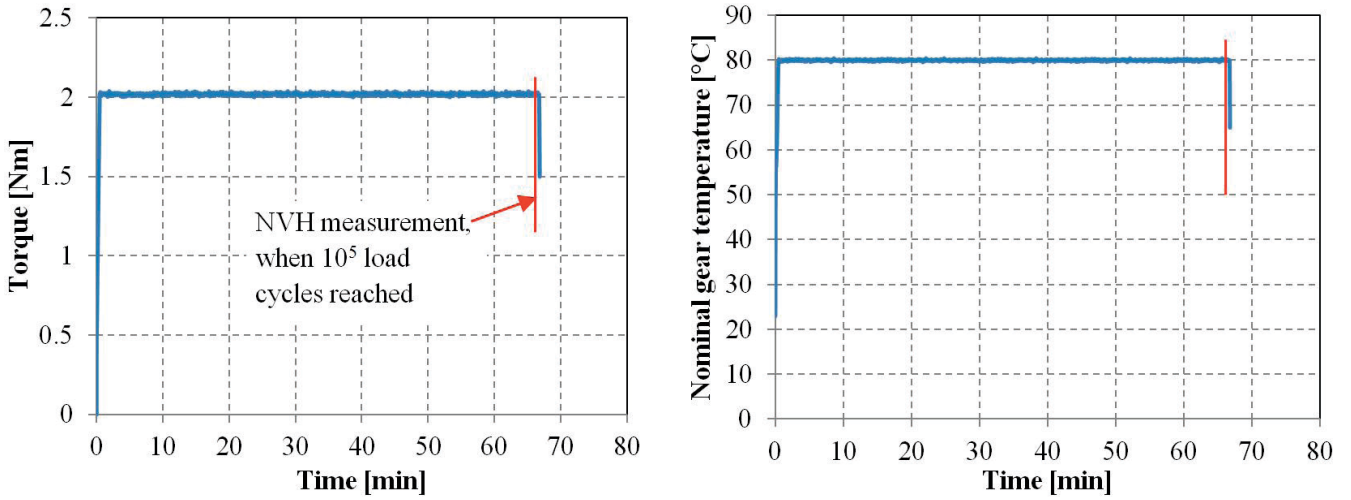


Figure 3—Torque and gear temperature were precisely controlled.

Index	Torque [Nm]	Rotational speed [rpm]	Nominal root stress [MPa]	Gear temperature [°C]
L1	2.0	500	50.74	80
L2	3.25	500	82.46	80
L3	2.0	1500	50.74	80
L4	3.25	1500	82.46	80
L5	2.0	2500	50.74	80
L6	3.25	2500	82.46	80

*All loads were tested in grease and in dry conditions. Three tests were executed for each selected test condition, and a new set of gears was used for each test.

Table 3—Test conditions.

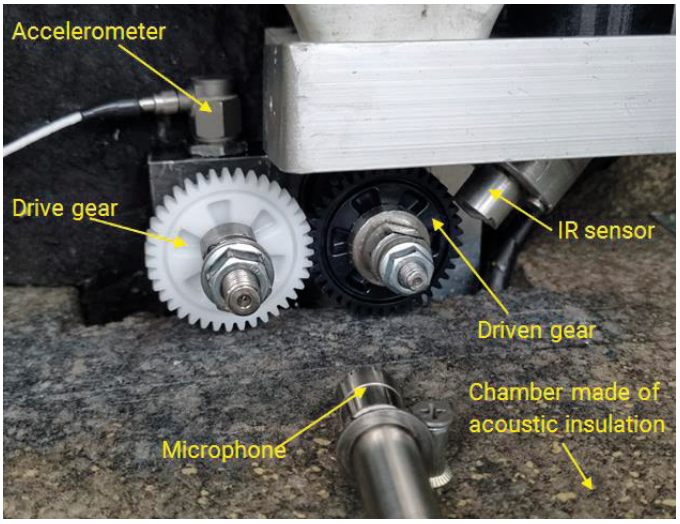


Figure 4—NVH testing set-up.

Testing Conditions

The gear pairs were tested inside a closed acoustic chamber, mounted on the gear test rig, isolating the tested gear pair from the surroundings. That way only the noise generated by the tested gear pair could be measured, without major influence from other noise sources. Rotational speed, torque and gear temperature were precisely controlled during all tests (Fig. 3). As the NVH performance depends on the operating conditions, the gears were tested at two torque levels, and for each torque level at three rotational speeds, evaluating the effect of both operating parameters. The gear temperature was controlled at 80 °C in all tested cases. The tested loads are summarized in Table 2. The tests were run in dry conditions. For each material combination, three test repetitions were conducted. A new gear pair was employed for each test. The center distance at which the gears operated was precisely set by a precision positioning mechanism with an accuracy of 0.01 mm.

Six material combinations were tested, employing grades commonly used for gear applications. A steel gear pair of the same geometry was tested as a benchmark for comparison. Tested material combinations:

1. Steel—Steel (reference) (536.30 MPa)
2. POM—PA9T+30%GF
3. PA66—PA9T+30%GF
4. POM—PA66
5. PA6+15%GF—POM+10%AF
6. POM—PA66+30%GF

The testing setup is presented in Figure 4. A Dytran 3055D1T (Dytran Inc., USA) accelerometer was mounted on the bearing housing near the driven gear and a PCB Piezoelectronics 378B02 (PCB Piezoelectronics Inc., USA) free-field condenser microphone was placed in front of the tested gear pair. Data acquisition was conducted by using Dewesoft's *SIRIUSm* (Dewesoft, d.o.o., Slovenia) module. The tests with plastic gears were run for 10^5 load cycles, where the operation was considered to reach steady state conditions, and the wear was not yet present affecting the NVH performance. After the 10^5 load cycles had been reached, the noise and vibration signals were captured. The duration of each measurement window was 10 s, with a sampling frequency rate of 20kHz. Signals, as presented in Figure 5, were acquired in each measurement. Steel gears were run for just a few minutes for the torque and rotational speed to stabilize; after that, the NVH measurement was made.

Three metrics are usually evaluated for the acquired signals, i.e., the peak value (max. amplitude), the peak-to-peak and the RMS value. The metrics are presented in Figure 5. The peak and peak-to-peak values represent only a single point value and do not consider the total signal energy; any fluctuation or transient vibration of a higher value can influence this metric. The increase of peak value or peak-to-peak may indicate the appearance of impacts in the signal, which can be isolated once a time. The RMS (root mean square) value is the effective value of the signal. It is calculated based on the entire sample using the following equation:

$$x_{RMS} = \sqrt{\frac{1}{n} \cdot (x_1^2 + x_2^2 + \cdots + x_n^2)} \quad (1)$$

More practically, the RMS value measures the vibratory energy of the system. Unlike the peak and peak-to-peak values, the RMS value is not a point value, but rather a representation of the total signal energy.

The measured sound pressure was converted to sound pressure level, which is a logarithmic (decibel) measure of the sound pressure relative to the reference value of the 20 μPa threshold of hearing. The threshold of hearing is the quietest sound that most young healthy people can hear. The following equation was employed for the conversion:

$$L_p = 20 \cdot \log_{10}\left(\frac{p}{p_0}\right) \quad (2)$$

where p is the root mean square sound pressure and p_0 is the reference sound pressure (20 μPa or 0.00002 Pa).

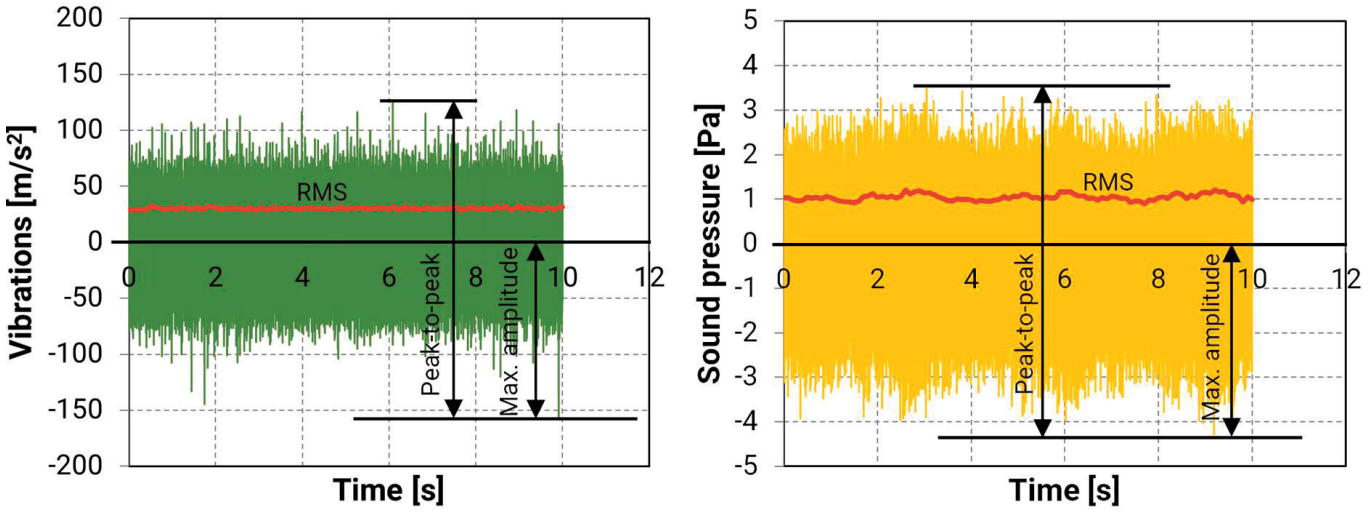


Figure 5—Acquired vibrations and sound pressure signal.

Results and Discussion

The average RMS values of the sound pressure level results are presented in Figure 6, and the average RMS values of measured vibrations are in Figure 7. The results show an average of three tests at each tested operating condition, and the error bars represent one standard deviation between the measured values. A relatively linear increase of measured sound pressure level could be observed for the benchmark steel gear pair while a much more complex behavior was found for the plastic gear pairs. The measured noise levels for the steel gear pairs were approx. 10 dB higher than the loudest tested plastic gear combination. Between the plastic gear pairs and at the lowest tested rotation speed, a difference of 10 dB could be observed between the best-performing and the worst-performing combination. Increasing the rotational speed led to an increase in the measured sound pressure level. A small difference between the measured noise levels could be observed at the highest rotational speed. It should be noted that an average person can distinguish a sound pressure level difference of 3 dB, which can hardly be recognized, especially at noise levels above 100 dB.

At this point, it must be stressed that the gear pairs were tested in an isolated acoustic chamber and only the noise generated by the gear pair was measured. In a real gearbox, most of the noise is usually generated by the housing, while the main cause for housing excitation is vibrations generated by the gears, which are transmitted to the housing through the bearings and shafts. In some cases, the RMS values of the vibrations for the steel gear pairs were more than compared to the plastic-plastic pairs;; hence, a much louder operation of gearboxes containing only steel gears can be expected.

All material combinations were tested at the same load, i.e., the same torque, rotational speed, and controlled gear temperature. However, the modal characteristics of the tested gear pairs are not the same since the materials exhibit different densities and stiffness. Hence, the gear's eigenfrequencies are located at different positions in the frequency domain. That means the steel/steel gear pair has a different eigenfrequency than the plastic/plastic gear pairs. Also, the eigenfrequencies of plastic/plastic combinations (composed of different materials) can vary substantially.

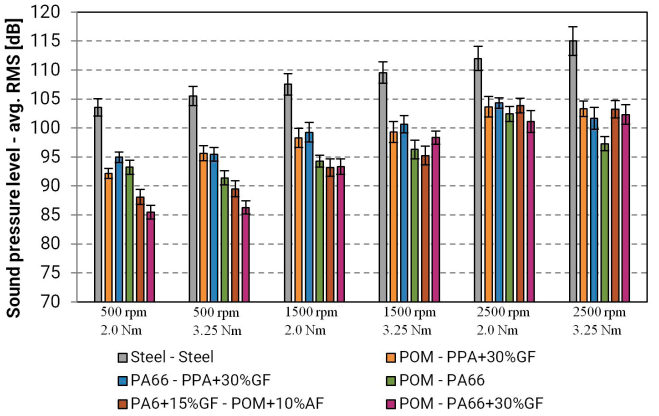


Figure 6—Sound pressure level, measured for the tested gear pairs. The temperature of plastic gears was controlled at 80°C in all tests (temperature measured on the teeth).

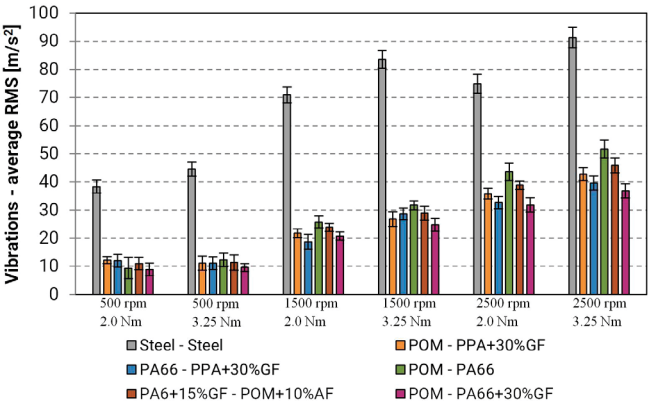
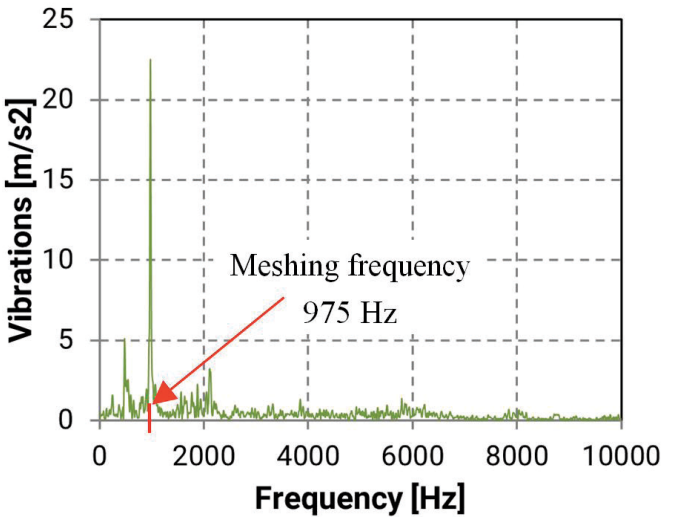


Figure 7—Vibrations, measured for the tested gear pairs. The temperature of plastic gears was controlled at 80°C in all tests (temperature measured on the teeth).



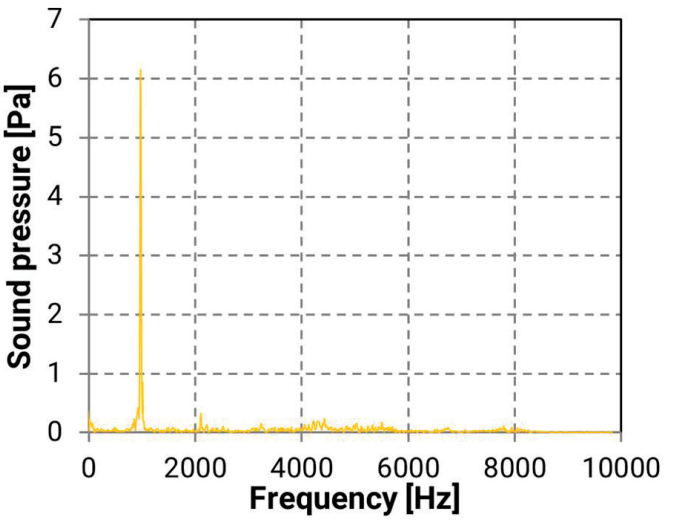


Figure 8—FFT of the measured vibrations and sound pressure signal. The rotational speed of the test was 1500 rpm.

If a structure is excited at the eigenfrequency or near it, the amplitude of the response rises significantly (in theory, it is an exponential rise). Therefore, one material pair can show higher vibrations at a certain rotational speed than the other and lower vibrations than the comparing material pair at a different rotational speed (excitation level). Such phenomena will also occur in a real application if the load is varying (which, many times, is the case).

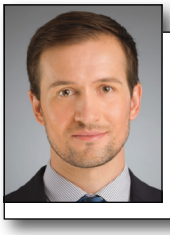
Fast Fourier transforms (FFTs) of the measured vibration and sound pressure signals were generated to verify that the measured NVH resulted from gear meshing and not any other associated effects, e.g., motor noise, bearings or exterior noise. It was crucial that for all the analyzed signals, the most pronounced peak in the frequency domain corresponded to the gear meshing frequency, as shown in Figure 8. By that, it could be confirmed that the measured values were the resulting NVH of the meshing gear pair.

Conclusions

The present results provide a quantitative comparison of the plastic gear's NVH level against that of a steel gear pair of the same geometry, operating at the same conditions. While the noise levels measured for the steel gear pairs were 10 dB or higher than those of the tested plastic gear pairs, the main benefit can be seen in the much lower vibrations generated by the plastic gear pairs. Vibrations generated by a gear pair are the main noise generator in most practical applications. The differences between the different plastic combinations were not on the same level as when compared to steel gear pairs. However, a difference in NVH performance could nevertheless be observed. The best-performing material combination (especially in terms of vibrations) was the POM—PA66+30%GF, while the highest vibrations against the plastic gear pairs were measured for the POM—PA66 gear pairs. The meshing stiffness of the POM—PA66 gear pair was the lowest among the tested pairs. While this ensured good damping, it also resulted in the highest transmission error among the tested pairs, which is the main source of vibrations in gear pairs. Gear pairs consisting of one unreinforced and one reinforced gear exhibited a higher meshing stiffness and, consequently, a lower transmission error, resulting in lower vibrations generated by the gear pair.

Future Outlook

Several open topics on the plastic gears NVH still need to be addressed and systematically studied. The professional public accepts that the plastic gear NVH increases with the increasing wear of the gears. To the best of the author's knowledge, there have not been any relevant studies published yet, where the wear's effect on the NVH would be systematically studied and evaluated. A similar open topic is the effect of grease. It is generally accepted that by introducing grease to the gearbox, the noise and vibrations get reduced. However, having such an effect more systematically quantified would be valuable.



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Rok Kalister is a VP of technology and product R&D at RD Motion. Holding a master's degree in Mechatronics Engineering at the University of Ljubljana, he has extensive knowledge in control systems design and product development, with a strong focus on polymer gear design and power transmission testing rig design.

Dr. Borut Černe is a cofounder and Co-CEO at RD Motion. With more than 11 years of experience in the fields of solid mechanics, polymer testing, programming, engineering design, and power transmissions, he holds a pivotal role in R&D operations and test rig development at the company.

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Croix Gear

HIRES TOM MARINO AS WEST REGION SALES REPRESENTATIVE

Croix Gear announces the addition of Tom Marino as sales representative for the west region. With nearly 40 years of industry experience and strong relationships across the gear manufacturing sector, Marino will play a key role in meeting the diverse needs of Croix Gear's customers in the Western United States.

"I am thrilled to join one of the nation's premier gear companies," said Marino. "Croix Gear's capabilities, including specialized bevel gear cutting equipment, set it apart in the industry. I look forward to leveraging my skills and experience to foster new business opportunities and deliver exceptional value to our customers."

Ruthie Johnston, CEO and owner, said, "We are thrilled to welcome Tom Marino to our team. Tom is a highly respected expert in the gear industry, bringing extensive knowledge and a wealth of experience in gear manufacturing. His expertise will greatly benefit our customers and strengthen our organization."

croixgear.com

Forest City Gear

BREAKS GROUND ON NEW WAREHOUSE

Forest City Gear is pleased to announce the groundbreaking of a new warehouse. The 50 ft. x 100 ft. climate-controlled warehouse will serve as storage for finished goods, while prioritizing storage space in the existing footprint for in-process items for Cut Teeth Only jobs.

"With this new building, we will be able to be more efficient with our footprint in both the FCG main building and Roscoe Works building, as we will no longer need to shuffle physical product storage in order to facilitate daily operation," says Jared Lyford, Forest City Gear director of operations.

"FCG continues to grow and serve our customers. Over the years, we have cannibalized all storage space and part-holding areas for production space. Many of our customers place blanket purchase orders with moving target dates for releases—we must be prepared to ship parts on demand. Of course, this requires secure, climate-controlled storage space for finished goods which we no longer have available," says Kika Young, president of Forest City Gear. "I am excited to build this warehouse facility on our existing campus to be able to better serve our customers and provide the flexibility they require. The future is bright, and we are excited to continue to grow our business in the best way possible to support customers."

forestcitygear.com

Solar Atmospheres

SOUTH CAROLINA FACILITY AWARDED PARKER AEROSPACE APPROVAL

Solar Atmospheres Greenville, SC facility is pleased to announce it has been awarded Parker Aerospace approval. This achievement expands Solar Atmospheres' reach, offering five facilities able to assist customers with Parker Aerospace thermal processing requirements.

Steve Prout, president of Solar Atmospheres' Greenville facility, shared: "We are excited to provide our customers in the Southeastern U.S. with another regional solution for aerospace and defense thermal processing. This approval allows us to save our customers time and money while maintaining the exceptional quality they expect."

Solar Atmospheres offers a wide range of vacuum thermal processing services, capable of handling development cycles and loads of up to 50,000 pounds at temperatures as high as 2400°F. As an AS9100 and Nadcap-accredited company, Solar Atmospheres ensures every product meets the highest industry standards, giving customers confidence in the reliability and precision of their heat treatments.

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Bonfiglioli

OFFERS METALWORKING SOLUTIONS AT EUROBLECH 2024

Bonfiglioli showcased its latest innovations at EuroBLECH 2024, the premier global event for the metalworking industry. This participation highlighted a suite of cutting-edge solutions tailored to meet the growing demands of smart manufacturing and advanced metal processing.

Throughout the fair, Bonfiglioli introduced customized technologies designed for diverse operational needs, offering flexibility and efficiency. Developed in collaboration with industry leaders, these solutions set new benchmarks in productivity while optimizing costs, positioning Bonfiglioli at the forefront of metalworking innovation.

EuroBLECH provided the perfect location to demonstrate how these solutions seamlessly integrate with existing systems, enhancing overall performance and reducing operational expenses. With a steadfast commitment

to innovation, collaboration, and adaptability, Bonfiglioli continues to drive the future of metalworking.

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David Brown Santasalo

LISTED AS TOP 100 KIRKLEES COMPANIES FOR FIFTH CONSECUTIVE YEAR

David Brown Santasalo has been recognized as one of the top 100 companies in the "Kirklees Top 100" list for the fifth consecutive year. Now into its fifth year, the Kirklees Top 100 Companies initiative aims to raise the profile of the local business community and forge stronger links around topics of shared interest between the top 100 companies and partners, the University of Huddersfield, Business Kirklees and the 3M Buckley Innovation Center (3M BIC).

The list was overseen by Professor Jill Johnes, Dean of Huddersfield Business School who specializes in production economics and was determined by a set of consistent metrics such as turnover, profit, employee numbers and growth. The top 100 businesses were unveiled at a launch event held in October.

"We are very pleased that our UK operations have been recognized amongst some of the most successful businesses in the Kirklees area. The business can trace its roots back to 1860 when we started specializing in gearwheel patterns for cast gears right here in Huddersfield. Since that time, we have kept our roots firmly planted in the area, most notably opening our Park Works facility in 1902, which is still part of our business today. The business continues to develop and now has a long-term land and marine orderbook and has expanded our industrial service center, most recently opening a secondary site at our Prospect Works location," David Armitt, CEO, David Brown Santasalo.

dbsantasalo.com

ABB

OPENS NEW $100 MILLION CAMPUS IN WISCONSIN

ABB recently began the phased opening of a new $100 million campus in New Berlin, WI to increase U.S. production capacity of industrial electric drives and service to fully meet Build America Buy America Act (BABAA) requirements. ABB employees, elected officials, education leaders, and media gathered for a ribbon cutting event to mark the first phase opening of the campus.

"ABB is a technology leader in electrification and automation and the U.S. market is an important growth engine for our business," said Brandon Spencer, president of ABB's Motion Business Area. "Investment in this modern manufacturing facility gives ABB access to a highly qualified workforce, strengthens localized supply chains, and keeps us close to our customers."

The need to reduce and avoid emissions is driving strong demand for ABB's electrification and automation solutions in the power, industrial, transport and building sectors. ABB empowers customers across the globe to optimize, electrify and decarbonize their operations.

"ABB is strengthening America's infrastructure and introducing new, cleaner technologies to help customers boost competitiveness while lowering their carbon footprint," said Tuomo Hoysniemi, president of ABB's U.S. Motion Business Area and Global Drive Products Division. "We are also using technology to run our own factory cleaner with building design features such as solar power, geothermal heat pump and modern HVAC systems, and advanced building controls. The innovations will help ABB meet its own 2030 sustainability goals."

While the increased footprint of the new facility will better serve ABB's future growth in the company's largest market, the highly automated production facility will be complemented by a digital Customer Experience Center and a state-of-the-art Innovation Lab to better serve customers in the United States. By locating a warehouse distribution center on the campus, ABB will reduce transportation costs and associated emissions.

The new campus will welcome more than 700 ABB employees and is expected to add an additional 100 new jobs over the next three years.

"It is important for business, government and educational institutions to work together to prepare the workforce for modern manufacturing," said Kelly Kling, Drives Site Leader and Head of Finance for US ABB Motion Business. "STEM education will better prepare the nation for the high demand of electrical and mechanical engineers, contractors and automation technicians. It is important for ABB, our customers, and will build a stronger America."

abb.com

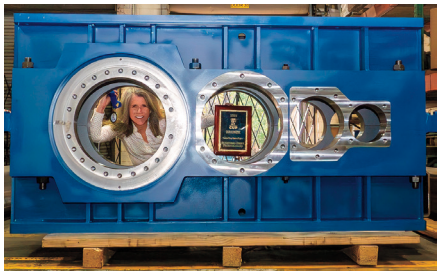
Sumitomo Drive Technologies'

PARAMAX 9000 SECURES MULTIPLE AWARDS AT VA MANUFACTURING GALA

This year's Virginia Manufacturing Gala, hosted by the Virginia Manufacturers Association (VMA) at the prestigious Virginia Museum of History and Culture, served as a showcase for the best in Virginia's manufacturing industry. At this prominent event, Sumitomo Drive Technologies stood out significantly, earning Bronze in the Virginia Manufacturing Cup and capturing 1st Place in the Industrial and Commercial Machinery category with its Paramax 9000 reducer.

The Paramax 9000 is the cornerstone of Sumitomo's large industrial gearbox

reducers, renowned globally for its robustness and durability. This speed reducer is designed to perform optimally in the most demanding environments, including industries like forestry, steel, and mining. Its capability to handle critical applications such as bulk material conveying, mixers, crushers, kilns, and cranes showcases the company's commitment to quality.



Support from over 53,000 votes highlights the industry's recognition and public endorsement of Sumitomo's impact on the manufacturing landscape in Virginia. This year's accolades reflect not just the company's achievements but its ongoing dedication to innovation and excellence in manufacturing. Sumitomo's success is supported by strategic advantages such as reduced average lead times, a substantial domestic inventory, and a dedicated team of engineers and manufacturers who are specialists in their fields.

At the gala, Sara Zimmerman, vice president of business development at Sumitomo Drive Technologies, shared her thoughts. "We are incredibly proud of our products, especially this year's submission. I want to take this opportunity to thank our employees, customers and suppliers who voted for us. We could feel the love tonight and are committed to providing the highest quality products with a 'cool' factor."

us.sumitomodrive.com

Emuge-Franken USA

ANNOUNCES MIKE PATTERSON AS NATIONAL SALES MANAGER

Emuge-Franken USA has announced the appointment of Mike Patterson as national sales manager for the U.S. and Canada. Patterson brings to Emuge extensive industry knowledge and management experience. He is responsible for leading the Emuge-Franken sales organization in the U.S. and Canada to further strengthen support for customers and distributor partners, as well as to grow market share.

"We are excited to welcome Mike as our national sales manager," said Bob Hellinger, president of Emuge-Franken USA/Canada, "With more than 30 years of combined experience in sales management and technical expertise in cutting tools and metalworking manufacturing, Mike is ideally suited for this role."

Mike Patterson

"I'm excited to join the Emuge team as national sales manager," said Patterson. "I look forward to applying my industry expertise and leadership to motivate field sales and distributors. Supporting the continued success of Emuge-Franken USA, and maintaining its reputation for outstanding innovation, quality and customer service in a broad range of cutting tools are key initiatives."

Patterson most recently served as the northeast general manager at Blackhawk Industrial, a large distributor providing industrial products, equipment, and manufacturing services. Prior to that, he spent over eight years at Kennametal, a manufacturer and supplier of tooling and industrial materials, where he held management and engineering roles, including as northeast sales manager for four years and channel partner (distribution) manager for two years. Earlier in his career, he gained hands-on experience as a CNC machinist, manufacturing engineer, and application engineer. Patterson holds a journeyman tool and die certification and a bachelor's degree in engineering/ industrial management from Manchester (CT) Community College. He also holds an associate's degree of applied science manufacturing technology from Naugatuck Valley Community College (CT).

emuge-franken-group.com

ECM USA's

VINCENT LELONG PRESENTED AT PURDUE HEAT TREATMENT CONSORTIUM (PHTC)

ECM USA's Vincent Lelong presented low pressure carburizing with vacuum furnace technology at Purdue University's School of Materials Engineering undergraduate seminar. This seminar regularly features industry speakers, some of whom are members of the Purdue Heat Treating Consortium. Dedicated to advancing the science and technology of industrial metal treating through cutting-edge research and collaboration with industrial professionals, this program aims to address real-world challenges and educate at all levels. Current and previous graduate projects involve contact fatigue properties, predicting residual stresses, and quantifying environmental properties. In his presentation, Vincent Lelong, ECM USA Synergy Center Manager, delved into the operating parameters and benefits of low-pressure vacuum carburizing (LPC). These details included test programs and the influence of high-pressure gas quench (HPGQ) testing done in the ECM USA Synergy Center located in Pleasant Prairie WI.

ecm-usa.com

JANUARY 7–10

CES 2025

Attracting a diverse range of professionals, including executives, engineers, designers, and entrepreneurs, CES (Las Vegas) is an excellent opportunity to connect, collaborate, and grow your professional network. Keynote addresses and panel discussions from industry experts offer valuable insights into market trends, consumer behavior, and emerging technologies that can help guide strategic decisions and future planning. Attendees can interact with new technologies firsthand, gaining a deeper understanding of their features and potential applications. The broad range of exhibits and industries represented at the show can inspire innovative solutions. Industries include 3D printing, AR/VR/XR, AI, cloud computing/data, construction tech, cybersecurity and more.

geartechnology.com/events/5112-ces-2025

JANUARY 28–30

IPPE 2025

The International Production & Processing Expo (Atlanta) is the world's largest annual poultry, meat and feed industry event of its kind. A wide range of international decision-makers attend this annual event to network and become informed on the latest technological developments and issues facing the industry. All segments of the industry are represented: feed milling, animal food, genetics, hatchery, live production and animal health, egg production & processing, poultry & meat processing, further processing, rendering, marketing, and all support activities. Exhibitors include Stober Drives, SEW Eurodrive, Kluber Lubrication, JIE and more.

geartechnology.com/events/5039-ippe-2025

FEBRUARY 4–6

Additive Manufacturing Strategies 2025

The Additive Manufacturing Strategies conference (New York) brings together AM stakeholders from all over the world. AMS includes panels and keynotes on topics most critical in the fast-growing world of additive manufacturing. Bringing together the industry's leaders in a contained networking environment makes AMS the place for startups to access capital, for financial institutions and investors to sharpen their radars, and for the AM industry to focus on the business of AM. AMS 2025 is "in-person only" to ensure maximum networking and discussion.

geartechnology.com/events/5108-additive-manufacturing-strategies-2025

FEBRUARY 11–13

Industrial IoT Conference 2025

The Industrial IoT Conference (Ft. Lauderdale, FL) explores the potential of intelligent machines, prescriptive analytics, sensor driven analytics, and block chain solutions. Attendees learn about the industrial IoT technologies that are driving the transformation in manufacturing, supply chain and operations. Attendees include implementors, manufacturing companies, supply chain professionals, service providers, IoT manufacturers and more. Topics include implementation, warehouse logistics, robotics, sensors, cybersecurity, data analytics and more.

geartechnology.com/events/5113-industrial-iot-conference-2025

MARCH 1–8

IEEE Aerospace Conference 2025

The International IEEE Aerospace Conference, with AIAA and PHM Society as technical cosponsors, is organized to promote interdisciplinary understanding of aerospace systems, their underlying science and technology, and their applications to government and commercial endeavors. The annual, weeklong conference (Big Sky, Montana) is set in a stimulating and thought-provoking environment. The 2025 conference will be the 46th in the series.

geartechnology.com/events/5055-ieee-aerospace-conference-2025

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Galactic Guidance

Liebherr provides bearings and slewing drives for radio astronomy facility

Matthew Jaster, Senior Editor

The ngVLA will directly image the formation of solar system analogues for life with astrochemistry as well as characterize the assembly, structure and evolution of galaxies.

Liebherr's components product segment and mtex antenna technology joined forces in 2023 to provide the antennas for the next generation Very Large Array antennas (ngVLA), which will offer a glimpse into the infinite space reach.

The ngVLA will be the largest radio astronomy facility in the Northern Hemisphere. The azimuth adjustment of the antennas is made possible by three-row roller bearings with a diameter of three meters and precisely matched slewing drives. In addition, gear ring segments together with the drives ensure accurate elevation adjustment of the antenna. The interaction of slewing bearings and drives guarantees precise control and positioning of the antennas for the exploration of the universe.

The ngVLA will directly image the formation of solar system analogues for life with astrochemistry, characterize the assembly, structure and evolution of galaxies, test theories of gravity with galactic center pulsars, reveal the explosive universe through multi-messenger discoveries and so much more.

"The ultra-sensitive imaging capabilities of these groundbreaking instruments will give us an unprecedented look into space and help unlock the secrets of the universe," explains Lutz Stenvers, managing director of mtex antenna technology GmbH.

The new generation antennas, boasting a diameter of 18 meters, will be positioned in a clearly defined pattern throughout North America. The area with a total of 244 antennas will cover approximately 1,000 kilometers. The special arrangement of the antennas will ensure optimal data reception from the cosmos.

"Cutting-edge technology, precision engineering and a tireless commitment to scientific discovery rockets the project to the forefront of astrophysical research," continues Stenvers. "And Liebherr's components take an important role in this."

The slewing bearing is used for azimuth adjustment of the antenna to enable its precise positioning. Therefore, this roller bearing has a diameter of 3.3 m. Its weight of 4,128 kg provides for more stability; its axial runout of 0.1 mm and radial runout of 0.05 mm plays a decisive role when it comes to precision. The slewing bearing is designed to be free of backlash, making it ideal for adjusting the azimuth of the antenna.

As a complementary feature to the slewing bearing, the gear ring segment is of great importance for the elevation adjustment of the antenna, meeting the high demands on the gear quality. The two gear ring segments, each positioned on the sides of the horizontal antenna rotation axis, ensure its elevation adjustment. In addition, the interaction of the azimuth drives with the slewing bearing enables a high degree of precision, with which

The mtex antenna technology and National Radio Astronomy Observatory team experienced Liebherr's ready-made roller slewing bearing for their next-generation Very Large Array antennas (ngVLA) for the first time in late 2023.

the satellite systems rotate around the tower axis. The key is a low torsional backlash and increased stiffness of the planetary gears. These optimizations make the adjustment mechanism of the entire system operate with maximum accuracy, targeting precise positioning in the long run. The elevation adjustment, which is responsible for the inclination of satellite dishes, uses the same drives as the azimuth adjustment, but with an adapted transmission ratio. The interplay of the two adjustment systems is indispensable for precisionantenna alignment. This expertise is crucial for the symbiosis of the slewing bearing, gear rings and slewing drives as a unit.

According to the National Radio Astronomy Observatory (NRAO), radio astronomy can also be done during the daytime. The ngVLA will not be limited to nighttime regions of the sky. By capturing high-resolution images of gravitational wave events, the ngVLA will become one of the most powerful tools of multi-messenger astronomy.

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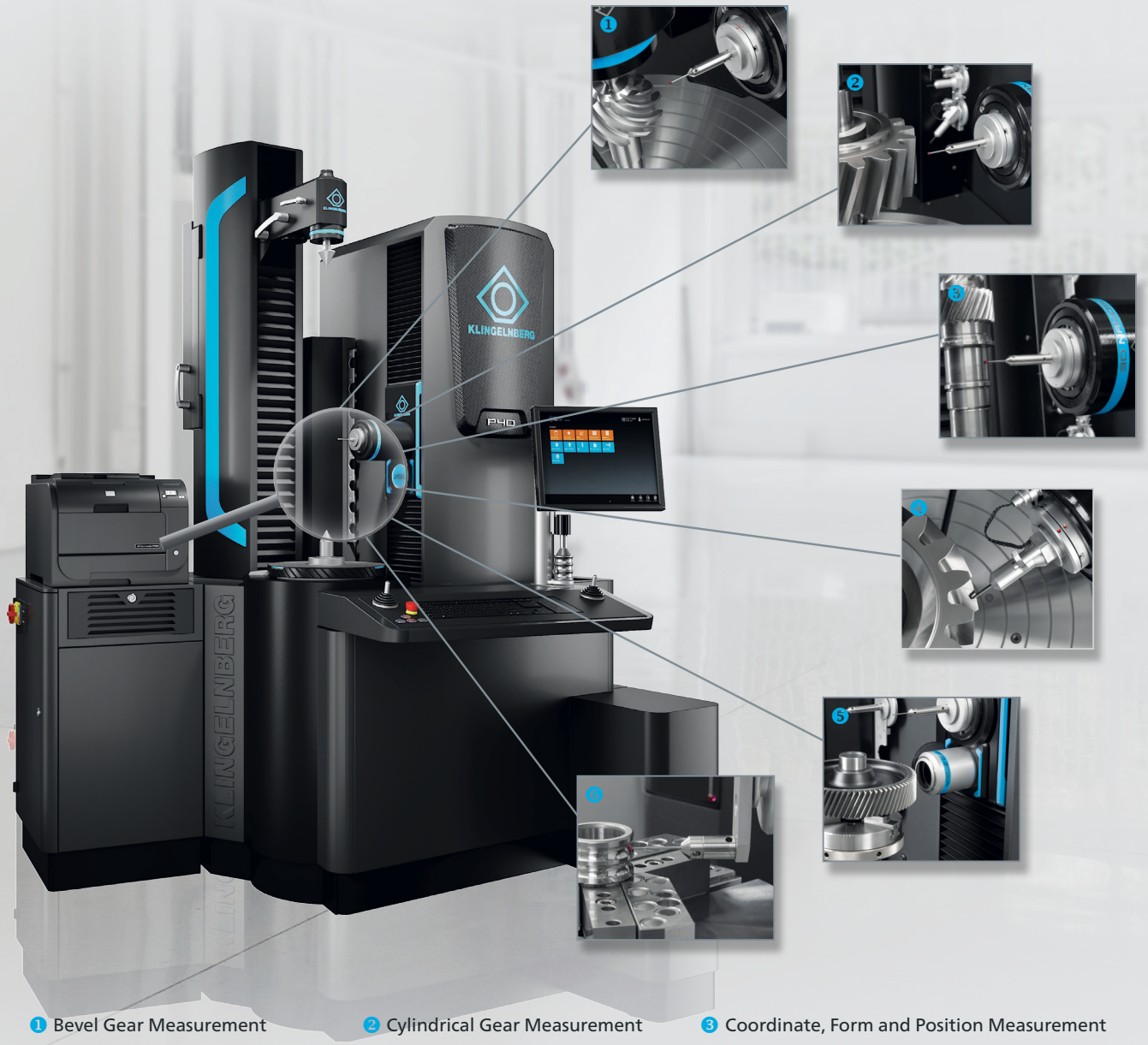

1 Bevel Gear Measurement
2 Cylindrical Gear Measurement
3 Coordinate, Form and Position Measurement
4 Roughness Measurement
5 Optical Measurement
6 Contour Measurement

The precision requirements for components and assemblies are steadily on the rise. To meet these demands, as many measurement tasks as possible should be combined into a single sequence – ideally directly on the shop floor rather than in the measuring room. A Klingelnberg Precision Measuring Center has rapid measurement capability for dimensions, shape, contour and surface roughness in one automated cycle, on one machine, which can be set up directly in the production environment. By combining measurement tasks traditionally performed on up to six different devices, it is possible not only to lower investment costs, but also to reduce setup times and quality costs.

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